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Dyeing, Fastness, and UV Protection Properties of Silk and Wool Fabrics Dyed with Eucalyptus Leaf Extract by the Exhaustion Process

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Abstract
This research was concerned with dye extraction from the leaves of eucalyptus and with the application of this dye for silk and wool fabric dyeing by the exhaustion process. Optimal results were achieved when dyeing at 90 °C for 40 minutes and at pH 4. Silk and wool fabrics dyed in a solution composed of eucalyptus extract from leaves in combination with a mordant compound showed a shade of yellowish-brown. An exception was when the fabrics were dyed with $FeSO_4$ mordant, resulting in a shade of dark grayish-brown. The colour fastness to light and rubbing after dyeing the silk and wool fabrics treated with the mordant was investigated, the results of which showed fair to good fastness, whereas the colour fastness to washing was at a good to very good level. The results confirmed that natural dyes from eucalyptus leaf extract have potential applications for fabric dyeing and producing ultraviolet (UV) protective silk and wool fabrics.

Key words: *natural dye, eucalyptus leaves, UV protection, silk, wool, dyeing.*

Introduction

Natural dyes have a wide range of shades that can be obtained from various parts of plants, including roots, bark, leaves, flowers and fruits [1]. Dyeing with natural dyes, however, normally requires the use of mordants, which are metallic salts of aluminum, iron, chromium, copper, among others, for ensuring a reasonable fastness of the colour to sunlight and washing [2]. The metal ions of these mordants can act as electron acceptors for electron donors to form coordination bonds with the dye molecules, making them insoluble in water. Lately, there has been increasing interest in natural dyes, as the public is becoming more aware of the ecological and environmental problems related to the use of synthetic dyes. The use of natural dyes cuts down significantly on the amount of toxic effluent resulting from synthetic dye processes. Natural dyes have also been used for dye-sensitised solar cells and for printing [3 - 5]. It is reported that some natural (vegetable) dyes not only dye with unique and elegant colours, but they also provide antibacterial and UV protective functions to fabrics. Thus, these natural dyes are applied on fibres or fabrics of cotton, wool, silk, and flax [6 - 11].

Eucalyptus is one of the most important sources of natural dye that gives yellowish-brown colourants. The colouring substance of eucalyptus has ample natural tannins and polyphenols, varying from 10% to 12% [12]. The major colouring component of eucalyptus bark is quercetin, which is also an antioxidant. It is used as a food dye with high antioxidant properties [13]. Eucalyptus leaves contain up to 11% of the major component, as well as tannin (gallic acid and ellagic acid) and flavonoids (quercetin, rutin etc.) as minor substances [14, 15]. The structures of the colouring components found in eucalyptus leaves are shown in ***Figure 1***. Tannins and flavonoids are considered to be very useful substances during the dyeing process because of their ability to fix dyes within fabrics.

Silk and wool fabrics dyed with the water extract of eucalyptus leaves in the presence of mordant $FeSO_4$ in the same padding bath using the pad-dry technique show a colour range from a brown-grey shade to a dark grey one [16]. The yield (exploitation) of the colouring component of eucalyptus leaf extract is surprisingly good in wool fabric (about 68% – 52%, from the lowest to the highest concentrations), which corresponds to medium deep brownish-grey shades in concentrations of more than 20 g/l of eucalyptus leaf extract [16]. In silk fabric the exploitation is less favorable, and the decline with deeper shades is more distinct (about 22% to 15% exploitation) [16]. An adsorption study was conducted with the use of an aqueous extract of eucalyptus leaves on silk fabric at three different temperature ranges (30 ºC, 60 ºC, and 90 ºC). The adsorption isotherm obtained was identified as a Langmuir type, or much closer to a Nernst type. When the temperature increased, the partition ratio and exhaustion percentages increased [17].

To further explore the properties of exhaustion dyeing, we investigated the dyeing, fastness and UV protection properties of silk and wool fabrics using an aqueous extract of eucalyptus leaves as natural dye. Different factors affecting dyeing ability were also thoroughly investigated.

