Indian Journal of Fibre & Textile Research
Vol. 41, December 2016, pp. 418-425

Ultraviolet protection properties of nettle fabric dyed with natural dyes

Deepti Pargai[a], Manisha Gahlot & Anita Rani

Department of Clothing and Textiles, G. B. Pant University Agriculture and Technology, Pantnagar 263 145, India

Received 24 Febaruary 2015; revised received and accepted 25 May 2015

This paper reports study on the UV protection properties of nettle fabric dyed with natural dyes cutch (*Acacia catechu)* and madder (*Rubia cardifolia).* Dyeing with cutch and madder dyes provides excellent UV protection to the woven nettle fabric even without mordanting. $FeSO_4$ and myrobalan mordant concentrations have no significant effect on UPF of the nettle fabric

Keywords: Mordant, Natural dyes , Nettle fabric, Ultraviolet protection factor

1 Introduction

Textile materials play a major role in protection of human beings against harmful UV radiations UV-A and UV-B. When ultraviolet radiation hits the textile materials, different types of interaction occur depending upon the substrate and its conditions. UV radiation is either reflected, transmitted or absorbed in to material[1]. The degree of ultraviolet radiation protection of textile material is measured by the ultraviolet protection factor (UPF). The UPF is the measure of ultraviolet (UV) radiation blocked by the fabrics. Higher UPF value is indicative of more blocking of UV radiation. Ultraviolet protection factor (UPF) is the scientific term used to indicate the amount of ultraviolet protection provided to skin by the fabric[2]. The ultraviolet protection provided by apparel depends on the fabric construction, thickness, porosity and extension of fabric, chemical characteristics; physico-chemical nature of fibre, dyeing and finishing treatment given to the fabric, moisture content of the fabrics and presence of ultraviolet absorbers[2]. The chemical structure of the fibres strongly affects the UPF of the textiles. The fibres vary in UV transparency, which influences the UPF of the textiles. There are several plants which are available in abundance and have not yet been given any commercial importance; nettle fibre is one of them. Nettle is a bast fibre and considered as an ecofriendly fibre of the future. The plant is naturally resistant to diseases and pest and unlike cotton do not require any pesticides to flourish. Nettle fibres are biodegradable. They require little energy to grow and are extracted from a renewable source. Nettle fibre can be as fine as cotton and they are far finer than flax[3]. The Himalayan Giant Nettle (*Girardinia diversifolia),* which belongs to the family Urticaceae, is locally known as *Allo* in the eastern and central regions of Nepal and Puwa in the western part of Nepal. There are several vernaculars to name such as *Bichchhu grass, Bhangre Sisnu, Lekhko Sisnu, Thulo Sisnu*, *Potale*, *Nagai*, etc[4, 5]. The lignin content of nettle (9.3%) is more in comparison to that of ramie, flax and hemp[6]. Lignin is a natural UV absorber and ensures good UV protection. The UPF also appears to be closely related to interaction of dye and fibre. The same dye can give very different results on different fibres. The dyes used to color textiles can have a considerable influence on their permeability to ultraviolet radiation. Depending on their chemical structure, the absorption band of many dyes extends in to the ultraviolet spectral region. As a result, such dyes act as ultraviolet absorbers and increase the UPF of the fabric[7]. The fabrics dyed with natural dyes have good ultraviolet protective properties and could absorb about 80% of the ultraviolet rays. The UV protective effect is strongly dependent on the absorption characteristics of natural dyes for UVR. Some recent studies reported an increase in the ultraviolet protection of cotton textiles when dyed with selected direct, vat and reactive dyes[8]. Darker colors on the same fabric (black, navy, dark red) absorb UVR much more strongly than the light pastel colors for identical weave[9]. Different natural dyes have different interactions with different fibres. Madder dye (hydroxyl anthraquinones based red dye)

