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Application of natural dyes from selected indigenous plants on cotton and silk fabrics

Abstract

Standard procedures for mordant dyeing were used to dye plain weave cotton and silk fabrics with dye from four selected indigenous plants viz: *A. coriaria, V. paradoxa, M. lucida and H. madagascarensis*. Alum and ferrous sulphate mordants were with the following mordanting methods; pre, simultaneous and post mordanting. Color fastness was used as a basis to evaluate the performance of each method. Color strength imparted on fabric was used as a basis to optimize the following selected dyeing variables viz: temperature, dyeing time, material to liquor ratio (M:L), and mordant concentration (o.w.f). Mordant dyeing under optimized conditions improved color strengths and fastness on both cotton and silk fabrics. According to the optimized variables, silk fabrics required a little more heating (80˚C to 95˚C) for a longer time (≈ 1hr 30mins) than cotton to achieve optimal strengths of color. The fastness obtained for various fastness characteristics on both fabrics dyed under optimized conditions varied from fairly good (3) to excellent (5) with cotton giving better fastness. However, silk recorded better color strength in term of k/s values in the range of (110 to 260) and more lustrous appearance was observed on it. Dye from M. lucida plant species recorded overall superior color characteristics on both fabrics and with both mordants.

Keywords: fastness, color strength, mordanting, optimized, dyeing variables.

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Janani Loum,[1] Robert Byamukama,[2] PAG Wanyama[3]

[1]Department of Polymer, Textile and Industrial Engineering, Busitema University, Uganda
[2]Department of Chemistry, Makerere University, Uganda
[3]Department of Chemistry, Kyambogo University, Uganda

Correspondence: Janani Loum, Department of Polymer, Textile and Industrial Engineering, Busitema University, P.O. Box 236, Tororo, Uganda, Email loumjanani75@gmail.com

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Introduction

Uganda harbors thousands of undocumented dye-yielding plants found both in homes and in the wild. A small fraction of these plant species have traditionally been used for coloring home based materials and also used in traditional medicine. From earlier studies, some indigenous dye-yielding plants have been identified *viz: M. lucida, V. paradoxa, S. cordatum, A. coriaria, and I.* arrecta among others.[1] Dyes from these plants have limited or no application in the textile industry due to various problems faced with their use. Due to these drawbacks, dyes from natural sources still find limited application in the textile industry globally.

Apart from the problem of their non-availability, natural dyes generally have; poor color fastness, lack of reproducibility of shades and lack of brilliance in color. These weaknesses coupled to the advent of more promising synthetic dyes in 1856, the use of natural dyes suffered markedly. The new synthetic dyes had good color fastness, good reproducibility of shades, brilliance of color and they are also easy to use.[2] The production and use of the synthetic dyes are alleged to; cause allergies, carcinogenic and detrimental to human health.[3] As a consequence of the current global environmental awareness, the interest in use of synthetic dyes is rapidly fading in preference of those from natural sources. Dyes from natural sources are generally considered to be non-toxic and biodegradable in nature.[4]

Due to the increasing civilization and global increase in population, the production of textile products is ever increasing to meet the growing demand. The increase in production and use of diverse textile products has led to an increased use of dyes which are largely synthetic. It has been reported that by the year 2008, the production and use of the synthetic dye stuff in the textile industry had reached an estimated amount of 10,000,000 tons per annum.[4] Europe which is the largest consumer of synthetic dyes accounting for 28% of the global market, her consumption of synthetic dyes by 2024 is projected at 411,060 metric tons.[5] This results to the release into the environment of enormous amounts of toxic wastes and unfixed dyes resulting to serious pollution with dire effect to human health.

The use of natural dyes has currently gained support due to the worldwide concern in the use of eco-safe biodegradable materials.[6] The natural dyes are also from renewable sources. Additionally, the natural dyes can be used for coloration of foods,[7] cosmetics,[8] medicines, leather processing, handicrafts,[9] pH indicators and dye-sensitizers in solar cells.[10] More importantly, many of them are used in traditional medicines in many cultures in Africa, Asia and Latin America.

