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Isolation of Dye from Sporophore of *Xylaria polymorpha* for Textile Dyeing and Spectrophotometric Characterization of Dyed Fabrics

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Abstract: The present study was aimed at isolating natural dye from *Xylaria polymorpha,* a wood rot fungus with club shaped fruiting body by standardizing the extraction protocol. Different fabrics viz. silk, wool and cotton were dyed using the extracted dye employing different common mordants of metallic salts and few natural mordants and the resultant shades, fastness properties and colour coordinates were compared on the test fabrics. The dye produced different shades of blackish brown on the dyed fabrics. Based on the highest absorbance, best performance of the dye was recorded with wool followed by silk whereas least absorbance was observed with cotton. The dye showed high affinity with wool and silk fabrics but relatively low affinity with cotton. It is found to hold very good to excellent colourfastness (rating 4-5) on wool and silk fabrics but good to very good (rating 3-4) on cotton against various colour retarding factors. The study evidently indicated that *X. polymorpha* dye is suitable for dyeing wool, silk and cotton thus establishing the fungus as a potential source of textile dye of biological origin. This is the first report on *X. polymorpha* as a viable source of textile dye of biological origin.

Key words: *Xylaria polymorpha,* natural dye, textile dyeing, colourfastness, colour coordinates.

Introduction

The textile industries consume huge volumes of pure water which is converted into wastewater contaminated with wide spectrum of hazardous chemicals which possess high toxicity value (EC50:3-6 %), if remain untreated [1]. Organically bound chlorine, a known carcinogen has been reported in about 40 percent of globally used colourants and hence significant amount of environmental degradation and human illnesses is caused by textile effluent. These chemicals evaporate into the air and enter into human body either through breathing or epidermal absorption thereby demonstrating allergic reactions and causing harm to children even before birth [2]. Industrial organic waste, especially aromatic textile dyes, are considered one of the most abundant and hazardous pollutants particularly, azo dyes are reported to be mutagenic and are linked to increasing incidences of cancer amongst textile workers [3-7]. Even drinking water after treatment has been reported to carry the effluents of dyeing industries discharged into the river indicating that the adopted effluent treatment based on pre-chlorination, flocculation, coagulation and flotation, commonly used by DWTP (Demineralization Water Treatment Plants), are not completely efficient to remove these dyes. These facts have been supported with

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mutagenic activity detected in such wastewater [8]. Hence looking to the toxicity of synthetic dyes coupled with worldwide consciousness over better environment, the revival of interest in natural dyes are increasing. Natural dyes are less toxic, less polluting, less health hazardous, non-carcinogenic and non-poisonous. Added to this, they are harmonizing colours, gentle, soft and subtle, and create a restful effect. Above all, they are environment-friendly and can be recycled after use. Natural dyes find application in many ways in clothes, foods, pharmaceuticals, paintings, paints and cosmetics. However in spite of its toxicity and environmental problems associated with the synthetic dyes, the textile manufacturers are not yet finding proper enticement in switching over to natural dyes for being more expensive than their synthetic counterparts. It is due the lack of scientifically validated information of dye-yielding sources, sustained supply of raw material, inconsistent yield and colour quality that warrants sincere scientific interventions if production and use of natural dyes is to be made a commercial reality. Despite lots of available traditional wisdom in this context, a very limited number of such information has been properly documented and scientifically validated. The technology of utilizing natural dyes in the modern clothing industry is also relatively new and is still being improved upon.

The problem of consistent supply in sufficient quantity at appropriate price can be ensured by increasing R&D work on natural dyes and technological improvements and finding new resources of natural dye. In recent year there has been increasing interest in using microorganism as a source of natural colours owing to cost efficiency, sustained raw material supply, less labour and land required and non-hazardous production process. However, very little efforts have so far been made to use fungi as source of natural dyes despite the fact that certain species can yield considerable amount of good quality colouring substance for textile applications. Use of fungi for production of natural dye has certain advantages over plant dye that includes availability of material in desired quantity, intense and consistent colours and can fulfill need of consumers and industries for overall development of natural dye sector. The chromophores of mushroom dyes contain a variety of fascinating organic compounds. Their pigmentation may vary with the age and some undergo distinctive colour changes on bruising; therefore, the colours of mushrooms are one of the essential features used in their identification. Furthermore, the pigments of mushrooms may protect the organism from UV damage and bacterial attack or play a role as insect attractants [9].

