


# Investigations of the Colorimetric and Fastness Properties of Modified Cotton Dyed with the Madder by Reflectance Measurements

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**Abstract:** The madder was used as a natural and environmentally friendly dye for the modified cotton fabrics, and pro that the natural dye the usability of plants in textile dyeing processes simultaneously. This paper deals with plant-based natural dye derived from Indian madder (*Rubiacordifolia*) roots applied to modified cotton fabrics. The impact on dye-ability is assessed in the presence of catalysts (ammonium chloride and ammonium sulfate) and then curing with various conditions from time and temperature. All stability properties have been observed, such as dye-ability, color characteristics, and strength properties of dyed modified cotton fabrics. The color intensity (K/S value) was very high for both dyes used, and the color quality was very satisfactory concerning washing and rubbing. Madder extract is very effective on a modified cotton fabric substrate.

**Keywords:** madder; colorfastness; natural dye; guar gum; color strength; cotton fabric.

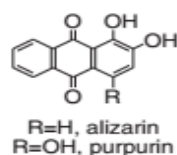
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## 1. Introduction

Warm climates are ideal for growing cotton produced in cotton plants' seed hair pods [1]. It is made of cellulose and is the primary component of textiles. Photodegradation, acid hydrolysis, oxidation, biodegradation, and grafting are reactions that act on the cellulose structure and cause its alteration; all these phenomena are related to each other [2]. Graft copolymerization is one of these phenomena by vinyl monomers mounted on cellulose. In particular acrylic was extensively investigated [3,4] due to its physical existence, and monomers Characteristics (transparency of water-repellence, Efficient flammability) may be used. Reactive polyblend cotton fabrics were prepared by graft copolymerization of vinyl monomers with natural polysaccharides such as Guar gum (GG) and then coated onto cotton fabrics in the presence of a catalyst (ammonium sulfate, ammonium chloride) [5], GG appeared with a chemically structure long straight chains of  $\alpha$ -D mannopyranosyl units linked by (1-4)  $\beta$ -glycosidic linkages with the ratio 2:1. Commonly used natural guar gum because of its cost-effectiveness, thickening effect, nontoxic, biodegradability, biocompatibility, high viscosity, and water-solubility, and now used in many industries [6] such as sizing; finishing agents in the textile and paper industries as a binder stabilizer and thickener in the cosmetics; food industries and as a fracturing fluid additive in mining and hydraulic fracturing processes [7,8]. However,

GG substitution is difficult to give dispersion without degradation due to insolubility, so try to change GG with reactive polyblends prepared below and then dyed with two kinds of dye, one extracted natural dye and the second reactive dye with this target.

Most natural dyes are extracted from the bark [9], leaves [10], roots [11,12], fruits [13], flowers, and seeds of plants [14,15], which are renewable resources. Madder is considered a natural dye, one of the prominent dye-bearing plants belonging to the family Rubiaceae [16]. And also contains around 80 species of perennial scrambling [17,18] with a perennial plant that measures 10 m long. Madder roots contain different anthraquinones, of which the most prominent structures are alizarin and purpurin, which are believed to account for the red color [19,20]; their chemical structures contain two organic red dyes; alizarin and purpurin madder [21]. The composition of the extracted anthraquinones differs between the varieties of Rubia; for example, the major component forming the natural dye of the European madder (*Rubia tinctorum*) is alizarin (1,2-dihydroxyanthraquinone, Fig. 1), while purpurin (1,2,4-trihydroxyanthraquinone, Fig. 1) is the major component of Indian madder (*Rubia cordifolia*) has been cultivated in large amounts as a source for red plant dyes in Europe, Asia and America for centuries [22-25]. The dyestuff is extracted from the dried roots of the plant, the bark much richer in anthraquinone derivatives (i.e., Anthraquinone glycosides) than the wooden parts. And although it is found in considerable amounts in the European madder, and also present in the plant's roots during storage, hydrolysis of the glycosides occurs, which is completed under the acidic conditions established in the dyeing procedure [15].



