Indian Journal of Fibre & Textile Research
Vol 44, September 2019, pp. 352-357

Colorimetric study of absorption behavior of madder natural dye on nylon using scanner

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Received 16 August 2017; revised received and accepted 1 January 2018

A scanner has been used as a low-cost instrument for measuring the colorimetric parameters of dyed nylon. The nylon fabric is dyed with madder natural dye using non-mordanting, pre-mordanting, and meta-mordanting. Then, the dyed samples are scanned by a scanner and the RGB values of obtained image are converted to CIELab and HSL color spaces. It is found that the scanner is able to evaluate the colorimetric characteristics of dyed samples. The obtained results are found comparable to the spectrophotometer results.

Keywords: Absorption behavior, Colorimetric study**,** Dyeing, Madder, Natural dye, Nylon

1 Introduction

Natural dyes are being used for carpet, rug, and cloth dyeing since time immemorial. These dyes are obtained from animal or plant without any chemical processing, and hence have many advantages as compared to synthetic dyes, such as ecofriendly, low toxicity and allergic reactions, in addition to biodegradability. For these reasons, the use of synthetic dyes has been declined, and application of natural dyes is gaining popularity all over the world[1-4].

Today, spectrophotometer is the most commonly used instrument for measuring the reflectance spectra and color specification of various samples. Because it is an expensive optical device, some researchers have studied using possibility of scanner and digital camera, as a low cost device, for measuring the reflectance spectra, color and opacity of textile fabrics and other samples[5-10].

Scanner is the most important input and additive color device[6,11]. Scanner captures light in reflected or transmitted forms. In the scanner, there are usually three arrays of charge-coupled device (CCD) sensor elements that are covered with color filters (typically red, green and blue). The captured light passes through these color filters and is then sensed by an array of CCDs to generate a RGB image[6,12-14].

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The RGB color space is a device-dependent color space and scanners cannot be used as a standard colorimetric device, because the spectral responses of scanner is not a linear transformation of CIE standard observer[6,8,9]. So, there is a need to characterize or calibrate the scanner. A common and simple solution is to convert the scanner RGB values to colorimetric values such as CIE XYZ or CIELab colorimetric values[7-9,15].

In this research work, the effect of different methods of dyeing such as non-mordanting, pre-mordanting, and meta-mordanting of nylon with madder on colorimetric specification has been investigated by a scanner. Madder is one of the oldest natural dyes, which can generate colors ranging from orange to violet[3]. In some study, we need only colorimetric properties and spectral reflectance isn't very important. As the cost of colorimeter is high in comparison with scanner, in this study, the spectrophotometer or colorimeter has been replaced with a scanner for measuring the colorimetric specifications of textile fabrics.

2 Materials and Methods

Scoured nylon (plain weave, 60 g/m^2, 40 ends/cm and 30 picks /cm) fabric was procured commercially. Madder (*Rubia tinctorum*) was obtained from Yazd Province, Iran. Aluminum potassium sulfate (KAl $(SO_4)_2.12H_2O$) and acetic acid (CH_3COOH) were obtained from Merck.

First, dye solution was extracted from madder natural dye, and then three different methods were used for dyeing the nylon samples, namely (i) non-mordanting method, (ii) pre-mordanting method, and (iii) meta-mordanting method. In non-mordanting method, the dyeing process was started at room temperature, and the content was heated to boil over 30 min and dyed for 1 h. Finally, the dyed nylon was washed with tap water and dried at room temperature. In pre-mordanting method, the samples were mordanted prior to dyeing by treating them with aluminum potassium sulfate salt at boiling temperature for 45 min. The mordanted samples were then rinsed with tap water and dried at room temperature. Subsequently, the mordanted samples were dyed with dyeing solution at room temperature. The dyeing process was done similar to the non-mordanting method. At the end, the dyed samples were rinsed with tap water and dried at room temperature. In meta-mordanting method, aluminum potassium sulfate and dye were added to dyeing bath simultaneously. Then, the dyeing process was started by raising the temperature to boil and dyed for 1 h. After cooling, the samples were washed with tap water and dried. The liquor-goods ratio was kept 40:1 for all dyeing methods. The concentration of mordant was 5% on the weight of the sample, and the *p*H was adjusted at 5 with acetic acid.

After dyeing, the reflectance spectra and color parameters of the dyed samples were measured by a Gretage Macbeth Color Eye 7000A spectrophotometer. The reflectance spectra were measured within the visible spectrum at 39 wavelengths with 10 nm interval from 380 nm to 760 nm.