Pigments production from microbes is advantageous over other sources because microorganisms can grow rapidly which may lead to a high efficiency in quality and quantity of the product *Monascus* species are widely used as a microbial source for natural red pigment production [10]. Monascus red pigments are of polyketide origin and are used commercially as non-toxic colorants for colouring rice wine, “Koji”, soybean, cheese and red meat [11]. The red pigments have attracted worldwide commercial interest [12, 13], but little information is available on the production of the pigment by other microbial sources. It has been reported that *Penicillium* may be the potential candidate to produce polyketide structure compounds [12]. Natural dyeing using the fungi derived colorants has been reported in some countries. However, published reports of scientific research on the subject are scanty [14]. Although the natural dyeing has age-old traditions, however, with systematic R&D interventions, efficiency and colourfastness of dye can be improved and a range of hues can be generated. Procedural improvement for dye extraction, dyeing and mordanting through systemically designed research ultimately lead to better quality dye production and textile dyeing. The present work was thus aimed at extracting natural dyes from *Xylaria polymorpha* and its characterization to ascertain its suitability as commercially acceptable textile dye.

Materials and methods

Fungus and fabrics

The fruiting body of *Xylaria polymorpha* (1.245 g) was collected from the premises of Forest Research Institute (FRI) Dehradun, India during the months of August-September, 2016. The collected fungal material was authenticated by the Plant Pathologist of Forest Pathology Division, Forest Research Institute, Dehradun. Pure silk, wool and cotton textile fabrics were purchased from Gandhi Ashram, an authorized outlet of KVIC at Dehradun, India. The fabrics were washed with non-ionic detergent (1 % owf) for 30 minutes, rinsed and dried at room temperature. The fabric material was wetted in water for 30 min prior to dyeing or mordanting

Chemical & analytical

All the chemicals *viz*., acetic acid, alum, copper sulphate, ferrous sulphate, potassium dichromate and stannous chloride used as mordants were of L.R. grade of chemicals and procured from local dealers. Pure Khadi silk, wool and cotton were used in dyeing experiments. The U.V. spectra were recorded on a UV spectrophotometer (Chemito make; Model 2700. The CIEL*a*b*, hue, chroma and K/S values were determined on a Reference Bench-top Spectrophotometer (Make-Gretag Mac Beth; Colour-Eye 7000A). Colour fastness of the different types of dyed fabric against washing, light, perspiration and rubbing were measured by using Laundrometer (Make: Metrex Scientific Instrument (P) Ltd.), Digital Light Fastness Tester (Make-Labin Scientific Instruments and Calibration (P) Ltd.), Perspirometer and Crockmeter (Make-Globe-Tex Industries) respectively.

Standardization of dye extraction parameters

Conditions such as combination of fungus biomass and extractant (material to liquor ratio i.e. MLR), and time duration for extraction was standardized for optimal extraction of dye from *X. polymorpha* fruiting body. Extraction experiments were carried out in 500 mL beaker containing 100 mL of distilled water with (0.1 g - 0.5 g) of sodium carbonate (Na_2CO_3) and different amounts of dried fruiting body of *X. Polymorpha* ranging from 1-10 g and then heated at 95-98^{0}C for 60 minutes. Before the standardization extraction experiments were carried out in acidic, alkaline and neutral medium and it was found that the highest OD of same materials under similar condition in alkaline medium, hence further extraction of dye was carried out in alkaline medium. For determination of standard duration for extraction of dye was carried out by keeping the MLR as standardized above and extracted for varying time ranging from 15 to 90 minutes. The dye extracts obtained from each of the experiments were cooled, filtered through whatman-1, and made to 100 mL., then 1 mL. of aliquot from each of the extracts were diluted to 100 mL and subjected to optical density (OD) measurement. Based on the highest value of OD, optimum values of MLR, alkali content and duration for dye extraction were determined. Natural dye from fruiting body of *X. polymorpha* was extracted using calculated values of MLR, duration and alkali content.