Experimental

Fabrics

A commercially produced wool fabric (thickness 0.36 mm, weight 193 g/m^2, fabric count per inch 62 × 54, plain-weave) was scoured with an aqueous nonionic surfactant solution at a temperature of 45 °C for 30 minutes, then it was thoroughly rinsed and air dried at room temperature. The scoured and bleached silk fabric (thickness 0.15 mm, weight 67 g/m^2, fabric count per inch 96 × 80, plain-weave) used thoughout this study was supplied by Chul Thai Silk Co., Thailand. The thread count, fabric thickness and fabric weight characteristics of the wool and silk fabrics were in accordance with ASTM D3775-98, ISO 5084-1996 and ISO 3801-1997, respectively.

Mordants and chemicals

The following laboratory-grade mordants were used:
- aluminium potassium sulfate dodecahydrate ($AlK(SO_4)_2 \cdot 12H_2O$),
- ferrous(II) sulfate heptahydrate ($FeSO_4 \cdot 7H_2O$),
- copper(II) sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$), and

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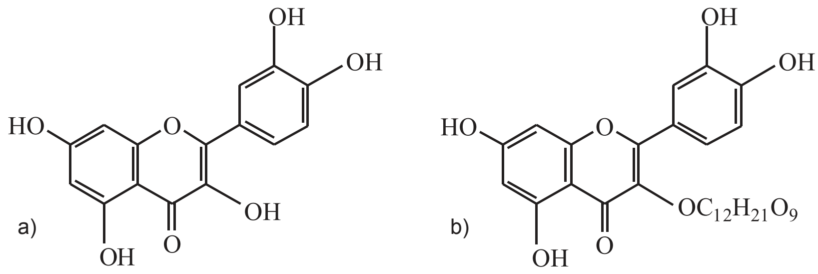


Figure 1. *Colour composition of the eucalyptus leaf extract dye; a) Quercetin (C.I. 75670), b) Rutin (C.I. 75730), c) Ellagic acid (C.I. 75270).*

- stannous chloride pentahydrate ($SnCl_2{\cdot}5H_2O$).

An anionic wetting agent, Altaran S8 (sodium alkylsulfate), and soaping agent, Syntapon ABA, were supplied by Chemotex Děčin, Czech Republic.

Instruments

The mordanting and dyeing were carried out in a dyeing machine (Linitest Type 7421) with programmable time and temperature control. A GBC UV/VIS 916 (Australia) spectrophotometer and a Datacolor 3890 were employed for the absorbance and colour strength measurements, respectively. Transmittance and ultraviolet protection factor (UPF) values were obtained by a Shimadzu UV 3101 PC UV-VIS-NIR scanning spectrophotometer in the 190 nm - 2100 nm range.

Dye extraction from eucalyptus leaves

Fresh eucalyptus leaves (*Eucalyptus camaldulensis*) were dried in sunlight for one month, crumbled using a blender, and then they were used as the raw material for dye extraction, which was achieved by the reflux technique. Seventy grams of the crumbled eucalyptus leaves was mixed with 1 litre of distilled water and refluxed for 1 hour. The sample was then filtered, and the dye solution was separated into two portions - one for evaporating under reduced pressure (rotary evaporator), and the other for dyeing. The crude dye extract of eucalyptus leaves obtained from the rotary evaporator was crumbled with a blender and used for obtaining a standard calibration curve. The dilution of the eucalyptus leaf extract gives a relatively clear solution with a linear dependance on the concentration–absorbance relation at an absorption peak (λ_{max}) of 262 nm [11]. The concentration of 20 g/L was calculated from a standard curve of concentrations of the eucalyptus leaf extract dye solutions versus absorbance at the wavelength mentioned.

Identification of the crude eucalyptus dye extracted

The crude eucalyptus leaf extract dye was characterised by UV-visible spectroscopy. A crude extraction solution (50 mg/l) was prepared by dissolving the crude eucalyptus leaf extract dye in distilled water. The spectrophotometer was scanned from 190 nm to 820 nm to obtain the UV-visible spectrum.

Dyeing method

Four different dyeing conditions were varied (temperature, dyeing time, pH and concentration of dye) to study the effect on the amount of eucalyptus leaf extract dye uptake by the silk and wool fabrics.

Temperature

Silk and wool fabrics were dyed separately in five sets of 100% on the weight of fabric (owf.) of the eucalyptus leaf extract dye solution at different temperatures, i.e. 30 °C, 60 °C, 70 °C, 80 °C and 90°C, at a liquor ratio of 1:50 and at pH 4 for 60 minutes.