[a]Corresponding author.
E-mail: pargai.deepti16@gmail.com

is extracted from the root bark of various rubiaceae plants. Excellent UV protection properties have been imparted to the linen fabric by the use of madder dye [10,11]. Similarly the main colorant in Acacia catechu is catechin. Catechin comes under the category of condensed tannins. *Catechu* contains 40 - 55% weight of tannin [12,13]. Tannins are polyphenolic compounds widely distributed in the plant kingdom and are believed to provide a chemical defence against predators and ultraviolet radiation to the plants[14]. Synthetic dyes as well as natural dyes can provide the UV protection properties to the fabric. But at present in the field of textiles, the application of natural dyes is on the rise because of the growing interest of the consumers towards the environmental sustainability. Hence, keeping in mind the above points there is a need for exhaustive research work aimed at designing textiles using natural fibres and natural dyes for efficient protection against harmful UV radiation, which is not only good for the protection of human being from UV radiation but also safe for the environment. Studies have been done on exploring UV protection properties on different textile fibres like silk, wool, cotton, and synthetic fibres after their dyeing with natural dyes. However, no such study has been done in the case of nettle fabric. The present research was aimed at studying protective properties of nettle fabric against UV radiation with the application of natural dyes. The main objective of the study was to enhance the UPF of the nettle fabric with the application of natural dyes and to study the effect of dye concentration, color strength and lightness value on ultraviolet protection factor (UPF) of the fabric.

2 Materials and Methods

2.1 Fabric

Desized nettle fabric of crepe weave was used for the study. Yarn count was 7.22 Ne_c. The physical properties of the woven nettle fabric are given in Table 1

2.2 Dyes and Mordants

Two natural dyes namely madder (*Rubia cardifolia*) and cutch (*Acacia catechu*) were used for dyeing experiments in powder form along with two mordants namely $FeSO_4$ and myrobalan. $FeSO_4$ was taken from the Department of Clothing and Textiles, G.B.P.U.A.T, Pantnagar, Uttrakhand, while madder cutch and myrobalan were procured from Kumaon Earth Kraft, Avani, Berinag, Uttrakhand.

Table 1—Physical Properties of the woven nettle fabric

Properties	Crepe weave fabric
Fabric count (warp × weft)	22 × 35
Fabric weight, GSM	206.40
Fabric thickness, mm	0.89
Cover factor	17.43
UPF	16.9

2.3 Dyeing and Mordanting

Extraction of color from dye powders was carried out by taking 10 g of raw material of each dye in 100 mL of distilled water in the two separate beakers at neutral *p*H and kept at 80°C in dye bath for 60 min. After extraction the solution were filtered. Filtrates were used as a dye solution. Nettle fabric samples of 1 g each were dyed in the dye solutions for 60 min at 80°C in separates beakers. For the selection of optimum *p*H of dye extraction liquor, nettle fabric samples of 1 g each were dyed in prepared dye solutions for 60 min at 80°C in separate beakers with acidic, alkaline and neutral *p*H. The dyed samples were tested for *K/S* value. The *K/S* values were determined using “SS5100A Spectrophotometer”. For this purpose, measurement of reflectance was performed at the wavelength of maximum absorption (λ_{max} 450 nm) under D65 illuminant (10° observer). The values of *K/S* were used as the basis for selection of *p*H of extraction liquor.

The nettle fabric samples were dyed using two selected natural dyes extracted at optimised *p*H using different concentrations of dyes (2, 4 and 6 g/100 mL) and one concentration was selected on the basis of UPF rating of dyed samples. UPF of the dyed experimental fabrics was determined by using “SDL UV penetration and protection measurement system (Compsec M 350 UV- Visible spectrometer)”. Specimen (5×5 cm) was cut and the transmittance measurements from 280-400 nm were recorded for each specimen. UV protection category was determined by the UPF values described by Australian Standards / New Zealand AS/NZS 4399 (1996).

The selected concentrations of both the dyes were used for the experiments related to the application of mordants using three different methods of mordanting, namely pre mordanting, simultaneous mordanting and post mordanting. In case of myrobalan, mordant solution was prepared by taking 0.10 g, 0.15g and 0.20g of myrobalan powder in 50 mL of distilled water, allowed to soak overnight, then boiled for 15-20 min and filtered. In case of metallic mordants, different concentrations of $FeSO_4$ (i.e. 0.01, 0.03 and 0.05 g) were dissolved separately in 10 mL of boiling water and then added to beaker containing 90 mL of water. The selection of one mordanting method for each concentration of mordant was done on the basis of *K/S* and lightness value. Selected samples were subjected to UPF testing.