**Figure 1.** Structure formula of madder natural dye.

The aim is to study the properties of cotton fabrics treated with (N-methylol -PAam-GG) under different curing conditions (i.e., times, temperatures, and catalysts) and dyed with madder as a natural dye in terms of color measurements and fastness properties (e.g., light, washing, and perspiration), and also, studying FTIR spectroscopy to determine the current functional groups present in both madder (as a natural dye), the cotton fabrics (modified and unmodified) dyed in the presence of catalysts (i.e.  $(\text{NH}_4)_2\text{SO}_4$  and  $\text{NH}_4\text{Cl}$ ), then understanding the new groups formed between natural dye and modified cotton fabrics, the difference between them before and after dyeing.

## 2. Materials and Methods

### 2.1. Materials.

Mill scoured, bleached, and mercerized plain weave cotton fabric (100%) weight 120 gm/m<sup>2</sup>, the thickness was 0.2 mm, the number of yarn/cm in warp direction 30 and weft 31 were supplied by El-NaserCompany for spinning weaving and dyeing. Mahalla El-Kubra Egypt. Guar gum (GG) was purchased from S.D. fine chemicals (Mumbai, India). Acrylamide, potassium bromates ( $\text{KBrO}_3$ ), thiourea (TU), sulfuric acid, sodium hydroxide, triethanolamine (TEA), and formaldehyde (HCHO) were laboratory-grade chemicals. Natural dye (Indian madder-*Rubiacordifolia*) was supplied by Company MisrScientific, Dokki-Giza, Egypt.

## 2.2. Preparation of the modified cotton fabrics.

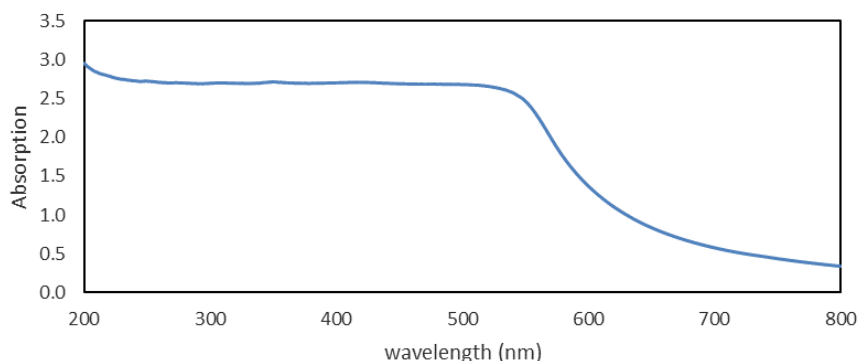
Preparation of a reactive composite [26,27] with 40% methylation based on the weight of (N-methylol -PAam-GG) content in the presence of 0.5 % of catalysts (i.e., ammonium chloride or ammonium sulfate). Then using, reactive composite was prepared for preparing modified cotton fabric by immersing, then padding to wet pick up 100 % and drying at 80°C. Then roast for 3 to 5 minutes at 120, 140, and 160 °C. Then, at 90°C, wash for 10 minutes with a solution containing 0.5gm/l nonionic detergent.

## 2.3. Extraction of natural dye.

Dried Indian madder (*Rubiacordifolia*) was used to obtain natural dye (anthraquinone dyeing compounds), which were conventionally extracted from the powdered (*Rubiacordifolia*) [28], especially from madder roots which contain the highest yield. Madder root powder was soaked in an aqueous solution of distilled water for 12 hours at a liquor ratio of 1:4, then boiled at 100°C for 30 minutes with constant stirring.

## 2.4. Optical density of dye extracted.

We measure the optical density for the extracted solution at different concentrations with a UV spectrophotometer Ultraviolet-visible (UV-vis) spectroscopy of the madder dye solution was performed, with a scanning range of 200-800 nm, by using Shimadzu (VIS) Double Beam Spectrophotometer with standard illuminant C (1174.83) model V-530 and bandwidth of 2.0 nm with accuracy  $\pm 0.05$  %, as shown in (Figure 2).