Apart from the problem of their non-availability, natural dyes generally have; poor color fastness, lack of reproducibility of shades and lack of brilliance in color. Some of these weaknesses can be improved by application of chemical agents called mordants.[11] Color characteristics imparted on fabrics normally vary with the mordant(s) used and the method of application of mordants namely: pre-mordanting, simultaneous mordanting or post-mordanting methods.[11] An in depth study is eminent for standardization of dyeing variables and evaluation of their appropriateness on dyes from selected sources since this information is yet insufficient.[12]

The complexity in dyeing with natural dye-stuffs is that, no single method of dyeing yields the same output in terms of color characteristics on fabrics. The color characteristics vary with the dye source, mordanting methods, geographical position of source, climate and dyeing variables. The purpose of this study is therefore to develop dyeing methods with good color outputs on cotton and silk fabrics for dyes from the selected indigenous plant species.

Materials and methods

Materials

Plain woven cotton and silk fabrics, spectra flash color data spectrophotometer with Mercury Blinded Tungsten Lamp (MBTL), Launder-o-meter. Manual crockmeter, analytical balance, constant temperature water bath, standard grey scale (1-5), standard dyed blue wool (1-8), alum AR, ferrous sulphate AR, sodium sulphate AR, acetic acid AR, distilled water, Sodium bicarbonate, non-ionic detergent.

Methods

Evaluation of various mordanting methods: Various methods of application of mordants were used in dyeing fabrics and their appropriateness was assessed on the basis of fastness of color produced on fabrics.

Fabrics pretreatment

The fabric samples were pretreated prior to dyeing process. Ten pieces of plain woven cotton and silk fabrics (8x10cm) each with average weights of 1.4g for cotton and 1.0g for silk were scoured. Scouring was achieved by soaking them in sodium bicarbonate solution (0.5gpl) and non-ionic detergent (Tweet® 80, 2gpl) at 50˚C for 25 minutes keeping the material to liquor ratio (M:L) at 1:40. The soaked fabrics were then washed and rinsed with tap water and made to dry at room temperature.

Extraction of crude dye liquor

Dye extracts were obtained from each of the selected plant sample by adopting standard aqueous method.[13] Dried and pulverized plant parts (200g) each of *A. coriaria* (stem bark), *V. paradoxa* (stem bark), *M. lucida (stem bark)*, and *H. madagascarensis*, (stem bark) were separately soaked in distilled water (1000cm^3) for 30 minutes. The mixtures were gently heated to 60˚C and maintained for 30 min later the temperature was increased to between 85˚C and 90˚C to boil and it was maintained at the boiling temperature for one hour to yield a crude dye extract. The extract was made to stand for 30min at ambient temperature and then filtered. The filtrate (dye liquor) was then immediately used for dyeing.

Mordant dyeing of fabrics

Pre-mordanting was done according to a standard method.[14] Ten (10) pieces of the scoured fabrics were transferred into a solution containing 10% on weight of fabric (o.w.f) of a mordant. It was gently heated at 60˚C for 30 minutes with gentle stirring. The mordanted fabrics were removed from the solution and squeezed to drive out the excess mordant solution. The fabrics were immediately transferred to a dye bath (280cm^3 for cotton, 200cm^3 for silk) and heated gently to 70˚C with intermittent stirring for 30mins. The material to liquor ration (M: L) of 1:20 and pH of 6.5 to 7.5 was maintained during the dyeing.

Simultaneous/meta mordanting was conducted according to a standard procedure.[15] Ten pieces of scoured fabrics were dyed using an open beaker (1000cm^3) to which dye extracts and 10% on weight of fabric (o.w.f) of a mordant and 20% (o.w.f) of sodium sulphate were added. The pH of dye bath was maintained between 6 and 8 using dilute sodium hydroxide solution and material to liquor ratio (M: L) was maintained at 1:20 in all cases. The dyeing temperature was maintained at 70ºC throughout dyeing. The dyed fabrics were removed from dye bath, washed with soap, rinsed with tap water and made to dry in an open air. This set of experiment was done for both mordants and on both fabrics.

In Post-mordanting, sample of ten pieces of fabrics (10 pieces) were dyed without use of mordant and material to liquor ratio (M: L) maintained at 1:20 in all dyeing and temperature was kept at 70˚C. The dye bath contact time was 30mins in all dyeing. After applying the dye, the fabrics were squeezed to remove excess dye and soaked in a mordant solution containing 10% on weight of fabrics of a mordant for 30 mins at 50˚C. The fabrics were removed and made to dry in the laboratory at room temperature.