The effect of dye concentrations on the UPF of the nettle fabric was studied. The relationship of color strength and lightness value with UPF was also studied. The data was also subjected to statistical analysis using correlation coefficient.

3 Results and Discussion

3.1 Selection of *p*H of Dye Extraction Liquors

It is clear from the Table 2 that in case of madder dyed samples, maximum *K/S* value (11.752) is observed with neutral *p*H and minimum (8.233) in case of acidic *p*H. The highest *K/S* value of 18.296 is observed in case of cutch dyed sample in acidic *p*H followed by *K/S* value of 13.075 for alkaline *p*H. On the basis of these results, neutral *p*H is selected for extraction of madder dye and alkaline *p*H is selected for cutch dye. Though the sample dyed with acidic *p*H for cutch dye shows maximum *K/S*, it is not selected because nettle is a cellulosic fibre and thus sensitive to acids. Hence, the sample dyed with alkaline *p*H (2^{nd} highest *K/S*) is selected for dyeing with cutch dye.

Color dimensions values (L*, a*, b*) are also observed for all dyed samples. It is clear form Table 2 that in case of madder dye the lowest lightness value is observed for the sample dyed in neutral *p*H which also has highest *K/S* value. However, in case of cutch dye lightness value is lowest in alkaline *p*H which is indicative of darkest shade in alkaline *p*H as compared to others. Srinivasan and Gatiwood[15] stated that the darker colors provide better UV protection due to increased UV absorption. This is only true for the same UV absorbent dye, provided that the other characteristics of the textiles e.g. fabric type and construction remain the same. It is clear from the Table 2 that both a* and b* values are in yellow- red quadrant. It can be inferred from the values that dark shade exhibits higher a* values and lower b* values.

3.2 Selection of Concentration of Natural Dyes

It can be inferred from Table 3 that the *K/S* value of madder dyed sample ranges from 13.402 (at 2% dye conc.) to 15.571 (at 6% dye conc). For cutch dyed sample it ranges from 5.571 (at 2% dye conc.) to 13.340 (at 6% dye conc.). The *K/S* value of the blank sample is found to be 1.515.

It is clear from Table 3 that the lightness values of dyed samples range from 56.452 (at 2% dye conc.) to 56.069 (at 6% dye conc.) for madder dyed samples and from 60.365 (at 2% dye conc.) to 58.308 (at 6% dye conc) for cutch dyed samples. The lightness value of the blank sample is found to be 63.249. It can be inferred from the results that color lightness values gradually decrease with the increase in dye concentration.

Table 3 also shows that in case of cutch dyed samples the highest UPF rating of 130 (excellent protection) is observed at 6% dye concentration followed by 116 rating (excellent protection) at 4% dye concentration as compared to 16.9 UPF rating (good protection) of blank sample. For madder dyed samples the pattern is similar, the highest UPF rating of 62.3 (excellent protection) is observed at 6% dye concentration followed by 54.01 (excellent protection) at 4% concentration of dye.

Table 2—Color strength (*K/S*) of samples dyed with dyes extracted in different *p*H

Dye	Extraction *p*H	Color strength (*K/S*)	Color dimension L*	a*	b*
Madder	Neutral[a]	11.752	65.247	17.281	20.987
	Alkaline	11.561	67.489	10.478	25.716
	Acidic	8.223	71.064	17.184	31.239
Cutch	Neutral	10.797	64.851	12.183	18.601
	Alkaline[a]	13.075	60.730	13.261	12.543
	Acidic	18.296	65.680	13.143	21.543

[a] Selected *p*H.

Table 3—Color strength (*K/S*), lightness value and UPF of samples dyed at different concentrations of dyes

Dye conc. %	Color strength (*K/S*)	Color dimensions L*	a*	b*	UPF
Blank[a]	1.515	63.249	1.921	11.731	16.9
Madder dye					
2	13.402	56.452	22.235	8.401	47.2
4	13.996	56.260	22.690	8.446	54.01
6[b]	15.571	56.069	23.498	8.884	62.3
Cutch dye					
2	5.571	60.365	10.528	12.093	102
4	9.01	59.400	12.740	14.476	116
6[b]	13.340	58.308	13.643	15.754	130

[a] Sample without dyeing.
[b] Selected concentrations of dye.