Dyeing time

Six sets of silk and wool fabrics were dyed in six sets of 100% owf. of the eucalyptus leaf extract dye solution at 90 °C, at a liquor ratio of 1:50 and pH 4, at different time intervals (10, 20, 30, 45, 60 and 90 minutes).

pH

Silk and wool fabrics were dyed in 100% owf. of the eucalyptus leaf extract dye solution in dyebaths at different pH values of 3, 4, 5, 6, 7 and 8, at a liquor ratio of 1:50 at 90 °C for 60 minutes.

Concentration of dye

Simultaneous dyeing was used. The dye concentration was varied at 20%, 40% and 80% owf. of the eucalyptus leaf extract dye, and four types of mordants (Al, Cu, Fe, and Sn) were used with 40% owf. of each concentration of the dye. The pH of the dyeing solution was adjusted to 4 with an acetic acid solution. Silk and wool fabrics were dyed at 90 °C at a liquor ratio of 1:50 for 60 minutes.

After dyeing, the dyed samples were rinsed with cold water, washed in a bath with a liquor ratio of 1:50 using 1 g/l of the soaping agent, Syntapon ABA, at 80 °C for 5 minutes, then they were rinsed and finally air-dried at room temperature.

Evaluation of colour strength and fastness properties

The colour strength (*K/S*) and *CIELAB* of the dyed samples were evaluated using a spectrophotometer (Datacolor 3890). All the samples measured showed a maximum absorption wavelength (λ_{max}) value at 400 nm. The *K/S* is a function of colour depth and is calculated by the Kubelka-Munk equation, $K/S = (1-R)^2/2R$, where *R* is the reflectance, *K* - the sorption coefficient, and *S* is the scattering coefficient. The colour fastness to washing, light and rubbing of the dyed samples was determined according to ISO 105-C06 A1S:1994, ISO 105-B02:1994 and ISO 105-X12:2001, respectively.

Evaluation of UV protection

The transmittance and UPF values of the original silk and wool fabrics, and fabrics dyed with the eucalyptus leaf extract were measured using a Shimadzu UV3101 PC (UV-VIS-NIR Scanning Spectrophotometer) in the range of 190 nm to 2100 nm. The *UPF* value of each fabric was determined from the total spectral transmittance based on AS/NZ 4399:1996, as follows [18]:

$$UPF = \frac{\sum_{\lambda=290}^{400} E_\lambda S_\lambda \Delta_\lambda}{\sum_{\lambda=290}^{400} E_\lambda S_\lambda T_\lambda \Delta_\lambda}$$

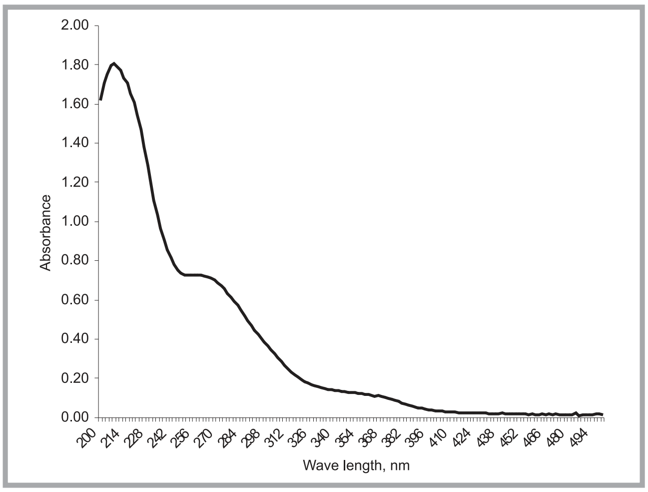


Figure 2. *UV-VIS spectrum of 50 mg/l of crude eucalyptus leaf extract dye in distilled water.*

where E_λ is the relative erythemal spectral effectiveness (unitless), S_λ - the solar ultraviolet radiation (UVR) spectral irradiance in W·m^{-2}.nm^{-1}, T_λ - the measured spectral transmission of the fabric, Δ_λ - the bandwidth in millimeters, and λ is the wavelength in nanometres. The UVR band consists of three regions: the UV-A band (320 nm to 400 nm), the UV-B band (290 nm to 320 nm), and the UV-C band (200 nm to 290 nm) [6]. The highest energy region, the UV-C band, is completely absorbed by oxygen and ozone in the upper atmosphere. Of the solar UV radiation reaching the earth's surface, 6% is in the UV-B region and 94% is in the UV-A region [19]. UV-A causes little visible reaction on the skin but has been shown to decrease the immunological response of skin cells [10]. UV-B is the most responsible for the development of skin cancers [10]. Therefore, the transmittance of UVR (UV-A and UV-B) through the fabrics was evaluated in this experiment. Fabrics with a UPF value in the range of 15 to 24 are defined as providing "good UV protection", 25 to 39 as "very good UV protection", and 40 or greater as "excellent UV protection" [10]. There is no rating assigned if the UPF value is greater than 50.