Evaluation of color fastness

Wash fastness was assessed according to standard test method 61, 2 (A) using a Launder-o-meter.[16] Dyed fabric samples were cut to suitable sizes, and each sample was attached to a bleached white cotton fabric of similar dimensions. The composite specimen was treated in a stainless steel beaker (100cm^3), containing 2g/l industrial soap and rotated in a washing machine at 40˚C for 30 minutes. The samples were washed with tap water, squeezed to remove excess water and made to dry. The color change was assessed against standard grey scale 1-5.

Light Fastness was done on a TEXLAB Light Fastness Tester where each sample was cut into small pieces and placed in a sample holder then exposed to MBTL (Mercury Blinded Tungsten Lamp) inside chamber for 24 hours. The change in color shades were graded against standard blue dyed wool on a scale of (1-8).

Fastness to rubbing both dry and wet was determined according to AATCC, Test method 8, using a manually operated crockmeter and grey scale 1-5.[16] In the dry-rubbing test, the fabric covered with the bleached fabric was rubbed 10 times. In the wet-rubbing test, the same procedure was used, with a fresh dry specimen and bleached cloth which had been wetted with distilled water and squeezed to remove excess water. Staining of bleached white cotton fabric by dyed fabrics was assessed on a standard grey scale (1-5).

Optimization of dyeing variables

In this section, mordanting methods that registered superior fastness characteristic with each plant and mordant were used in the evaluation of the other dyeing parameters. The color characteristic on fabrics considered here as a basis is the color strength in terms of K/S values. Four experimental variables were considered for optimization namely; dyeing temperatures, dye bath contact time, concentration of mordant on weight of fabrics, and material to liquor ratio (M: L). During the study of one variable, the other four variables were kept at standard values as used in earlier experiments and optimized variables were used in subsequent experiments.[17]

Evaluation of color strength and fastness

The color strengths (K/S values) on fabrics dyed under various conditions were evaluated in comparison to fabrics dyed under standard experimental conditions (previously used conditions). These conditions includes; material to liquor ratio (M:L, 1:20), mordant concentration (10%, o.w.f), dye bath contact time of 30 mins and pH of 6.5 to 8 and dyeing temperature of 70˚C.

Data analysis

Data obtained from the experiments were treated to obtain optimal values for variables of interest on a one by one basis i.e. single factor variable. Linear regression optimization with single factor variable on excel was employed.

Results and discussions

Methods for application of mordants

Data on color fastness was read and analyzed on a case by case basis. Interpretation was drawn basing on the meanings of the data values. Generally, ferrous sulphate mordants produced darker shades and in contrast, alum mordant produced lighter shades on both types of fabrics. Mordant dyeing method that registered superior fastness grades were selected as the suitable method for mordant dyeing in each case. For the rub and wash fastness, a numerical grading on a scale of 1–5 against standard grey scale was used, where 1 is very poor and 5 is excellent. Light fastness was graded on a system of 1 to 8, against standard dyed wool where 1 is very poor and 8 is excellent.

Fastness of dyed fabrics

The data on color fastness of dyed fabrics are summarized in Table 1and Table 2 for cotton and silk respectively. The following abbreviations are frequently used: CC- color change, CS-color staining, PREM-pre-mordanting, SM-simultaneous mordanting, POM-post-mordanting. Discussion is done with respect to each dye source (plant species).

Cotton fabrics

A. coriaria: poor light fastness (3) with alum mordant registered across all mordanting methods. However, POM registered a very good wash fastness of color change (CC) (4-5) with minimum color staining (CS) (4-5) and excellent rub fastness of (5) despite of the general poor light fastness registered. With ferrous sulphate mordant, PREM recorded a good was fastness of CC (4) with minimum CS (4-5) and excellent dry and wet rub fastness (5) with a good light fastness of (6).

V. paradoxa: SM recorded a very good (4-5) and good (4) wash and rub fastness with CS (4) though a poor light fastness (3-4) was registered using alum. With ferrous sulphate mordant, PREM gave a good CC (4) with CS (4-5) and very good wash and rub fastness (4-5) however, a weak light fastness (4) was noted.