It can also be inferred that the UPF values of blank sample (sample without dyeing) represent good protection category which further improves after dyeing and is found in the category of very good to excellent protection. The good UV protection category of the nettle may be due to its lignin content.

As from the results it is clear that in case of both madder and cutch dyed samples the highest UPF rating is observed at 6% concentration of both dyes, Hence, 6% concentration of dyes is selected for the further work. The cutch dyed samples have higher UPF ratings than the madder dyed samples at each concentration. This may be due to the presence of higher tannin content in acacia catechu.

Correlation between concentration of dye and UPF value of nettle fabric is also established. The value of correlation coefficient is found to be 0.998 for madder dyed sample at 5 % level of significance, which means that there is a strong positive correlation between the concentration and UPF of samples. For cutch dye the correlation coefficient is found to be 0.999 which also represents the strong positive correlation significant at 5% level.

Correlation between *K*/*S* value and UPF of dyed fabric is also established. The value of correlation coefficient is found to be 0.980 for madder dyed at 5% level of significance and 0.998 for cutch dyed sample which is significant at 5% level of significance. This means that there is a strong positive correlation between the *K/S* and UPF of the dyed fabric. Results are in accordance with the findings that UPF values for colorants applied at higher concentration give higher UPF value. It is also reported in a study that dyeing of fabrics in deeper shades and darker colors improves the UV protection properties [16,17]. Correlation between lightness value and UPF of dyed fabrics is also established. The value of correlation coefficient is found to be -0.998 for madder dyed samples and -0.999 for cutch dyed samples at 5% level of significance which means that there is a strong negative correlation between the lightness values and UPF of the dyed fabric. The negative correlation between two variables i.e. lightness value and UPF indicates that as the lightness value is increased, the UPF value decreases. Wun[18] also concluded in his study that fabric UV protection could be modified by color lightness value.

3.3 Selection of Mordanting Method

Tables 4 and 5 present the data of color strength and color dimensions for dyed and mordanted crepe weave nettle fabrics. The CIE L*a*b* values of samples dyed in presence and absence of mordants are determined in order to study the effect of mordanting on hue change. At the time of selection of dye concentration, it is observed that *K/S* and lightness values have a positive and negative correlation respectively with the UPF value of the fabric. From that observation, it can be inferred that as the *K/S* value increases, the UPF value is also increased while the lightness values are found to be decreased. Hence, *K/S* and L* are considered as criteria for the selection of optimum mordanting method for each concentration of mordant. It can be observed from Tables 4 and 5 that usually the sample which has the highest *K/S* value shows the the lowest lightness value. In case of synthetic dyes, Wun[18] also stated that the lightness value is decreased with increased dye concentration. In case of samples having the highest *K/S* values but at the same time lowest lightness values, selection is done on the basis of the highest *K/S* value only.

3.3.1 Madder Dyed and Ferrous Sulphate Mordanted Fabric

It is clear from Table 4 that at 0.01g/100 mL concentration of $FeSO_4$, *K/S* value of dyed sample is found to be the highest (22.310) for post-mordanting method. While at 0.03 g/100 mL and 0.05 g/100 mL concentration of $FeSO_4$, the *K/S* values are found to be the highest, i.e. 24.890 and 24.224 respectively, for pre-mordanting method. In case of pre-mordanting method, firstly $FeSO_4$ mordant reacts with the nettle fibre and subsequently the madder dye molecules to form a complex with this structure, resulting in a relatively more stable dye-fibre bond. While at 0.01 g/100 mL concentration of $FeSO_4$, may be a very small amount (0.1g/100mL) of mordant could not form complex with the nettle fibre in the same method but in case of post-mordanting method, firstly the madder dye molecules adhere to the nettle fabric subsequently the molecules of $FeSO_4$, form complex with this structure which is relatively more stable bonding.