Dyeing of silk, wool and cotton fabrics

Dyeing on silk, wool and cotton samples was carried out by post mordanting method, which produced improved shades in terms of hue and darkness. The dye bath was set 10 g per liter of the dye by keeping the material to liquor ratio of 1:30. The dye bath was heated up to a temperature of 80-85^{0}C and maintaining the solution level for 45 minutes for dyeing the silk and wool samples and a temperature of 90-95^{0}C was maintained for cotton for 60 minutes. The dye bath was cooled to room temperature and the dyed fabrics were directly transferred to mordant bath for mordanting.

Mordanting of dyed fabrics

Most of the natural dyes are mordant dyes and require a mordant for fixing it to the fabric. Post mordnating techniques were adopted for mordantoing of dyed fabrics. Common mordants like alum, copper sulphate, potassium dichromate, iron salts and tin salts have affinity for both the dye and the fabric and form an insoluble precipitate on combining with the dye in the fiber. Solutions of 0.5 percent of different mordant were prepared and the dyed samples were directly immersed in the mordant bath by keeping the material to liquor ratio of 1:30. Mordants used for study were alum, copper sulphate, ferrous sulphate, potassium dichromate and stannous chloride. Two natural mordants *Terminalia chebula* fruit pericarp powder and *Phyllanthus emblica* fruit powder were also examined to produce fast and durable shades on the applied fabrics. The dyed textile samples using dyes extracted from *X.*

polymorpha fruiting body were mordanted with different mordants and were separately codified as XP 1 (without mordant), XP 2 (Alum), XP 3 (Copper Sulphate), XP 4 (Ferrous Sulphate), XP 5 Potassium dichromate), XP 6 (Stannous chloride), XP 7 (*Phyllanthus emblica*) and XP 8 (*Terminalia chebula*). Numeric values are indicative of mordant treatments for the three types of fabrics i.e. silk, wool and cotton for further studies.

Determination of colour fastness of dyed fabrics

Fastness of dyed textile fabrics indicate the resistance which the fabrics exhibits to losing its shade when subjected to the action of different agent such as light, washing, rubbing, human perspiration etc. which can give rise to loss or change of shade and to staining of the other textiles. Usually a textile fabric faces many external conditions which can affect the colour of the textiles; therefore the dyed fabrics were tested for their colour fastness properties against washing, light, crocking/rubbing and perspiration. Colour fastness of dyed fabrics to light, wash, crocking and perspiration was carried out by standard methods; IS: 2454: 1985, IS-687:1979 IS-766: 1988 and IS-971: 1983 respectively [15]. The dyed fabric samples were assessed against the standard grey scales for change of colour and staining on adjacent and rubbing fabrics, while for light fastness, comparison up to Blue wool standard 5 was done.

Determination of colour coordinates

All the dyed and mordanted silk, wool and cotton samples were tested for their L*, a*, b*, C*, h^0 and K/S values using Reference Bench Top Spectrophotometer. CIE stands for Commission Internationale de l'Eclairage system of colour analysis, an international clearinghouse for colour research at universities and research laboratories who developed CIE L* a* b* or CIELAB colour scale to be used by everyone for comparison of colour values. L*, a*, and b* signify respectively the luminosity or lightness, redness or greenness and yellowness and blueness of a sample. Positive a* is red and negative a* is green where as positive b* is yellow and negative b* is blue.

Other aspects, like hue, chroma and K/S ratio of the dyed fabrics were also studied so as to get a more precise result of the colour coordinates.

Hue: Hue is the attribute by which a sample differs from achromatic (i.e. hueless) colour of same lightness.

Chroma: It is the colourfullness at a given luminance level. Chroma is the colourfulness of an area judged in proportion to the brightness of a similarly illuminated area that appears to be white or highly transmitting.