Table 1 Color fastness of selected plant dyes on cotton fabrics dyed with application of alum and ferrous sulphate mordants

Plant species	Mordanting method	Alum mordant					Ferrous sulphate mordant				
		Wash fastness		Rub fastness		Light fastness	Wash fastness		Rub fastness		Light fastness
		CC	CS	Dry	Wet		CC	CS	Dry	Wet	
Albizia c.	Pre	4	4-5	5	5	3	4	4-5	5	5	6
	Meta	3-4	3-4	5	5	3	4-5	4	5	5	5
	Post	4-5	4-5	5	5	3	4	3-4	5	5	6
Vitellaria p.	Pre	4	4	3-4	2-3	4	4	4-5	4-5	2-3	4
	Meta	4-5	4	4	2-3	3-4	3	4	3-4	2	5
	Post	3-4	4	3-4	2-3	4-5	3-4	4-5	3-4	2	4
Morinda l.	Pre	4	2-3	4	3-4	5-6	4	2-3	4	3	5-6
	Meta	4	2-3	4	3	4-5	3	2	4-5	3	6
	Post	5	2	4-5	4	5-6	5	2	4	3	6
Harungana m.	Pre	2-3	4-5	3-4	3-4	4	2-3	4	4	3	4-5
	Meta	2-3	4	3	3-4	4	2-3	4-5	3	3	5-6
	Post	3	4	3	4	2-3	3	4-5	3	3	5

Table 2 Color fastness of selected plant dyes on silk fabrics dyed with application of alum and ferrous sulphate mordants

Plant species	Mordanting method	Alum mordant					Ferrous sulphate mordant				
		Wash fastness		Rub fastness		Light fastness	Wash fastness		Rub fastness		Light fastness
		CC	CS	Dry	Wet		CC	CS	Dry	Wet	
Albizia c.	Pre	4-5	2-3	2-3	2	2-3	2-3	4-5	3	2-3	3-4
	Meta	4	3	3	2-3	2	3	4-5	1-2	1-2	3
	post	4-5	3	3-4	3	3	2-3	4-5	3	2-3	5
Vitellaria p.	Pre	3-4	4-5	3-4	3	4	2-3	4-5	2	2-3	3
	Meta	3-4	4-5	3	3	4-5	1-2	4-5	3	2	3-4
	post	3-4	4-5	4	3	4	2-3	4-5	3	2	3-4
Morinda l.	Pre	4	2-3	4	3-4	5	4	2-3	4	3	5-6
	Meta	5	2	4-5	4	6	5	2	v	4	6
	post	4	2-3	4-5	4	5-6	4	2-3	4	4	5
Harungana m.	Pre	2-3	4-5	4	4	4	2-3	4	4	3	4-5
	Meta	2-3	4	3-4	3	4	2-3	4-5	3	2-3	5-6
	post	3	4	4	3	2-3	3	4-5	4	3	5

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M. lucida: the following were observed with alum mordant, POM recorded an excellent CC (5) with CS (2) and very good (4-5) wash and rub fastness and fairly good light fastness (5-6). With ferrous sulphate mordant, POM gave an excellent CC (5) wash fastness with CS (2-3) and good (4), (6) rub and light fastness respectively.

H. madagascariensis: a general inferior fastness was recorded across all mordanting methods. With alum mordant, PREM registered better results of the other methods with a light fastness of (4), dry and wet rub fastness of (3-4) and a poor wash fastness of (2-3). For ferrous sulphate POM recorded a better fastness with light fastness of (5) and the wash and rub fastness of (3) were recorded.

Silk fabrics

A. coriaria: POM with alum produced an overall superior fastness with a very good was fastness CC (4-5) and CS (3) and an average dry and wet rub fastness of (3-4) and (3) respectively however, poor light fastness of (3) was recorded.

Ferrous sulphate mordant registered generally poorer fastness across all mordanting methods. However, post mordant dyeing recorded a fairly good light fastness of (5). Both the wash and wet rub fastness recorded were generally poor (2-3) and a fair dry rub fastness (3) the CS (4-5) was recorded in washing.

V. paradoxa: with alum, POM recorded a light fastness of (4-5) and the other fastness recorded was fairly good in the range of (3) and (4) a good CS (4-5) registered. Generally poor fastness was also registered with ferrous sulphate. POM also registered poor fastness performance recorded in the range of (2-3) and (3-4) though a good CS (4-5) was recorded and it's considered a better method.