Results and discussion

UV-visible spectrum

The UV spectrum of the crude eucalyptus leaf extract dye in an aqueous solution is presented in ***Figure 2***, from which it can be observed that the dye can absorb radiation in the UV-C region (200 to 290 nm), the UV-B region (290 to 320 nm) and the UV-A region (320 to 400 nm). Absorption in the UV-B region can be expected to offer good protection from harmful UV radiation.

Effect of dyeing conditions

Dyeing silk and wool fabrics in the eucalyptus leaf extract dye solution showed that a rise in temperature can increase the colour strength (*K/S* value). Based on ***Figure 3.a***, the maximum colour strength is obtained at 90 °C. The colour of the wool and silk fabrics was yellowish-brown.

The effect of dyeing time on *K/S* values is shown in **Figure 3.b**. A longer dyeing time means higher colour strength (*K/S* values) until the dye exhaustion attains equilibrium, and there is no significant increase after further increases in the dyeing time. The best results with respect to time for dyeing silk and wool fabrics were obtained at 60 minutes.

The effect of the pH value on the *K/S* values is illustrated in ***Figure 3.c***. The maximum dye uptake is observed at pH 4. The dye uptake increases from the initial pH 3 until pH 4 and then decreases with an increase in pH to 8. In the alkaline solution, reaction with hydroxide ions (OH^-) converts ammonium ion (NH_3^+) to ami-