CIELab coordinates[3,16] (L* describes lightness, a* defines redness-greenness, b* defines yellowness-blueness, C* is the chroma or saturation, and h is the hue angles) were calculated under 10˚ standard observer and D_{65} standard illuminant.

The dyed samples were scanned using a HP Scanjet G3010 scanner at 200 ppi condition. To obtain the color parameters (RGB), the mean filter was applied, because the obtained images were not smooth and RGB values of pixels were changed in image. The raw and filtered images of nylon dyed by 100% madder natural dye with pre-mordanting method are shown in Fig. 1. The colorimetric parameters (CIELab) of images were obtained. At the start, the RGB values of images were converted into CIEXYZ color space[10]. In this method, first the scanner RGB values were converted to sRGB color space by using following equations:

$$\begin{cases} R = \dfrac{R}{255} \\ G = \dfrac{G}{255} \\ B = \dfrac{B}{255} \end{cases} \qquad \ldots(1)$$

$$r = \begin{cases} \dfrac{R}{12.92} & R \le 0.04045 \\ \left(\dfrac{R + 0.055}{1.055}\right)^{2.4} & R > 0.04045 \end{cases} \qquad \ldots(2)$$

$$g = \begin{cases} \dfrac{G}{12.92} & G \le 0.04045 \\ \left(\dfrac{G + 0.055}{1.055}\right)^{2.4} & G > 0.04045 \end{cases} \qquad \ldots(3)$$

$$B = \begin{cases} \dfrac{B}{12.92} & B \le 0.04045 \\ \left(\dfrac{B + 0.055}{1.055}\right)^{2.4} & B > 0.04045 \end{cases} \qquad \ldots(4)$$

$$\begin{cases} \overline{R} = 100 \times r \\ \overline{G} = 100 \times g \\ \overline{B} = 100 \times b \end{cases} \qquad \ldots(5)$$

Then, the sRGB values were converted to CIEXYZ color space by using following equation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} \begin{bmatrix} \overline{R} \\ \overline{G} \\ \overline{B} \end{bmatrix} \qquad \ldots(6)$$

The CIEXYZ values were converted into CIELab (1976) color space by using following equation[16]:

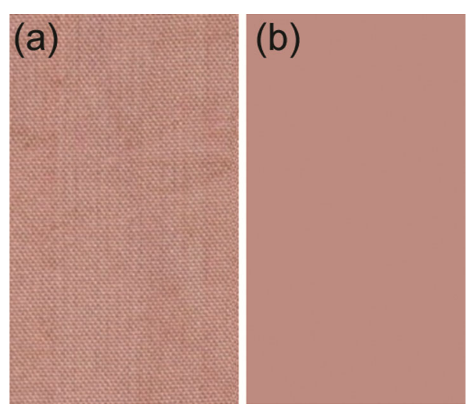

Fig. 1 — Mean filtration of sample dyed by 100% madder natural dye with pre-mordanting method (A) raw and (B) filtered images

$$\begin{cases} L^* = 116 \; f\left(\frac{Y}{Y_n}\right) - 16 \\ a^* = 500 \; \left[f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right)\right] \\ b^* = 200 \; \left[f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right)\right] \end{cases} \quad \ldots(7)$$

where

$$\begin{cases} f(I) = (I)^{1/3} & I > \left(\frac{24}{116}\right)^3 \\ f(I) = \left(\frac{841}{108}\right)(I) + \frac{16}{116} & I \le \left(\frac{24}{116}\right)^3 \end{cases} \quad \ldots(8)$$

where X_n, Y_n and Z_n are the tristimulus values of a specified white object color stimulus.

Also, the RGB values of images were converted to HSL (H is the hue angles, S is the saturation and L is the brightness that describes lightness) color space using the following equations[17]:

$$\begin{cases} R = \frac{R}{255} \\ G = \frac{G}{255} \\ B = \frac{B}{255} \end{cases} \quad \ldots(9)$$

$$\max = Max\ (R, G, B) \quad \ldots(10)$$

$$\min = Min\ (R, G, B) \quad \ldots(11)$$

$$d = \max - \min \quad \ldots(12)$$

$$v = \max \quad \ldots(13)$$

$$s = \begin{cases} 0 & \max = 0 \\ \frac{(\max - \min)}{\max} & \max \ne 0 \end{cases} \quad \ldots(14)$$

$$h = \begin{cases} \frac{(g - b)}{d} & r = \max \\ 2 + \frac{(b - r)}{d} & g = \max \\ 4 + \frac{(r - g)}{d} & b = \max \end{cases} \quad \ldots(15)$$

$$H = \begin{cases} 60 \times h & h \ge 0 \\ (60 \times h) + 360 & h < 0 \end{cases} \quad \ldots(16)$$

Then, the results of scanned images in various color spaces were compared with spectrophometric results in qualitative method.