M. lucida: with alum mordant, POM registered good wash fastness CC (4) with CS (2-3) and very good (4-5) wet and a good (4) dry rub fastness an average light fastness (5-6) was also recorded. With ferrous sulphate mordant, SM recorded an excellent CC (5) with CS (2), and very good (4-5) and good (4) dry and wet rub fastness respectively additionally, good light fastness (6) was also registered.

H. madagascariensis: PREM registered better results of the other methods with a light fastness of (4) and dry rub and wet rub fastness of (4) and a poor wash fastness of (2-3) with alum mordant. For ferrous sulphate, POM recorded a better fastness with light fastness of (5), a fair wash fastness CC (3) and CS (4-5) and wet rub fastness of (3) were recorded. A good dry rub fastness (4) was however registered with the mordant.

Table 3 contains a summary of the mordanting method suitable for each mordant and fabrics for a particular dye yielding plant. This was arrived at after careful interpretation of the data on color fastness of dyed fabrics. In some cases, alternative mordanting methods may be used depending on the end use of the fabric. It is important to note that color fastness on fabrics is affected by many factors and in the present stage of the study; mordanting methods have been preliminarily evaluated. The other factors were studied in the section for optimization of dyeing variables.

Optimized dyeing variables

Dyeing is a chemical reaction and its speed is affected by many variables. Mordant dyeing is a typical complex formation between the fabric, mordant and the dye compounds. Dyeing of fabrics is essentially an exothermic process. The heat of dyeing is considered as a measure of bonding force of the dye with the fibre. The enthalpy of heat (ΔH°) is depicted as energy of broken bonds minus energy of formed bonds. The greater the value of energy of bonds formed between the fibre and the dye, the more stable the dyeing will be. If this value is greater than the energy of broken bonds, the heat of dyeing is negative.[18]

Table 3 Mordanting methods adopted for cotton and silk fabrics for dye from selected plant with the use of alum and ferrous sulphate mordants

Plant species	Mordanting method			
	Cotton fabric		Silk fabric	
	Alum	Ferrous sulphate	Alum	Ferrous sulphate
Albizia c.	POM	PREM	POM	POM
Vitellaria p.	SM	PREM	POM	POM
Morinda l.	POM	POM	POM	SM
Harungana m.	PREM	SM	POM	POM

The mechanism of fibre dye complexation in the presence of mordant follows a pseudo-second order model.[18] A pseudo second order reaction has molecularity greater than two but only two molecules are involved in the rate determining step which decides the order of the reaction. Hence order is two but molecularity is more than two. Such reactions are observed both on surfaces and in solution.

The rate determining species here are the dye and mordant, the presence of the fibre is a third non rate determining factor. In a study of dyeing kinetics of dye from *A. vasica* on wool, pseudo second order mechanism with activation energy of 69.039 Kjmol-1 was established indicating a chemisorptions.[19]

For optimal dyeing, it is therefore important to study and optimize some essential kinetic factors namely; time, concentration and temperature. The optimized variables are recorded in Table 4 & Table 5 for cotton and silk fabrics in that respect. Generally dyeing is a slow process that takes a much longer time than those recorded in the table but for the purpose of time saving, a favorable time that yield an acceptable level of color strength is necessary. This ranged between 1 hr and 1hr. 30mins.in all cases.

The concentration of mordants for optimal color strength ranges between 10 and 15 (o.w.f) for alum and 15 to 20 on (o.w.f) sulphate. This has been observed for both the cotton and silk fabrics with the two salts (mordants). Mordant is an important ingredient in dyeing and it has been reported to enhance UV protection property of naturally dyed cotton,[20] wool and silk[21] substantially depending on its concentration and nature of dye.

Color strengths in terms of K/S values for fabrics dyed under optimized conditions were also recorded. On cotton fabrics, the greatest color strengths were observed on dye from *V. paradoxa* for both mordants followed by fabrics dyed with *M. lucida* dye.

The above time trend is also observed in the case of silk fabrics as in Table 6. However, the greatest strengths of color are realized with dye from H. madagascariensis plant followed by dye from *M. lucida* plant species. The dyeing temperatures vary between 80˚C and 95˚C (simmering temp.) in all cases. Heating was meant to speed up the rate of chemical reaction i.e. bonding and complexation. Dyeing would be done at normal room temperature since it is an exothermic process. The problem is that it will take a longer time to obtain the desired dye exhaustions on fabrics.