K/S values

Kubelka-Monk equation defines a relationship between spectral reflectance (R in %) of the sample and its absorption (K) and scattering (S) characteristics, represented as follows:

$$K/S = \frac{[1 - 0.01\ R^2]}{2[0.01\ R]}$$

K/S grows to infinity as reflectance decreases to zero

Results

Standardization of dye extraction parameters

Based on the highest value of optical density for a particular amount of *X. polymorpha*, the standard material to liquid (water) ratio (MLR), alkali content and duration of extraction was standardized. The OD for standardization of MLR was found to be 0.721, 0.930, 1.013, 1.132, 1.226, 1.290, 1.311, 1.115, 1.021 and 0.962 for 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 g of weight of *X. polymorpha*. Similarly for extraction duration the observed OD was 1.134, 1.206, 1.392, 1.311, 1.270, and 1.226 for the extraction period of 15, 30, 45, 60 and 75 minutes respectively. Since in alkaline medium OD was maximum, hence alkali content for extraction of dye was also standardized. Different weight of sodium carbonate (Na_2CO_3) was used for extraction of fruiting body, for 0.1, 0.2, 0.3, 0.4 and 0.5 g of Na_2Co the OD observed was 1.034, 1.335, 1.342, 1.487 and 1.276 respectively.

Dyeing and mordanting of fabrics

Dyeing of silk and wool with *X. polymorpha* dye was carried out in 1.0 % dye solution with material to liquor ratio of 1:30 for 45 minutes at a temperature of 80-85^{0}C, while for cotton dyeing was continued for 60 minutes. Mordant concentration of 0.5 g/100 mL and mordanting time 30 minutes for silk and wool and 45 minutes for cotton were found to be optimum by visual observations of dyed and mordanted samples. The criteria for evaluation were the depth of colour, evenness of dye and brightness of shade. The dyed samples were directly immersed in the mordant bath by keeping the fabrics to liquor ratio of 1:30. The bath was heated to a temperature of 80-85^{0}C for 30 minutes for fixing the dye on silk and wool samples. For cotton samples the mordanting was continued for 60 minute at a temperature of 95-98^{0}C. The samples were taken out from the bath, washed with water and dried in shade.

Determination of colour fastness of dyed fabrics

Different types of fabrics i.e. silk, wool and cotton, dyed using *X. polymorpha* dye were subjected to colour fastness studies against washing, perspiration, rubbing and light and determination of colour coordinates including CIEL*a*b* and K/S values as per Indian Standards (IS).

Colour fastness to washing

The dyed and mordanted textile fabrics e.g. silk; wool and cotton were tested for their colour fastness to washing. The results of colour fastness of dyed and mordanted fabrics to washing are given in Table 1.

Table 1. Colorfastness to washing (IS: 687: 1979)

No.	Test Fabric	Change in color of test fabric on grey scale			Staining on adjacent fabric 1			Staining on adjacent fabric 2		
		Silk	Wool	Cotton	Silk (Silk)	Wool (Wool)	Cotton (Cotton)	Silk (Cotton)	Wool (Cotton)	Cotton (Wool)
1	XP 1	4-5	4/5	3/4	4/5	4/5	4	4/5	4	4
2	XP 2	4/5	4/5	4	4/5	4/5	4-5	4/5	4/5	4-5
3	XP 3	4	3/4	4	4/5	4	4-5	4/5	3/4	4-5
4	XP 4	4/5	4-5	4	4/5	4-5	4-5	4/5	4-5	4-5
5	XP 5	4/5	4	4-5	4/5	4-5	4/5	4/5	4	4-5
6	XP 6	4-5	4	4-5	4/5	4-5	4/5	4/5	4/5	4/5
7	XP 7	4	4	3/4	4-5	4-5	4-5	4-5	4-5	4-5
8	XP 8	4-5	4-5	4	4/5	4/5	4-5	4/5	4/5	4-5

Colorfastness to light method (IS: 2454: 1985)

Colour fastness of textile materials to daylight is of considerable importance to the consumers. As the daylight exposure takes a long time to complete a test, a quick method of determining colour fastness to the light is by the use of artificial light (Xenon light). The data regarding colour fastness of dyed and mordanted fabrics to light are given in Table 2.