**Figure 2.** Absorption spectrum of madder (Natural dye).

## 2.5. Dyeing process.

Modified cotton fabrics (MCF) were dyed for 60 minutes at 80°C with natural dye extracted from madder root powder, with a liquor ratio kept at 1:40 based on fabric weight. The samples were washed with distilled water, followed by nonionic detergent, and dried.

## 2.6. Colour measurements.

The color strength values indicated on CIE ( $L^*$ ,  $a^*$ ,  $b^*$ ), where  $L^*$  indicates lightness (lighter or darker), and  $a^*$  and  $b^*$  are the color directions; finally, CIE ( $C^*$ ,  $h^*$ ) where  $C^*$  is the chroma axis and  $h^*$  is the hue angle were evaluated using Data color 650 Spectrophotometer with illuminant D65 and 10° observer. The color intensity as K/S values for all dyed samples was calculated through Kubelka–Munk equation:

$$\left(k/s = \frac{1-R^2}{2R}\right) \text{-----eq.1}$$

where: K is the absorption coefficient, R is the reflectance of the dyed sample, and S is the scattering coefficient.

All measured samples showed a maximum absorption wavelength value ( $\lambda_{\max}$  at 480 nm). The color difference ( $\Delta E^*$ ) is calculated by:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \text{-----eq. 2}$$

Where  $\Delta L^*$  denotes the difference between lightness values,  $\Delta a^*$  denotes the difference between red/green values, and  $\Delta b^*$  denotes the difference between yellow/blue values of the batch and standard [29,30].

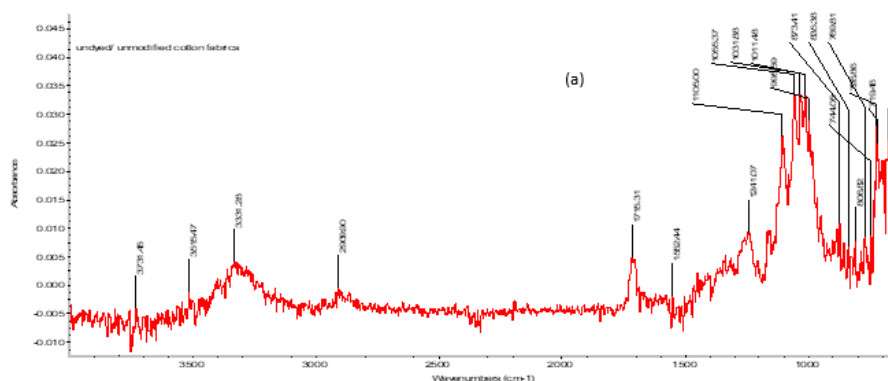
### 2.7. Fastness tests.

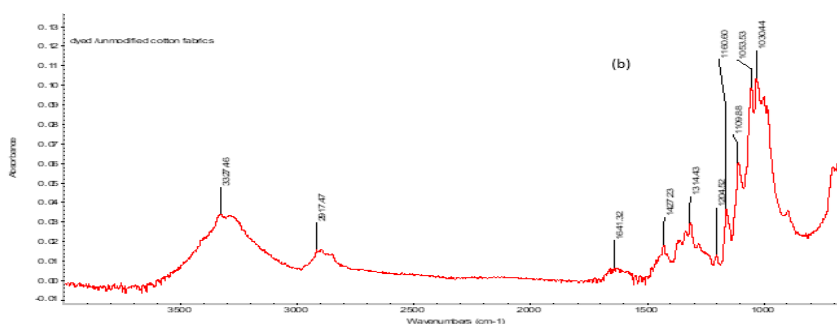
The colorfastness to washing, light, perspiration and crocking of the dyed samples were determined according to ISO 105-C06: 2010 (B1S), ISO 105-B02: 1994, ISO 105-E04: 2008 and AATCC Test Method 8-2007, respectively. The extent of photo-fading of the dyed samples was evaluated by color difference ( $\Delta E^*$ ) measurement in a Sun Test CPS1 (Atlas) equipped with an air-cooled xenon arc lamp (1700 W) and a daylight filter for simulation of outdoor solar radiation under a  $42 \text{ Wm}^2$  illumination for different periods (0.5-48 hrs.) at the temperature of approximately 32-62°C and relative humidity of approximately 40-65 %. The Indian madder-dyed modified cotton fabrics were evaluated in terms of color change and the degree of staining using a grayscale. The madder dyed modified's dry and wet rub fastness were tested according to the ISO 105-X12:2001 method.