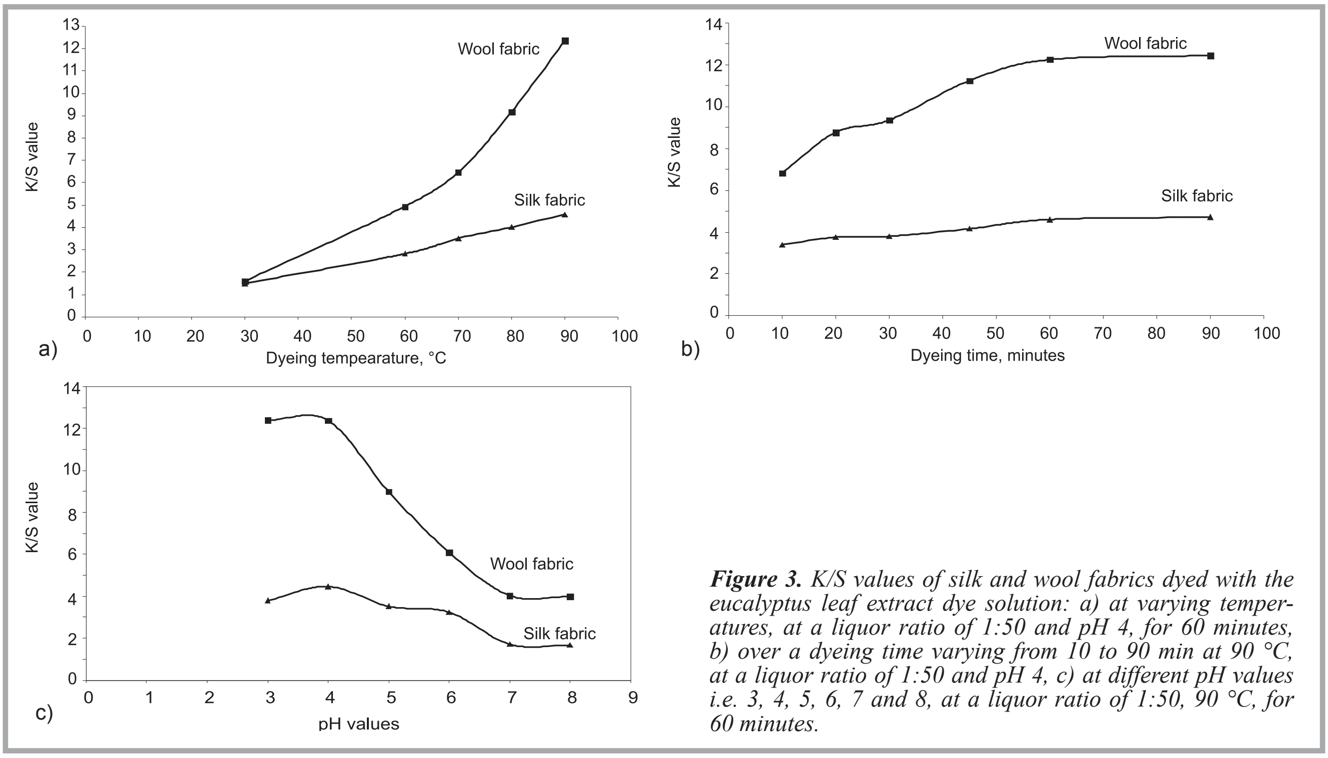


Figure 3. *K/S values of silk and wool fabrics dyed with the eucalyptus leaf extract dye solution: a) at varying temperatures, at a liquor ratio of 1:50 and pH 4, for 60 minutes, b) over a dyeing time varying from 10 to 90 min at 90 °C, at a liquor ratio of 1:50 and pH 4, c) at different pH values i.e. 3, 4, 5, 6, 7 and 8, at a liquor ratio of 1:50, 90 °C, for 60 minutes.*

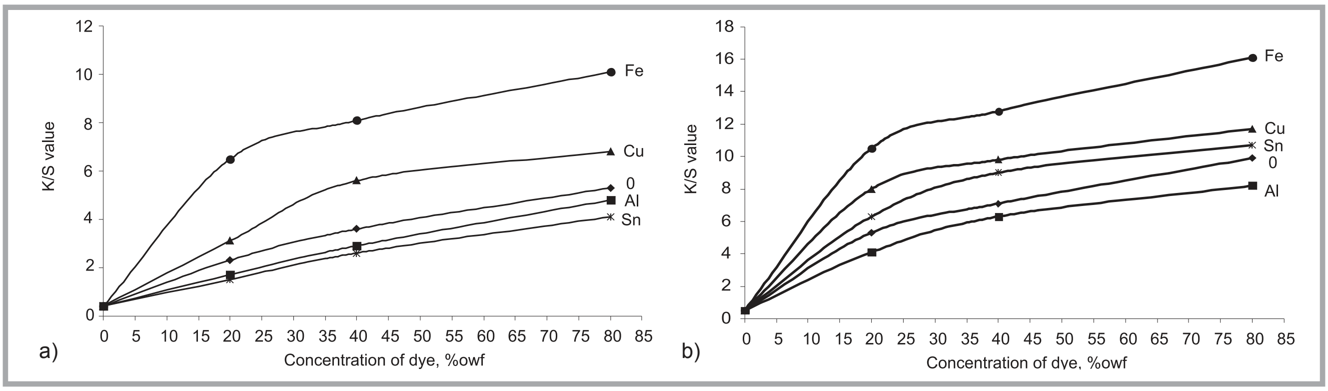


Figure 4. *K/S values of (a) silk fabric and (b) wool fabric dyed with varying concentrations of the eucalyptus leaf extract dye: 20%, 40% and 80% owf., using 40% owf. metal mordants, at a liquor ratio of 1:50, at 90 °C and pH 4 for 60 minutes; 0 - without mordant.*

no (NH_2) groups, and the fibre becomes carboxylate ion (COO^-) [20]. In addition, electrostatic repulsion occurs between the anionic colourants and protein fibres, which leads to a decrease in dye uptake.

Figure 4 shows the *K/S* values of the silk and wool fabrics dyed with eucalyptus leaf extract dye solution. The *K/S* values increase with an increase in dye concentration. The mordant activity sequence for the silk was $FeSO_4$ > $CuSO_4$ > without mordanting >$AlK(SO_4)_2$ > $SnCl_2$ and $FeSO_4$ > $CuSO_4$ > $SnCl_2$ > without mordanting > $AlK(SO_4)_2$ for the wool fabrics. In all cases, the ferrous sulfate mordant yielded the best dyeing results. The wool fabric dyed with eucalyptus leaf extract showed a higher colour strength than the silk fabric, which is because wool fabric contains more functional groups than silk fabric [21].