Table 4 Optimized Dyeing variables for cotton with corresponding color strengths

Plant species	Alum mordant					Ferrous sulphate mordant				
	Temp (˚C)	Time (mins)	Mordant (o.w.f)	M:L ratio	K/S value	Temp. (˚C)	Time (mins)	Mordant (o.w.f)	M:L ratio	K/S value
Albizia c.	85	77	15	0.09375	104.2	90	80	20	0.097222222	116.5
Vitellaria p.	70	60	20	0.083333333	126.5	90	60	15	0.083333333	118.2
Morinda l.	75	65	15	0.086805556	185.2	80	60	10	0.083333333	117.3
Harungana m.	75	85	12	1:50	101.5	80	85	12	0.097222222	116.9

Table 5 Optimized Dyeing variables for silk with corresponding color strengths

Plant species	Alum mordant					Ferrous sulphate mordant				
	Temp (˚C)	Time (mins)	Mordant (o.w.f)	M:L ratio	K/S value	Temp. (˚C)	Time (mins)	Mordant (o.w.f)	M:L ratio	K/S value
Albizia c.	95	80	10	60	111.9	95	90	15	60	115.9
Vitellaria p.	95	80	10	50	187.2	95	85	20	70	116.3
Morinda l.	80	90	15	75	198.2	80	90	12	80	216.2

Table 6 Fastness of cotton fabrics dyed under optimized conditions

Plant	Alum mordant				Ferrous sulphate mordant			
	Wash	Dry rub	Wet rub	Light	Wash	Dry rub	Wet rub	Light
Albizia c	4-5	5	5	4	4	5	5	6
Vitellaria p	4	3-4	3	5	3-4	4-5	3	5
Morinda l	5	4-5	3	5	5	4-5	3-4	6
Harungana m	3	3-4	3-4	4	3	4	3	5-6

For general apparel, a grade of 4 or 5 is acceptable, whereas for curtain or automotive fabric a grade of 7 or 8 is required. According to the results in Table 6 & Table 7, none of the dye can have application for curtain and automotive since the maximum light fastness recorded was (6-7) which is below the requirement. However a good number recorded fastness of between (4) and (5). Those with poor wash fastness find little application on apparels that require frequent laundering like in daily clothing and bed linens.

On silk fabrics, improved fastness were registered for both alum and ferrous in the range of fairly good (3-4), good (4), very good (4) and excellent (5). The mordant dyeing under optimized dyeing conditions improved color strengths and fastness on both cotton and silk fabrics. To achieve better optimal color strengths on silk fabrics, heating to higher temperatures of between 80˚C to 95˚C and for a longer time (approximately 1hr 30 min) is required and cotton fabrics can get optimal color characteristics at averagely lower temperatures (70 to 90˚C) within 1 hr to 1hr 20 min. The difference in degree of crystallinity of a polymer unit in a fibre is a factor that makes silk to achieve optimal color characteristics after more vigorous treatment. This is because the increase in crystallinity of polymer units of a fibre decreases the rate of diffusion of dye into the fibre structure. Silk and cotton fibre have distinct structures unique to each where silk is a protein fibre and cotton is a cellulosic fibre, both exhibiting different degree of crystallinity. Silk is a bio-composite of fibroin and protein gum sericin glued together the fibroin consists of numerous amino acids units linked to form a highly crystalline and uniformly oriented chains which are positioned parallel to the silk fibre axis[22] this makes silk a highly crystalline fibre. Cotton fibre is partially crystalline and amorphous with the degree of crystallinity between 70 and 80 %.[23] It is known that dye uptake and exhaustion is slower in more crystalline fibers. This is observed in the slow dye absorption of silk exhibited in averagely longer optimized dyeing exhaustion time than cotton counterpart.

Table 7 Fastness of silk fabrics dyed under optimized conditions

Plant	Alum mordant				Ferrous sulphate mordant			
	Wash	Dry rub	Wet rub	Light	Wash	Dry rub	Wet rub	Light
Albizia c	4-5	3-4	3-4	4	3	3-4	2-3	5
Vitellaria p	3-4	4	3	5	2-3	3	2-3	3-4
Morinda l	5	4-5	4	6	5	4-5	4	6-7
Harungana m	3	4	4	4-5	3-4	4	3	5-6

Dyeing processes that occurs in aqueous solutions involves the distribution of dye between two phases, i.e. the dye liquor and the solid substrate as a result of physicochemical interactions between the molecules.