Table 4 indicates that at 0.01g/100 mL concentration of $FeSO_4$, the lightness value of sample is found to be the lowest (20.522) for post-mordanting method. At 0.03 g/100 mL and 0.05g/100 mL concentrations of $FeSO_4$, the lightness values of dyed samples are found to be the lowest, i.e. 18.924 and 18.997 respectively for pre-mordanting method.

An increase in *K/S* values is observed in pre- and post-mordanted samples of all the three concentrations

Table 4—Color strength, color dimensions and WMS of madder dyed and mordanted nettle fabric samples

Conc. of mordant g /100 mL	Mordanting method	Color strength (*K/S*)	Color dimensions		
			L*	a*	b*
Control sample[a]	-	18.862	25.467	22.291	9.855
$FeSO_4$					
0.01	Pre	19.639	24.778	20.059	10.485
	Simultaneous	10.960	22.074	7.585	10.075
	Post[b]	22.310	20.522	6.958	3.652
0.03	Pre[b]	24.890	18.924	2.432	1.295
	Simultaneous	11.814	22.799	7.778	10.903
	Post	21.968	20.040	5.172	2.927
0.05	Pre[b]	24.224	18.997	2.551	1.227
	Simultaneous	12.191	23.862	9.444	12.381
	post	21.936	20.012	4.831	2.808
Myrobalan					
0.10	Pre[b]	19.941	23.777	21.013	10.541
	Simultaneous	15.659	25.443	23.402	14.226
	Post	15.964	23.816	20.236	10.749
0.15	Pre[b]	17.960	23.905	21.764	11.455
	Simultaneous	15.244	24.702	21.975	13.065
	Post	15.155	24.251	20.593	10.842
0.20	Pre[b]	17.622	23.826	21.109	12.168
	Simultaneous	15.463	25.333	23.062	14.878
	Post	12.830	24.177	19.775	11.792

[a]Sample dyed without mordanting.
[b]Selected mordanting method.

of $FeSO_4$ as compared to control sample (unmordanted sample). But a decrease in *K/S* is observed for simultaneous mordanted samples as compared to control sample. On the basis of results, post-mordanting method is selected for 0.01g/100 mL concentration of $FeSO_4$, as it exhibites the highest *K/S* and the lowest lightness value. At 0.03g/100 mL and 0.05 g/100 mL of $FeSO_4$, the pre-mordanting method is selected as it shows highest *K/S* value and lowest lightness value.

It can be observed from the Table 4 that a* and b* values are lying in yellow and red quadrant. A decrease in a* values is observed in mordanted samples as compared to control sample and b* values are also found to be decreased except in case of pre and simultaneous mordanted samples at 0.01 g/100 mL concentration and simultaneous mordanted sample at 0.03 g/100 mL and 0.05 g/100 mL concentration of $FeSO_4$. The chroma values given in Table 4 show that all mordanted samples has less brightness as compared to control sample.

3.3.2 Madder Dyed and Myrobalan Mordanted Fabric

It is clear from Table 4 that at 0.10, 0.15 and 0.20 g/100 mL concentrations of myrobalan the *K/S* values are found to be the highest for pre-mordanting method. In pre- mordanting method, firstly myrobalan mordant reacts with the nettle fibre and subsequently the madder dye molecules form a complex with this structure, resulting in a relatively more stable dye fibre bond. Lightness values of samples are found to be the lowest for pre-mordanting method. A decrease in *K/S* value is observed in all the samples except for pre-mordanting method at 0.10 g/100 mL concentration of myrobalan, where the *K/S* value is found to be more as compared to control sample. On the basis of results, the pre-mordanting method is selected for further work for all three concentration of myrobalan, as for each concentrations pre-mordanting method exhibites highest *K/S* value, and the lowest lightness value.

It can also be observed from the Table 4 that a* and b* values lye in yellow and red quadrant. A decrease in a* value except in case of simultaneous mordanted samples at 0.10 g/100 mL and 0.20 g/100 mL concentration and increase in b* value are observed in mordanted samples as compared to control samples. The chroma value given in the Table 4 shows that most of the mordanted samples have more brightness than blank except pre and post-mordanted samples at 0.10g/100 mL concentration and post-mordanted samples at 0.15g/100 mL and 0.20 g/100 mL concentrations of mordant.