Colorfastness to crocking/rubbing (IS: 766: 1988)

The rubbing fastness determines the color fast ness of textile materials to rubbing off and staining to other materials. The test specimen was fix to the rubbing device by means of clamps such that the long direction of the specimens the track of the device. The data of colour fastness to rubbibg is presented in Table 3.

Colorfastness to perspiration (IS: 971: 1983)

This method is intended for the determination of colour fastness of textile materials of all kinds and in all forms to the action of human perspiration. Specimen of the textile in contact with adjacent fabrics were treated in two different solutions containing histidine, drained and placed between two plates under a specified pressure in a testing device. The data of colour fastness against human perspiration for silk, wool and cotton are presented in Tables 4, 5 and 6 respectively.

Determination of colour coordinates

Different types fabrics of i.e. silk ,wool and cotton dyed using *X. polymorpha* fruiting body dyes were subjected to determination of colour coordinates including CIEL*a*b* absorbance and K/S values. Results of the study are presented in Table 7.

Discussions

Optimization of dye extraction parameters

Extraction parameters viz., MLR and time were standardized based on optical density (OD) of extracted dye with different levels of the variables. The highest optical density 1.290, 1.487 and 1.392 was recorded for MLR of 7.0 g/100 mL., alkali content (sodium carbonate) of 0.4 g/100 mL. and extraction time of 45 minutes. Natural dye was extracted from *X. polymorpha* with optimized

Table 2. Colorfastness to light method (IS: 2454: 1985)

No.	Test fabric	Change in color of test fabric on grey scale			Change in color of test fabric on blue wool standard		
		Silk	Wool	Cotton	Silk	Wool	Cotton
1	XP 1	4	4	4	4	4	4
2	XP 2	4-5	4	4/5	4	4	4
3	XP 3	4/5	4/5	4/5	4	4	4
4	XP 4	4-5	4/5	4/5	4	4	4
5	XP 5	4-5	3/4	4	4	3	4
6	XP 6	4-5	4	4	4	4	4
7	XP 7	4/5	4/5	4	4	4	4
8	XP 8	4/5	4/5	4	3-4	4	4

Table 3. Colorfastness to rubbing (IS: 766: 1988)

No.	Test fabric	Staining on rubbing cloth dry rubbing			Staining on rubbing cloth wet rubbing		
		Silk	Wool	Cotton	Silk	Wool	Cotton
1	XP 1	4	4	4	3-4	3/4	4
2	XP 2	4-5	4-5	4/5	4-5	4-5	4-5
3	XP 3	3	4	4/5	3-4	4	4/5
4	XP 4	3	3/4	4-5	3-4	4-5	4
5	XP 5	4-5	4-5	4/5	4-5	4-5	4-5
6	XP 6	4/5	4/5	4/5	4-5	4	4-5
7	XP 7	4/5	4-5	4-5	4-5	4-5	4-5
8.	XP 8	4/5	4-5	4-5	4-5	4-5	4-5

Table 4. Colorfastness to perspiration (silk) IS: 971: 1983

No.	Test fabric (Silk)	Acidic			Alkaline		
		Change in color of test fabric on grey scale	Staining on adjacent fabric 1	Stainingon adjacent fabric 2	Change in color of test fabric on grey scale	Staining on adjacent fabric 1	Staining on adjacent fabric 2
1	XP 1	4-5	4/5	4-5	4	4	4/5
2	XP 2	4/5	4/5	4/5	4/5 (pink)	4/5	4/5
3	XP 3	4	4	4-5	4/5	4/5	4
4	XP 4	4/5	4/5	4-5	4	4/5	4/5
5	XP 5	4	4/5	4/5	4/5	4/5	4/5
6	XP 6	4-5	4/5	4/5	4/5	4/5	4/5
7	XP 7	4	4-5	4-5	4	4	4/5
8	XP 8	4-5	4/5	4-5	4/5	4/5	4/5