## 3. Results and Discussion

### 3.1. FTIR analysis.

FTIR spectroscopy has long been recognized as a powerful tool for structural information. The position, intensity, and shape of vibration bands are useful in clarifying conformational and environmental changes of polymers at the molecular level [31]. The spectra were divided into regions  $3600\text{-}3000 \text{ cm}^{-1}$ , corresponding to the regions assigned to different (OH stretching) modes;  $3000\text{-}2800 \text{ cm}^{-1}$  corresponds to the region assigned to asymmetric and symmetric (CH banding) stretching groups;  $1700\text{-}1500 \text{ cm}^{-1}$  correspond the region assigned (C=O vibration or NH amide I) modes,  $1500\text{-}1150 \text{ cm}^{-1}$  collected bands of CH and OH bending region, and  $1200\text{-}800 \text{ cm}^{-1}$  corresponding to fingerprint region with multiple C-O vibrations [32,33].





**Figure 3.** FTIR-ATR with absorbance spectra diagram of (a) undyed/unmodified and (b) dyed/unmodified cotton fabrics with madder (as a natural dye).

As shown in Figure 3 shows the FTIR-ATR with absorbance spectra of both cotton fabrics unmodified (dyed and undyed) in (Fig. 3a,3b), it is clear that the characteristic absorbance band of both cotton fabrics unmodified (dyed and undyed) and also, for cotton fabrics modified and dyed that measured different wavelengths and the most characteristic functional chemical groups present under investigation were analyzed in Table 1 [34-39].

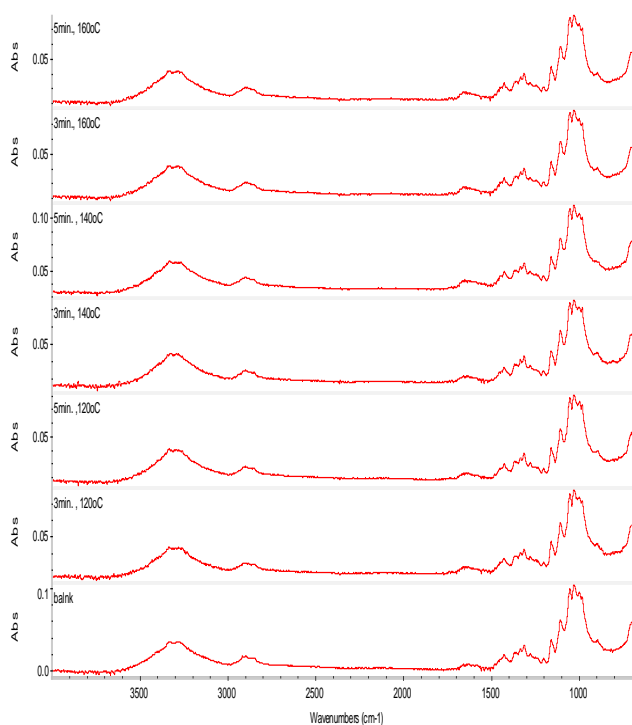
**Table 1.** Comparison of FTIR-ATR absorbance bands of undyed/ unmodified, dyed /unmodified, and dyed modified cotton fabrics.

Wavenumber (cm <sup>-1</sup> )		Assignment group		
Modified cotton fabrics	Unmodified cotton fabrics	Undyed	Dyed	
1053	1055.37	1055.37	1053.53	Asymmetric in-plane ring C-O stretching
1109	1105	1105	1109.88	Asymmetric bridge C-O-C
1160	1166.23	1166.23	1160.6	Associated with C-O-C stretching group
1204	1206.86	1206.86	1204.52	OH in-plane bending
1314	1317.44	1317.44	1314.43	CH wagging
1427	-	-	1427.23	OH (bending)
1645	-	-	1641.32	NH (amide II) or Adsorbed water (OH) or C=C stretching alkene
2900	2986.29	2986.29	2917.47	Symmetrical stretching modes of C-H bonding
3333	3331.28	3331.28	3327.46	Hydrogen bonded and hydroxyl O-H group