Table 4 also shows that the decrease in lightness values is higher for $FeSO_4$ mordanted samples as compared to myrobalan mordanted samples, indicating darkening of color in case of $FeSO_4$ mordant. This is also a common feature of natural dyes with iron mordant, and the shade turns more towards grey-black.

3.3.3 Cutch Dyed and Ferrous Sulphate Mordanted Fabric

It is clear from Table 5 that at 0.01 g/100 mL concentration of $FeSO_4$, *K/S* value of samples is found to be the highest (17.733) for simultaneous mordanting method. However, at 0.03 g/100 mL and 0.05 g/100 mL concentrations, the *K/S* values are found to be the highest i.e. 20.536 and 22.854 respectively for pre-mordanting method. In case of pre- mordanting method, firstly $FeSO_4$ mordant reacts with the nettle fibre and subsequently the molecules of catechin component of cutch dye form a complex with this structure, resulting in a relatively more stable dye-fibre bond. However at 0.01 g/100 mL concentration of $FeSO_4$, may be the very small amount (0.1g/100mL) of mordant could not form complex with the nettle fabric in case of pre mordanting, but in case of simultaneous mordanting method, the $FeSO_4$ mordant form complex with molecules of catechin component of the cutch dye which is more stable.

Table 5 indicates that at 0.01g/100 mL concentration of $FeSO_4$, the lightness value of samples is found to be lowest (28.567) for post-mordanting method, while at 0.03g/100 mL and 0.05 g/100 mL concentrations the lightness values are lowest for post-mordanting method, i.e. 27.292 and 27.821 respectively.

Table 5— Color strength, color dimensions and weighted mean score of visual evaluation of cutch dyed and mordanted nettle fabric

Conc. of mordant g/100 mL	Mordanting method	Color strength (*K/S*)	Color dimension		
			L*	a*	b*
Control sample[a]		9.801	35.266	14.054	14.301
		$FeSO_4$			
0.01	Pre	14.919	37.574	14.998	16.794
	Simultaneous[b]	17.733	37.033	14.317	16.124
	Post	12.081	28.567	3.428	3.537
0.03	Pre[b]	20.536	33.151	10.712	10.885
	Simultaneous	17.000	36.935	14.008	15.863
	Post	13.871	27.292	2.137	1.612
0.05	Pre[b]	22.854	32.376	10.020	9.705
	Simultaneous	13.004	36.395	13.100	15.098
	Post	15.409	27.821	1.713	2.427
		Myrobalan			
0.10	Pre[b]	19.462	37.076	15.731	17.494
	Simultaneous	15.771	38.305	14.297	16..119
	Post	6.464	37.459	9.135	15.037
0.15	Pre[b]	16.062	36.565	13.892	16.644
	Simultaneous	14.063	37.727	14.458	16.261
	Post	6.260	37.087	9.389	14.331
0.20	Pre[b]	22.010	36.872	15.838	17.107
	Simultaneous	15.964	37.074	14.432	15.989
	Post	7.020	37.707	9.759	14.699

[a]Sample dyed without mordanting.
[b]Selected mordanting method.

An increase is observed in *K/S* value of all samples as compared to control sample, while a decrease is observed in lightness values in all samples except for pre and simultaneous mordanted samples at 0.01g/100 mL concentration and simultaneous mordanted sample at 0.03 g/100 mL and 0.05 g/100 mL concentrations.

Simultaneous mordanting method is selected for 0.01g/100 mL concentration of $FeSO_4$, on the basis of the highest *K/S* value. But this sample does not exhibit the lowest lightness value. At 0.03 g/100 mL and 0.05 g/100 mL concentrations of $FeSO_4$, *K/S* values are found to be the highest for pre-mordanting method and lightness values are found to be the lowest for post-mordanting method, because in this case samples are of black color. Hence, pre-mordanting method is selected for 0.03 g/100 mL and 0.05 g/100 mL concentrations of $FeSO_4$.

It is observed that both a* and b* values are found to be the lowest in case of post-mordanted samples at each concentration of mordant. This may be attributed to the reason that the hue of sample has changed to grey after post mordanting.