Table 5. Colorfastness to perspiration (wool) IS: 971: 1983

No.	Test fabric (wool)	Acidic			Alkaline		
		Change in color of test fabric on grey scale	Staining on adjacent fabric 1	Stainingon adjacent fabric 2	Change in color of test fabric on grey scale	Staining on adjacent fabric 1	Staining on adjacent fabric 2
1	XP 1	4/5	4/5	4/5	4/5	4/5	4/5
2	XP 2	4/5	4/5	4-5	4	4/5	4/5
3	XP 3	4	4-5	4-5	3/4	3/4	4
4	XP 4	4/5	4/5	4/5	4	4	4/5
5	XP 5	4	4	4	4	3/4	4
6	XP 6	4	4-5	4-5	4	4/5	4/5
7	XP 7	4/5	4/5	4-5	4/5	4/5	4
8	XP 8	4	4	4	4/5	4	4/5

Table 6. Colorfastness to perspiration (cotton) IS: 971: 1983

No.	Test fabric (cotton)	Acidic			Alkaline		
		Change in color of test fabric on grey scale	Staining on adjacent fabric 1	Stainingon adjacent fabric 2	Change in color of test fabric on grey scale	Staining on adjacent fabric 1	Staining on adjacent fabric 2
1	XP 1	4	4-5	4/5	4	4/5	4/5
2	XP 2	4/5	4/5	4/5	4/5	4/5	4/5
3	XP 3	4	4/5	4-5	4	4/5	4-5
4	XP 4	4-5	4/5	4/5	4/5	4/5	4/5
5	XP 5	4-5	4-5	4/5	4/5	4/5	4/5
6	XP 6	4/5	4/5	4/5	4/5	4/5	4/5
7	XP 7	4-5	4/5	4/5	4/5	4/5	4/5
8	XP 8	4-5	4	4-5	4	4-5	4/5

Table 7. CIEL*a*b* and K/S values

No.	Test fabrics	L*	a*	b*	C*	h^0	K/S
				Silk			
1	XP 1	75.19	2.03	11.22	11.4	79.76	2.78
2	XP 2	71.76	1.97	8.82	9.04	777.44	3.08
3	XP 3	67.31	1.01	11.09	11.14	84.82	3.50
4	XP 4	72.02	1.99	9.30	9.51	77.89	2.94
5	XP 5	70.25	1.34	11.21	11.29	83.19	3.30
6	XP 6	72.07	1.80	9.99	10.15	79.80	2.91
7	XP 7	69.68	2.75	13.03	13.31	78.07	3.81
8	XP 8	64.64	2.62	15.29	15.52	80.28	5.15
				Wool			
1	XP 1	61.24	6.74	22.33	23.32	73.20	6.91
2	XP 2	58.02	4.79	18.9	19.49	75.76	6.52
3	XP 3	51.66	1.20	18.9	18.94	86.36	9.21
4	XP 4	52.50	4.59	17.48	18.07	75.28	8.53
5	XP 5	40.98	4.55	25.55	25.95	79.90	22.71
6	XP 6	59.49	3.38	25.53	25.76	82.45	8.36
7	XP 7	51.63	6.38	21.09	22.03	73.16	12.39
8	XP 8	50.64	5.67	20.51	21.28	74.56	13.77
				Cotton			
1	XP 1	71.96	0.98	2.88	3.05	71.21	0.94
2	XP 2	67.62	0.64	3.61	3.67	80.03	1.05
3	XP 3	71.26	0.35	2.94	2.96	83.26	0.92
4	XP 4	66.27	2.10	11.17	11.37	79.38	2.26
5	XP 5	71.38	0.95	2.64	2.81	70.14	0.94
6	XP 6	70.52	0.68	3.81	3.87	79.83	0.97
7	XP 7	69.89	0.84	5.80	5.86	81.78	1.23
8	XP 8	62.92	1.10	5.51	5.61	78.72	1.91

condition of MLR, alkalinity of extractant and extraction time. The yield of the dye was recorded to be 13.1 % on moisture free basis. We attained the yield in good amount by boiling the fruiting body at 95-98^{0}C as reported by other researcher [16-18]. The similar conditions of extraction have been reported from fruit of *Mallotus phillipensis* [19].