3 Results and Discussion

Figure 2 shows the images of nylons dyed by 100% madder natural dye with non-mordanting, pre mordanting and meta-mordanting methods. As shown in this figure, the lightness, hue and shade of samples are different.

In order to investigate the ability of scanner to verify the colorimetric characteristics of dyed samples, the colorimetric parameters of dyed samples are obtained by scanner and spectrophotometer. For this purpose, the RGB values of scanned images are converted into CIELab and HSL color spaces. The colorimetric analysis of madder natural dye on nylon is carried out by analyzing the color parameters, such as lightness (L*) or brightness (L), chroma (C*) or saturation (S), hue angle (h˚ or H), and chromaticity distribution (a*-b* diagram).

The lightness of nylon dyed with madder natural dye is shown in Fig. 3. According to spectrophotometric analysis, the lightness of dyed samples is decreased with an increase in dye concentration. Also, same result is also shown by scanner in CIELab and HSL color spaces. As seen in this figure, the samples dyed by meta-mordanting method are lighter than the samples dyed by other dyeing methods. The result is same in both scanner and spectrophotometric methods.

The chromaticity distribution of the dyed samples using both scanner and spectrophotometer is shown in Fig. 4. In this figure, the horizontal axis is a* (greenness-redness) and the vertical axis is b* (blueness-yellowness). It can be seen that the samples dyed with non-mordanting method have more yellow shade in both scanner and spectrophotometer evaluations.

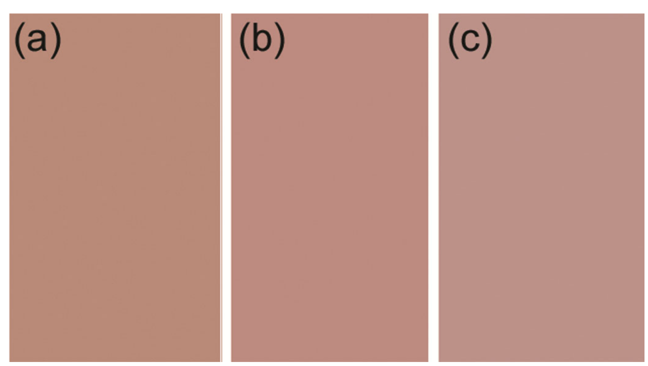

Fig. 2 — Images of samples dyed by 100% madder natural dye with various dyeing methods (A) non-mordanting, (B) pre-mordanting, and (C) meta-mordanting

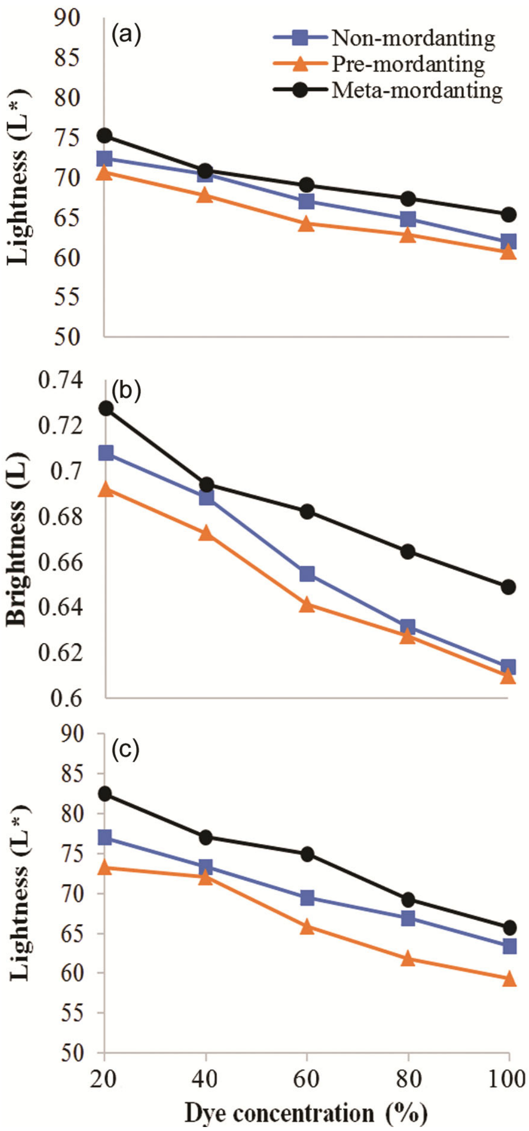

Fig. 3 — Lightness of dyed nylon using scanner in (A) CIELab and (B) HSL color spaces, and using (C) spectrophotometer in CIELab color space