The chroma value given in Table 5 shows that most of the mordanted samples has less brightness than blank samples except pre and simultaneous mordanting at 0.01 g/100 mL concentration of mordant and simultaneous at 0.05 g/100 mL concentration.

3.3.4 Cutch Dyed and Myrobalan Mordanted Fabric

It is clear from Table 5 that at 0.10, 0.15 and 0.20 g/100 mL concentrations of myrobalan, the *K/S* values are found to be the highest for pre mordanting method i.e. 19.462, 16.062 and 22.010 respectively and the lightness value of samples are found to be the lowest i.e. 37.076, 36.565 and 36.872 respectively for pre-mordanting method.

An increase is observed in *K/S* for all samples as compared to control sample, except for post-mordanted samples at each concentration. Lightness values are also found to be increased in all myrobalan mordanted samples of cutch dye. On the basis of results at 0.10, 0.15 and 0.20 g/100 mL concentrations of myrobalan, the pre mordanting method is selected, as samples of pre-mordanting method exhibit highest *K/S* values and lowest lightness values.

It can be observed from Table 5 that a* and b* values lie in yellow and red quadrant. An increase in a* values is found as compared to control sample except in case of post-mordanted samples at 0.10 g/100 mL and 0.20 g/100 mL concentrations and pre-and post-mordanted samples at 0.15 g/100 mL concentration. An increase in b* values is found in all mordanted samples as compared to control sample. The chroma values given in the Table 5 show that most of the mordanted samples have more brightness than control samples except for post-mordanted samples at each concentration.

3.4 UPF of Selected Madder and Cutch Dyed Samples

Table 6 shows the results of UPF of madder and cutch dyed samples for each concentration of both mordants with the selected mordanting methods. It is clear that in case of samples dyed with madder dye and mordanted with $FeSO_4$ the highest UPF rating of 95.89 (excellent UPF category) is observed at 0.03 g/100 mL concentration of $FeSO_4$ mordant pre-mordanting method, whereas in case of samples mordanted with myrobalan, the highest UPF rating of. 72.1 is observed at 0.15 g/100 mL concentration of myrobalan for pre-mordanting method.

In case of samples dyed with cutch dye and mordanted with $FeSO_4$, the highest UPF rating of 164.1 (excellent UPF category) is observed at 0.03 g/100 mL concentration of $FeSO_4$ for pre-mordanting method, whereas in case of sample mordanted with myrobalan the highest UPF rating of 176.0 is observed at 0.10 g/100 mL concentration of myrobalan for pre- mordanting method.

On comparison of UPF values of mordanted samples, it can be observed that the pre mordanted samples of both dyes exhibit higher UPF as compared to other mordanting methods. Hussain and Elhassaneen[19] also reported in their study that the cotton fabric dyed with onion skin dye in the absence of mordant shows yellowish white shades. Three mordanting techniques are compared and it is found that the pre-mordanting gives the highest depth of shade on cotton fabric. Hence, pre-mordanting is found to be the best technique for use in ultraviolet protective clothing. The sequence of mordant activity and UPF of the three mordanting methods in cotton fabric are as follow:

Pre-mordant > Simultaneous mordanting > Post-mordanting > undyed

It can also be observed from Table 6 that in such samples where mordant does not improve the UPF values as compared to control sample, the UPF values of control samples as well as mordanted sample itself lye in range the of very good to excellent protection. Any value above 25 offers very good UV protection while the value above 50 offers excellent UV protection.

In case of madder dyed samples it is found that as the concentration of $FeSO_4$ is increased from 0.01 g/100 mL to 0.03g/100 mL, the UPF value is found to increase from 89.2 to 95.8 as compared to control (UPF 62.3). But on further increasing the concentration of $FeSO_4$ mordant to 0.05 g/100 mL, the UPF value drops to 54.8, i.e. less than that of control. The UPF value may decrease due to the reduction in K/S value. The decrease in K/S with an increase in concentration of $FeSO_4$ mordant is due to the aggregation of the madder dye molecules by the addition of excess $FeSO_4$, which causes a reduction in the madder dye solubility, and leads to its precipitation and difficulty of penetration during dyeing.