Ferrous sulfate and copper sulfate mordants are well known for their ability to form coordination complexes and to readily chelate with the dye. As the coordination numbers of ferrous sulfate and copper sulfate are 6 and 4, respectively, some coordination sites remain unoccupied when they interact with the fibre. Functional groups such as amino and carboxylic acid on the fibre can occupy these sites. Thus, the metal can form a ternary complex on which one site is with the fibre and the other site is with the dye [22]. Stannous and alum ions form weak coordination complexes with dye; they tend to form quite strong bonds with the dye but not with the fibre, hence they block the dye and reduce dye interaction with the fibre [22].

The value results obtained (***Table 1***) show that wool and silk fabrics dyed with stannous and without a mordant show a bright yellow and yellowish-brown colour, respectively. The samples mordanted with alum and copper sulfate produced a medium to dark yellowish-brown colour. With ferrous sulfate, the colour shade was darker and duller, which may be associated with the change of ferrous sulfate into a ferric form by reacting with oxygen in the air. Ferrous and ferric forms coexist in the fibre, and their spectra overlap, which results in a shift in λ_{max} and, consequently, a colour change to a darker shade [23]. Additionally, tannins in the eucalyptus leaf extract combine with ferrous salts to form complexes, which also results in a darker shade of the fabric [24].

It can be concluded that silk and wool fabrics can be successfully dyed with eucalyptus leaf extract due to the tannin richness of eucalyptus leaves [25]. Tannin contains phenolic compounds that can form hydrogen bonds with the carboxyl group of protein fibres. Additionally, there are two other possibilities involved: (a) the anionically charged phenolic groups form an ionic bond with cationics (amino groups) in the protein sub-

Table 1. *Colour value of dyed silk and wool fabrics using 40% owf. mordants, with varying quantities of dye concentrationł* ***Note:*** *1   80% owf. dye concentration.*

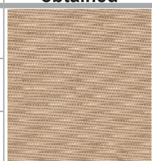
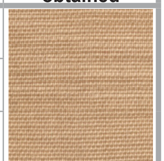
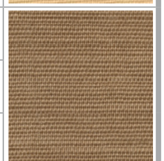
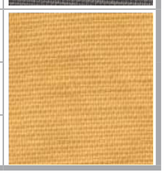
Type of mordants	Dye conc., % owf	silk fabric				wool fabric			
		L*	a*	b*	[1]Colour obtained	L*	a*	b*	[1]Colour obtained
Without mordant	20	75.0	3.4	15.4		67.8	4.2	23.0	
	40	70.1	3.9	19.9		64.0	4.0	25.2	
	80	66.4	4.8	20.9		61.0	6.8	26.7	
$AlK(SO_4)_2$	20	77.5	0.4	23.5		77.8	0.5	34.9	
	40	72.6	0.8	23.1		74.7	1.3	34.5	
	80	68.2	1.2	26.5		71.6	2.3	33.3	
$CuSO_4$	20	68.0	4.9	22.4		52.9	4.3	24.1	
	40	63.4	5.9	23.8		49.5	5.0	24.3	
	80	61.5	6.2	26.1		48.0	5.7	24.6	
$FeSO_4$	20	34.7	2.1	-2.7		35.3	0.5	4.7	
	40	32.4	2.4	-2.2		34.3	0.6	5.2	
	80	29.5	3.3	-0.8		29.3	0.7	6.1	
$SnCl_2$	20	83.2	1.9	20.7		80.6	1.5	34.3	
	40	81.1	2.9	22.0		79.3	8.4	50.8	
	80	78.5	3.4	23.7		75.8	12.6	63.4	

Table 2. Colour fastness to washing at 40 °C (ISO 105-C06 A1S: 1994).

Fastness	Silk fabric					Wool fabric				
	Without	Al	Cu	Fe	Sn	Without	Al	Cu	Fe	Sn
Colour change	4	4-5	4-5	4-5	4-5	4	4-5	4-5	4-5	4-5
Colour staining										
- Acetate	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5
- Cotton	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5
- Nylon	4	4-5	4-5	4-5	4-5	4-5	4-5	4	4	4-5
- Polyester	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5
- Acrylic	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5
- Wool	4-5	4-5	4	4	4	4-5	4-5	4	4	4-5

Table 3. Colour fastness to light (ISO 105-B02: 1994).