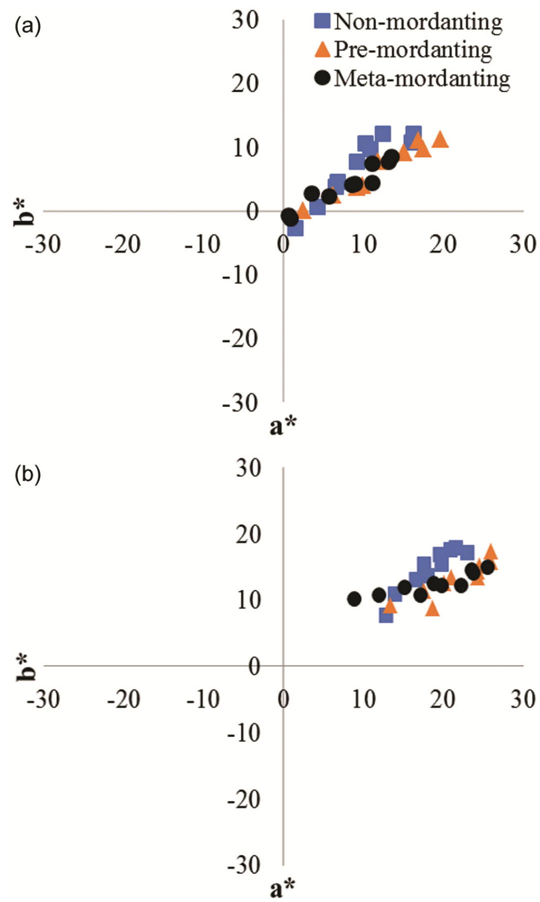

Fig. 4 — CIELab color values of dyed nylon using (a) scanner and (b) spectrophotometer

Figure 5 shows the chroma of dyed samples using scanner in CIELab and HSL color spaces and spectrophotometer in CIELab color space. As shown in this figure, the chroma of samples dyed with madder natural dye by non-mordanting method is higher in spectrophotometer and also in scanner estimates. In order to further investigate the ability of scanner for assessment of color parameters, the obtained hue by scanner is compared with that obtained by spectrophotometer. The hue of dyed samples is shown in Fig. 6. It is clearly indicated that the hue of samples dyed by non-mordanting method is higher than those of the samples dyed by pre-mordanting and meta-mordanting methods. Also, it can be found that the assessments by scanner show this result.

In order to investigate the scanner's ability to compare the color charactristics of samples with different dye concentrations, the correlation coefficient between scanner mesurements and spectrophotometric parameters is obtained (Table 1). As shown in this table, although the correlation coefficient between L*, a*, b* and C* measured by scanner and color parameters measured by spectrophotometer is almost good to fairly good, the correlation coefficient between obtained h° by scanner and obtained h° by spectrophotometer in non-mordanting and pre-mordanting methods is very low. The correlation coefficient between obtained L and S by scanner and obtained L* and C* by spectrophotometer is good to fairly good. However, the correlation coefficient between obtained H by scanner and obtained h° by spectrophotometer in non-mordanting and pre-mordanting methods is also