The correlation is established between mordant concentration and UPF values. The value of correlation coefficient is found to be 0.304 and 0.504 for madder dyed + $FeSO_4$ and madder dyed + myrobalan mordanted samples respectively. It is 0.522 and 0.054 for cutch dyed + ferrous sulphate and cutch dyed + myrobalan mordanted samples respectively. It indicates weak to moderate positive correlation but these values are not significant at 5% level of significance. Hence, it can be inferred from the results that the dye concentration has significant effect on UPF of the fabric, while the mordant concentration has no significant effect on UPF values

Table 6—UPF of selected dyed and mordanted samples

Dye	Mordant	Concentration g/100mL	Mordanting method	UPF	Category
Madder	Ferrous sulphate	0.01	Post	89.2	Excellent
		0.03	Pre	95.8	Excellent
		0.05	Pre	54.4	Excellent
	Myrobalan	0.10	Pre	50.4	Excellent
		0.15	Pre	72.1	Excellent
		0.20	Pre	33.0	Very good
Cutch	Ferrous sulphate	0.01	Simultaneous	29.9	Very good
		0.03	Pre	164.1	Excellent
		0.05	Pre	66.7	Excellent
	Myrobalan	0.10	Pre	176.0	Excellent
		0.15	Pre	140.9	Excellent
		0.20	Pre	117.2	Excellent

4 Conclusion

Nettle fabric has good UV protection ability. Dyeing with *Acacia catechu* and *Rubia cardifolia* dyes provides excellent and very good UV protection respectively, to the woven nettle fabric even without mordanting. The use of mordants increases the UPF value only in some cases. The mordant concentration has no significant effect on UPF values. Pre mordanted samples of both dyes exhibit higher UPF as compared to other mordanting methods. The UPF values of *Acacia catechu* dyed samples are found to be better as compared to *Rubia cardifolia* dyed samples.

References

1 Algaba I & Riva A, *J Text. Inst*, 97(2006) 349.
2 Crews P C & Kachman S, *AATCC Rev,* 31(6) (1999)17.
3 Krishanan G & Karthick N *Asian text J,* 35(4) (2012) 67.
4 Friis I, *Kew Bulletin*, 36 (1981) 143.
5 Gurung G V, Field Survey Report, GTZ/DDDP - Allo (*Girardinia diversifolia*) Consultancy, (1988) 35.
6 Madan S, *Extraction and processing of Girardinia hterophylla: An agro based fiber for various textile applications*, M.Sc. thesis, G. B. Pant University of Agriculture and Technology, Pantnagar, (2000)153
7 Das B R, *The Open Text J*, 35 (2010) 14.
8 Feng X X, Zhang L L, Chen J Y & Zhang J C, *J Clean Prod*, 15 (2007) 366.
9 Saravanan D, AUTEX *Res J*, 7 (2007) 56.
10 Samanta A K & Agarwal P, *Indian J Fibre Text, Res*, 34(2009) 384.
11 Katarzyna S C & Zimniewska M, *Inst Natural Fibres Medi Plants*, 71(2001)60.
12 Gupta D, *Dyeing properties of natural dyes some practical and theoretical aspect*, paper presented at the workshop on dyeing and printing with natural dyes, Indian Institute of Technology Delhi, 3-5 September 2001.
13 Rangri J L & Chaturvedi L, College *Pharmacy New Nandanvan*, 12(2007)16.
14 Svobodova A, Jitka P & Daniela W, *Biomed*, 147(2003) 137.
15 Srinivasan M & Gatewood B M, *Text Chem Color*, 32 (2000) 36.
16 Sarkar A K, *BMC Dermatology*, 15 (2004) 1.
17 Gies P H, Roy C R, Toomey S & McLennan A, *Mutat Res*, 422 (1998) 15.
18 Wun T F, *Investigation of ultraviolet protective lightweight knitwear fabric with direct dyes and optical brightening agents*, M.Sc thesis, The Hong Kong Polytechnic University, Institute of Textiles & Clothing, Hong Kong, 2012.
19 Hussein A & Elhassaneen Y, *J Am Sci*, 10 (2012) 129.