Fabric	Colour change				
	Without	$AlK(SO_4)_2$	$CuSO_4$	$FeSO_4$	$SnCl_2$
Silk	4	3-4	4	4	4
Wool	3-4	3-4	3-4	4	3-4

Table 4. Colour fastness to rubbing (ISO 105-X12: 2001).

Mordant	Colour staining							
	Silk fabric				Wool fabric			
	Warp direction		Weft direction		Warp direction		Weft direction	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
without	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5
$AlK(SO_4)_2$	4-5	4-5	4-5	4-5	4-5	4	4-5	4
$CuSO_4$	4-5	4	4-5	4	4-5	4	4-5	4
$FeSO_4$	4	3-4	4	3-4	4	3-4	4	3-4
$SnCl_2$	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5

strate, and (b) a covalent bond may also form through an interaction between any quinine or semiquinone groups present in the tannins and suitable reactive groups on the silk and wool fibres [26].

Effect of the dyeing technique on fastness properties

The fastness rating of silk and wool fabrics dyed with or without mordants at a dye concentration of 80% owf. are presented in ***Tables 2*** to ***4***. ***Table 2*** indicates that the washing fastness ratings of the silk and wool fabrics dyed with eucalyptus leaves were good to very good (4 to 4-5). However, the light fastness was only fair to good (3-4), as shown in ***Table 3***. The colour fastness to rubbing is shown to be in the range of 4 to 4-5 (good to very good), except for the silk and wool fabrics mordanted with ferrous sulfate, whose rating was only 3-4 (fair to good) when subjected to wet rubbing, as seen in ***Table 4***.

The good fastness properties of silk and wool fabrics dyed with eucalyptus leaf extract is attributed to the fact that these dyes contain tannin, which may help in covalent bond formation with the fibre, thereby resulting in good fixation on the fibrous material. Moreover, these tannins, having a phenolic structure, can form metal chelation with different mordants. Hence, after mordanting, these tannins are insoluble in water, ultimately improving washing fastness [26].

UV protection property

To investigate the UV-protection property of the eucalyptus leaf dye, the UV transmittance spectra of the silk and wool fabrics with and without dyeing and the dyed silk and wool fabrics with mordants were compared. (Percentage UV transmittance data with and without a mordanting agent are displayed in ***Figure 5.a*** for dyed silk fabrics and in ***Figure 5.b*** for dyed wool fabrics). The results show a significant difference between the dyed and undyed fabrics - the undyed fabrics yield a high UV transmittance. The UV transmittance of the undyed silk was in the range of about 14% to 23% in the UV-B band and about 23% to 25% in the UV-A band, while the undyed wool was in the range of about 4% to 12% in the UV-B band and about 12% to 37% in the UV-A band, indicating that the resistance of the undyed fabrics to ultraviolet rays was very poor, while the UV transmittance of the silk and wool fabrics dyed with the eucalyptus leaf extract appeared to be lower than 5% in the UV-B region. Generally, the UV protection property of fabrics is evaluated as "good" when the UV transmittance is less than 5% [6, 27]. For the samples mordanted with $AlK(SO_4)_2$, $CuSO_4$, $FeSO_4$ and $SnCl_2$, the percent of UV-B transmittance was in the range of about 3.0% to 4.5%, 1.7% to 2.4%, 1.4% to 1.9% & 3.7% to 5.0%, respectively, for the silk fabric, and 0.8% to 2.3%, 0.9% to 1.7%, 0.7% to 1.2% & 1.2% to 1.9%, respectively, for the wool fabric. It can clearly be seen that the values