Dyeing and mordanting of fabrics

Dyeing of silk and wool with *X. polymorpha* dye was carried out in 1.0 % dye solution with material to liquor ratio of 1:30 for 45 minutes at a temperature of 80-85^{0}C, while cotton fabric was dyed with the same MLR at 90-95^{0}C for 60 minutes. The dyeing experiments were carried out in acidic medium; pH of dye bath was maintained at 4.5 using glacial acetic acid as natural dyeing produces bright and stable shade in acidic medium [20]. Mordanting was carried out using post mordanting methods as it produced better depth of colour, evenness of dye and brightness of shade [19]. Research work reported on dyeing of silk, wool and cotton fabrics using *Thermomyces* dye [21] and mordanting of dyed fabrics using myrobalan (*Terminalia chebula*) as a natural mordant which is used in this research work. Several fungi species have been reported to produce pigments for textile dyeing such as *Trichoderma* sp. and *Aspergillus* sp. [22], *Monascus purpureus, Isaria spp., Emericella spp., Fusarium spp.* and *Penicillium spp.,* [23], *Aspergillus* sp. and *Penicillium* sp. [24]. Generally mordants are required for binding fiber and dye molecule, however a recent study on chemical and physical interactions between the extracted pigments from *Scytalidium cuboideum, Scytalidium ganodermophthorum, Chlorociboria aeruginosa,* and *Chlorociboria aeruginascens* [25] and materials have shown that amorphous and crystalline layer formed on substrate which can explain the resistance of the pigment against UV light and colour fastness.

Colour fastness of dyed silk, wool and cotton fabrics

Colour fastness to washing

The data regarding colour fastness of dyed and mordanted fabrics to washing are given in Table 1. The data show that change in colour on grey scale in silk fabrics in sample XP 2, XP 4 and XP 5 are 4/5 while XP1, XP 6 and XP 8 are 4-5; XP 3 and XP 7 exhibited rating of 4. In wool samples XP 3 and cotton samples XP 1and XP 7 demonstrated the rating of ¾ and rating of all other remaining samples were 4, 4-5 and 4/5. Similarly staining on adjacent fabrics 1and 2 in the case of silk, wool and cotton were 4, 4-5 or 4/5 which are very high rating and signifies the dye as good as synthetic one. Only in the case of XP 3 the staining on adjacent fabrics 2 was ¾. Hence cotton comparatively has lesser washing fastness due to weak bonding between fiber and dye molecule. The colour fastness of dyed silk and cotton fabrics to washing, dyed using *Aspergillus* sp. and *Penicillius* sp., were found satisfactory [24]. In a study the colour fastness to washing and crocking of fabrics dyed with wood-staining fungal pigments were compared to colour fastness of commercial dyes using an alternative mechanical testing method. The study revealed that mechanical colour reading method, along with statistical analysis, provided an objective, repeatable gauge of colorfastness [26].

Colour fastness to light

The values of light fastness of silk, wool and cotton fabrics are depicted in Table 2, the change in colour of test fabric on grey scale for most of the silk, wool and cotton samples are 4, 4-5 and 4/5, however in XP5 of wool it is ¾. Similarly rating of light fastness on blue scale of wool in XP 5 was 3 and in silk 3-4 for XP 5, for all the remaining samples it is 4. These values indicate that the dyed silk, wool and cotton fabrics have satisfactory stability against light exposure. These values of light fastness were also in accordance of the reported value of light fastness of silk fabrics dyed using *Thermomyces* sp. Dyes [21, 27, and 28].

Colour fastness to rubbing

As evidenced in Table 3, rubbing fastness of silk under dry conditions for XP1, XP 2, XP 5, XP 6, XP 7 and XP 8 for silk, wool and cotton are 4, 4/5 and 4-5 however for XP 3 and XP 4 the dry rubbing fastness of silk is 3-4 which is lesser than the other samples. Most of the wool and cottons samples exhibited dry and wet rubbing fastness 4, 4-5 or 4/5, which is better than as described by earlier researcher [21] while dry and wet rubbing fastness of some of silk sample was similar (3-4). Improvement of colour fastness properties was observed when the dyed fabrics were treated with mordants [27, 29, 30], hence mordanting make the fiber more resistance towards external colour fading conditions.