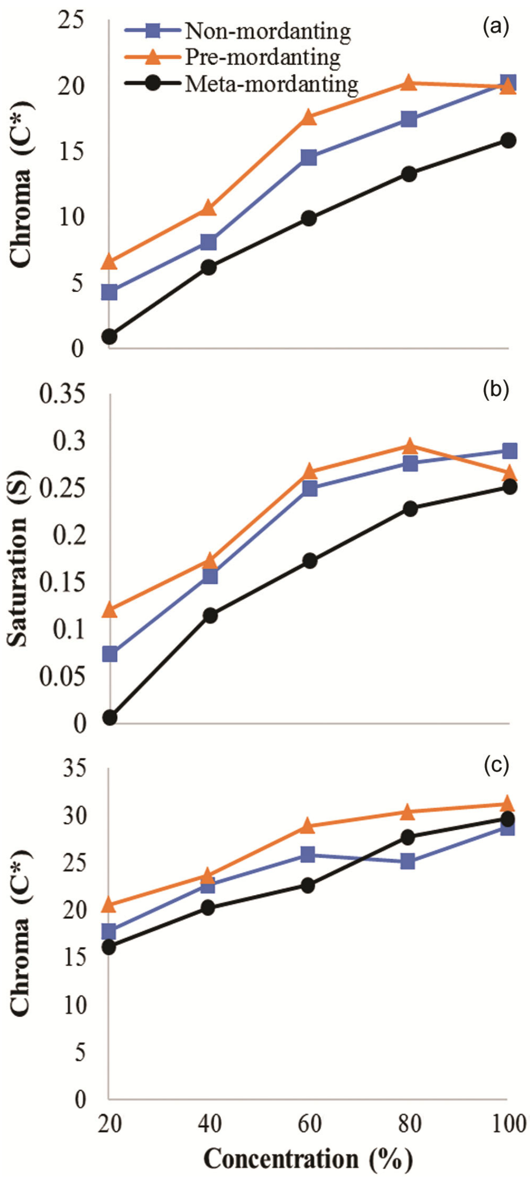

Fig. 5 — Chroma of dyed nylon using scanner in (A) CIELab and (B) HSL color spaces, and using (C) spectrophotometer in CIELab color space

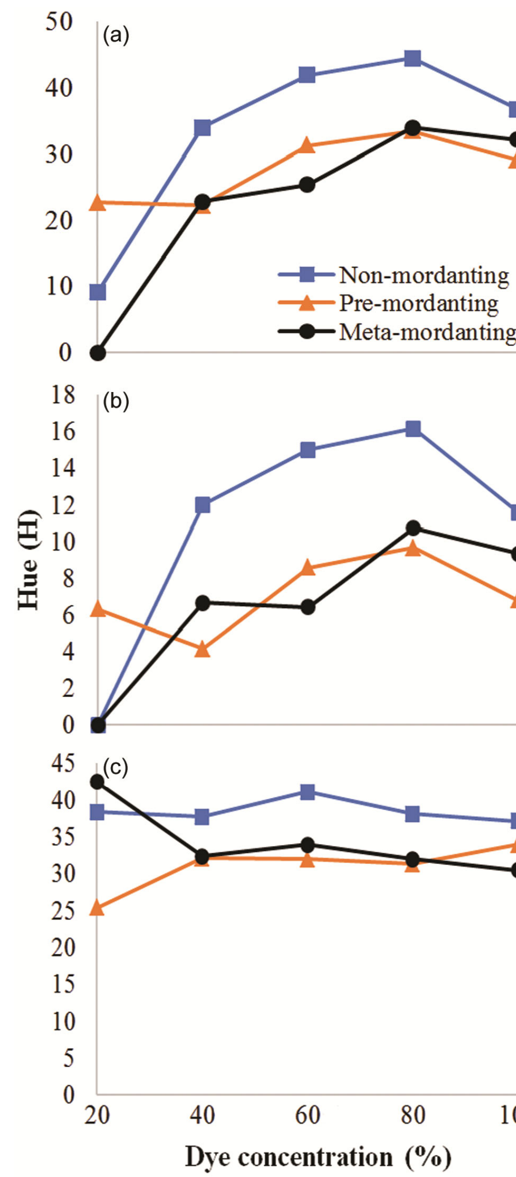

Fig. 6 — Hue of dyed nylon using scanner in (A) CIELab and (B) HSL color spaces, and using (C) spectrophotometer in CIELab color space.

Table 1 — Correlation between color parameters obtained by scanner and by spectrophotometer

Dyeing method	Correlation coefficient							
	CIELab					HSL		
	L*	a*	b*	C*	h°	H	S	L
Non-mordanting	0.996	0.961	0.919	0.948	0.180	0.205	0.957	0.955
Pre-mordanting	0.977	0.991	0.916	0.997	0.477	0.090	0.975	0.986
Meta-mordating	0.978	0.984	0.951	0.990	0.959	-0.941	0.976	0.988

very low and the correlation coefficient between obtained H by scanner and obtained h° by spectrophotometer in meta-mordanting method is negative. This means that the obtained H by scanner is decreased while the obtained h° by spectrophotometer is increased and vice versa.

4 Conclusion

In this research, the nylon samples are dyed by madder natural dye using different dyeing methods, such as non-mordanting, pre-mordanting, and meta-mordanting. Then, dyed samples are scanned using scanner and the RGB values are obtained. Then, colorimetric parameters of images are compared with colorimetric parameters obtained using spectrophotometer. In this way, the RGB values of images are converted into CIELab and HSL color spaces. The comparison is carried out by analyzing the color parameters such as lightness or brightness, chroma or saturation, hue angle, and chromaticity distribution. The obtained results show that the scanner is able to evaluate the colorimetric characteristics of samples dyed using different dyeing methods. However, the correlation between obtained hue by scanner and obtained hue by spectrophotometer is not good. So, the scanner is a low-cost and useful industrial instrument for measuring and comparing the colorimetric parameters of dyed fabrics.

Acknowledgement

The authors would like to express the grateful thanks to Iran National Science Foundation (INSF) for supporting this research.

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