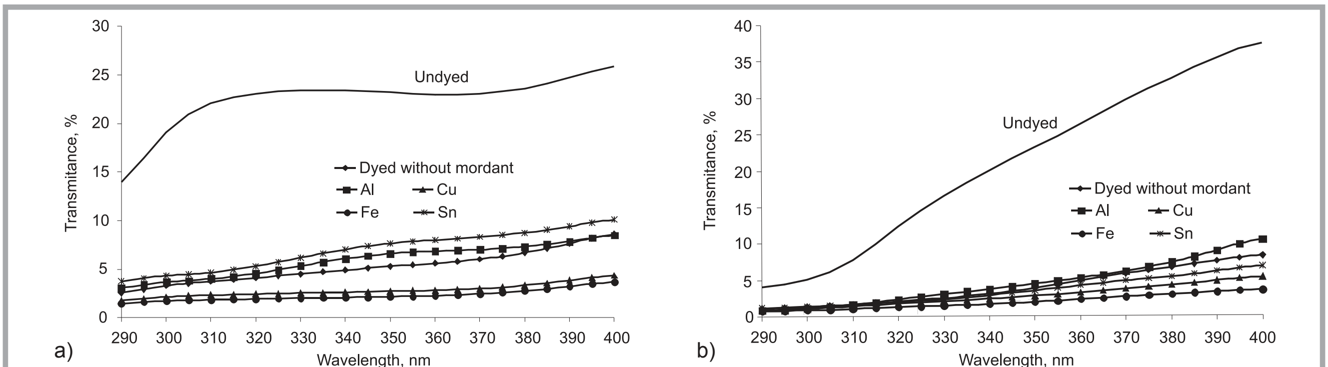


Figure 5. *UV transmission of silk (a) and wool (b) fabric dyed with 20% owf. eucalyptus leaf extract dye solution, using 40% owf. metal mordants.* ***Note:*** *Al = $AlK(SO_4)_2$, Cu = $CuSO_4$, Fe = $FeSO_4$, Sn = $SnCl_2$.*

Table 5. *UPF values and protection class of silk and wool fabrics dyed with 20% owf. eucalyptus leaf extract dye solution, using 40% owf. metal mordants.*

Condition	Silk fabric		Wool fabric	
	UPF	UV Protection class	UPF	UV Protection class
Undyed	4.6	No Class	10.8	No Class
Dyed without mordant	26.9	Very Good	53.1	Excellent
$AlK(SO_4)_2$	24.5	Good	52.8	Excellent
$CuSO_4$	38.6	Excellent	65.0	Excellent
$FeSO_4$	53.3	Excellent	87.8	Excellent
$SnCl_2$	20.8	Good	55.7	Excellent

of spectral transmittance decrease with mordants such as $AlK(SO_4)_2$, $CuSO_4$, $FeSO_4$, and $SnCl_2$, with different mordants having different effects on the spectral transmittance of the dyed fabric [6]. Additionally, the colour and colour depth of the fabric can be related to UV transmittance, where light colours transmit more UV radiation than dark ones [28].

Table 5 shows the *UPF* values and protection class of the silk and wool fabrics dyed with the eucalyptus leaf extract, with and without metal mordants. The undyed silk and wool fabrics have high transmittance values and low *UPF* values of 4.6 and 10.8, respectively, which cannot be rated as offering any degree of protection because the *UPF* values are less than 15, while the dyed samples of silk and wool fabrics without metal mordants show *UPF* values of 26.9 and 53.1, classified as "very good UV protection" (*UPF* values between 25 and 39) and "excellent UV protection" (*UPF* values equal to or greater than 40) for silk and wool fabrics, respectively. The wool fabrics dyed with metal mordants were rated as "excellent UV protection". The silk fabric mordanted with $CuSO_4$, and $FeSO_4$ also had "excellent UV protection". "Good UV protection" (*UPF* values between 15 - 24) was observed in the silk fabrics dyed with $AlK(SO_4)_2$ and $SnCl_2$ mordants. Wool fabrics are rated as "excellent UV protection" after dyeing with or without a mordant because wool fabric has low porosity and high weight and thickness. Therefore, wool fabric gives a high UPF by allowing less UV penetration.

Conclusions

The best result for wool and silk dyeing was achieved when a temperature of 90 °C and pH 4 were employed for 60 minutes. The wool fabric dyed with eucalyptus leaf extract shows higher *K/S* values than the silk fabric. The use of a ferrous sulfate mordant gives rise to the best dyeing, exhibiting a darker shade. The silk and wool fabrics dyed with a eucalyptus leaf extract dye solution with or without mordants showed a yellowish-brown shade (except with stannous chloride, which produced shades of bright yellow). The use of mordants not only improves colour strength but also provides shade differences. The fastness properties of the samples were good to very good (4 to 4-5), whereas light fastness was fair to good (3-4). The silk and wool fabrics dyed with eucalyptus leaf extract with or without metal mordants have good to excellent UV protection properties. However, undyed fabrics cannot be rated as offering any degree of protection. In summary, wool and silk fabrics can be successfully dyed with a eucalyptus leaf extract dye solution with or without metal mordanting and can be used in the development of UV protective fabrics.

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