Colour fastness to perspiration

The data for perspiration fastness for silk, wool and cotton are given in Table 4, 5 and 6 respectively. Change in colour of dyed and mordanted silk (Table 4) fabrics under acidic perspiration exhibited very good to excellent (4-5 and 4/5) colour fastness properties, wool and cotton fabrics also rating of staining on adjacent fabrics 1 and 2 were 4-5 and 4/5 for all the tested silk samples. Similarly under alkaline condition the tested silk fabrics demonstrated 4-5 and 4/5 for all the samples. In alkaline condition, the silk fabrics mordanted with alum (XP 2) changed to pink when exposed to Histidide Monohydyrocloride Monohydrate, Sodium Chloride and Disodium Hydrogen Orthophosphate Dodecahydrate.

Tested wool fabrics (Table 5) and cotton fabrics (Table 6) exhibited rating of very good to excellent (4-5 and 4/5) for both change in colour and staining on adjacent fabrics 1 and 2 under acidic and alkaline conditions. The fastness of dyed and mordanted silk, wool and cotton fabrics against human perspiration in the present study was acceptable as the ratings were very high, as reported by other researcher the perspiration fastness was significantly increased when the dyed textile fabrics were treated with alum, stannous chloride, calcium chloride, ferrous sulphate ammonia, vinegar etc [28, 29-30].

Colour coordinates of dyed and mordanted fabrics

For quantification of shade produced the colour coordinates of dyed and mordanted fabrics were determined (Table 7). In silk the darkest shade was obtained when the fabrics mordanted with natural mordant i.e. fruit pericarp of *Terminalia chebula* (XP 8). The value of L*, b*, K/S and absorbance for XP 8 was 64.64, 15.29, 5.15 and 1.0888 respectively. This is very encouraging as using a natural mordant the darkest shade obtained in equal concentration with other chemical mordants. Similar value of b* 21.81 but more value of L* (85.27) i.e. lighter shade has reported using *Trichoderma* spp. dye [31-32]. In wool the darkest shade was produced by treatment with potassium dichromate as mordant (XP 5). The values of L*, b*, K/S and absorbance were 40.98, 25.55, 22.71 and 1.6271. Similar shade was produce with frits of *Phyllanthus emblica* (XP 7) and fruit pericarp of *Terminalia chebula* (XP 8). Hence fruit of *Phyllanthus emblica* and *Terminalia chebula* may be used as natural mordant in place of synthetic mordants which are available in plenty on very reasonable price, this will help the natural dyeing sector more beneficial. In the case of cotton fabrics the shade produced were lighter than the wool and the darkest shade was obtained again by mordanting with the fruit pericarp of *Terminalia chebula* (XP 8). The values of L*, b*, K/S and absorbance were 62.92, 5.51, 1.91 and 0.751.

Conclusion

Exploring fungal species as source of natural dye for textile applications is a relatively new field being explored by researchers in recent times. Natural dye being an eco-friendly substitute for synthetic dye with negligible or no adverse effect on human health has caught the attention of researchers. In the present study, the process parameters like fungus biomass and extractant (material to liquor ratio i.e. MLR), alkali content and time duration are optimized for extraction of dye from *X. polymorpha.* The yield of dye is found to be considerable at the optimized conditions. The dye produced had the best fastness characteristics against various colour fading conditions. The overall fastness of the dyed wool and silk fabrics is high and moderate in case of dyed cotton. The present approach of tackling adverse environmental consequence of production and dyeing process with the use of fungal pigment provides a new possibility for eco-friendly textile dyeing. However, the chemical constituents present in fungi contributing to the dyeing of fabrics require further investigation. It can be concluded from the present study that fungi can be a potential source of dyes which can be adequately applied on textile fibers. The fungi can be produce at large scale through in-vitro culture and conditions for maximization of pigmentation can be standardized. Therefore, natural dyes from fungal sources can be commercially produced on mass scale in an inexpensive and environmentally friendly manner.

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Conflict of Interest

None declared

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