Convectional diffusion in the dye-bath during which the dye molecules move within the liquor towards the fibre is accelerated by relative movement of the liquor and fibre.[23] Adsorption is required where the dye molecules adhere to the fibre surface. The fibre surface refers to the outer visible surface of the fibre and the surface of pores which penetrate deep into the fibre interior.[23]

To a great extent this stage influence color uniformity on fabrics. These express the need to speed up molecular movements by creating turbulence in dye bath through intermittent stirring and heating during the dyeing. The inadequacy of these leads to prolonged exhaustion time and more importantly uneven distribution of dye on fabrics which results to loss of beauty.

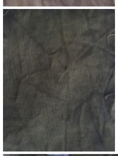
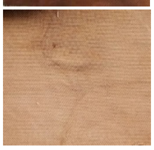
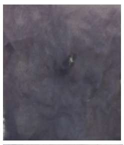
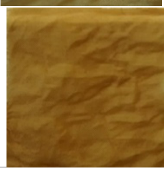
There is also molecular diffusion of the dye from the fibre surface to the internal structure of fibre interior. This process is rather slow and the rate of which can be increased by raising the temperature of the dye solution.[23] Raising the dyeing temperature helps to increase fibre swelling and hence improved dyeability. As can be noted from the optimization study, better dye exhaustions were achieved at higher temperatures in the range of 80ºC to 90ºC in most cases. These recorded dyeing times are only optimal with consideration of other cost factors like energy otherwise the longer the time taken for dyeing the better is the dye exhaustion on fabrics.

The last step is the attachment of dye molecules on the fibre molecules by bond formation between the dye and fibre molecules and their stability depends on the type of bonding.[23] The bond strength depends on the type of dye compounds and the bonding enhancer which are involved and fastness of the dye on fibre is dependent on the strength of the bonds formed between the dye and fibre molecules. This attempts to explain why color fastness of dye varies with the source of dye, the mordant used and the fibre type. This was noted in this study where dyeing with ferrous sulphate mordants registered relatively better fastness grades compared to alum on both silk and cotton fabrics. From the study it was also noted that color fastness has no direct relationship to color strength.

Shade produced on silk and cotton fabrics are included in Table 8 and from that it can be noted that ferrous sulphate mordant impart darker shades on fabrics with lighter shades recorded with alum mordant. As can be noted from the table, shades produced on silk fabrics are a little more brilliant than those on cotton. It is postulated that this difference is a result of the difference in fineness (linear density) of the fibre surface of silk.

The fineness of a textile fibre is described by its linear density, the linear density of silk fibre is between 0.19 and 0.44 tex and that of cotton 0.13 and 0.21 tex.[23] The differences in the range of linear densities show that silk is a finer fibre and therefore it produces more lustrous shades due to its shiny surface.

Table 8 Color shades produced on cotton and silk fabrics dyed under optimized variables with alum and ferrous sulphate mordants

Plant	Shades on cotton fabrics		Shades on silk fabrics	
	Alum	$FeSO_4$	Alum	$FeSO_4$
A. c				
V. p				
M. l				
H. m				

Key: A.c-Albizia coriaria, V.p-Vitellaria paradoxa, M.L-Morinda lucida, H.m-Harungana madagascariensis.

Conclusion

From the study, it has been found that color fastness and strengths of dyes on fabrics vary with the source of dye, the mordant used, mordanting method and the type of fibre. Additionally, color fastness has no direct relationship to color strength since some strong colors on fabrics exhibited poor fastness and vice versa. Dyeing under optimized conditions improves color strengths and fastness for both cotton and silk fabrics. To achieve better strengths of color, silk fabrics required a little more heating to higher temperatures (80˚C to 95˚C) and for a longer time (≈ 1hr 30 min) than cotton fabrics. The fastness on both fabrics dyed under optimized conditions vary from fairly good (3) to excellent (5) with cotton fabric giving better fastness. However, the color strengths in terms of k/s values are stronger on silk with k/s values ranging from 115 to 222 and in cotton the k/s values range is from 101 to 126. Dye from M. lucida plant species gave overall superior color characteristics on both fabrics and with both mordants.

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Conflicts of interest

The authors have no conflicts of interest regarding the publication of this paper.

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