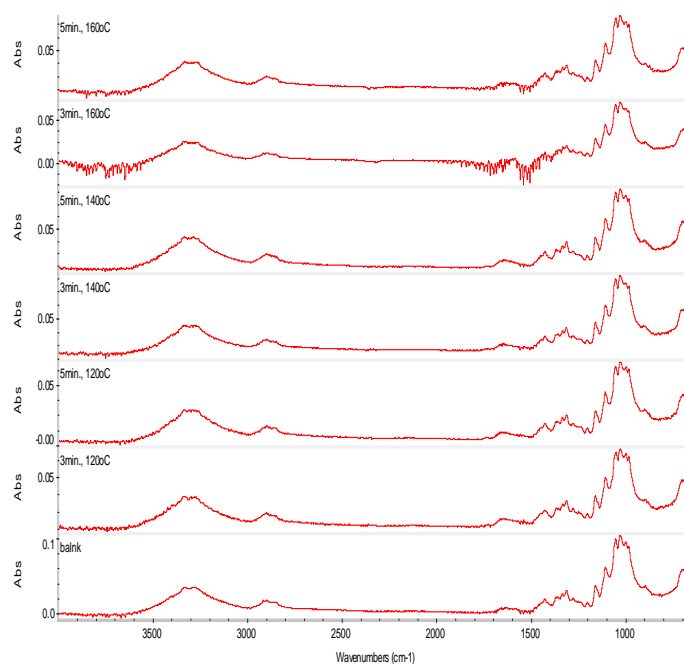
Notably, there is a substantial difference between unmodified cotton fabrics (dyed and undyed) and dyed modified cotton fabric; at  $\sim 3333 \text{ cm}^{-1}$ , there is a large peak that is an O-H stretch or H-bonded stretch, suggesting the presence of functional groups of alcohol or phenol. And also, another peak at  $\sim 1645 \text{ cm}^{-1}$  indicates the possible existence of NH (amide II) or adsorbed H<sub>2</sub>O as (OH group.) or C = C conjugated alkene bond or amines or cyclic alkene. There is another peak at  $2900 \text{ cm}^{-1}$ , which is symmetric stretching of C-H bonding. However, since the presence of long conjugated double bonds has been known to be the source of red color in some natural dye extracts, the color of the dye extract may have come from the C=C conjugated alkene bond, where the visible light wavelength of maximum absorption of the madder dye dropped within the red color spectrum at a last recognized peak at  $1427 \text{ cm}^{-1}$ , where the visible light wavelength of the madder dye's maximum absorption falls within the red color range, indicating that the conjugated double bond may be the actual functional group that has lent its deep red color to the madder dye. There is yet another, but not known, peak in the fingerprint field. The potential explanation for why this peak was not detected may be linked to its intensity, where the amplitude of a peak is influenced by the dipole moment in the compound by the functional group molecules [40-42]. Peaks appeared during this phase special peaks of characteristics that unique feature appears for the dyed cotton fabrics (modified and unmodified) at peaks  $\sim 1640$  and  $\sim 1427 \text{ cm}^{-1}$  wavenumbers [43]. It does not appear in the plain,

undyed unmodified cotton fabrics; this could be a result of the existence of anthraquinone groups in madder, as shown in Table 1.

FTIR range shows the subtleties of the useful gatherings in Figures 4 and 5. For all samples of the cotton texture unmodified and adjusted that dyed as we noticed that the new groups seem normal for the presence of color on the outside of all samples (modified and unmodified) of cotton textures utilized dyed with the madder during the dyeing interaction process that extraordinarily noted on the absorption band strength at 1645 and 1427  $\text{cm}^{-1}$ , that ascribed to The amide gathering (N-H) and (OH) bending.



**Figure 4.** FTIR absorbance spectra of the modified and unmodified cotton fabric dyed with the madder and catalyst  $(\text{NH}_4)_2\text{SO}_4$ .

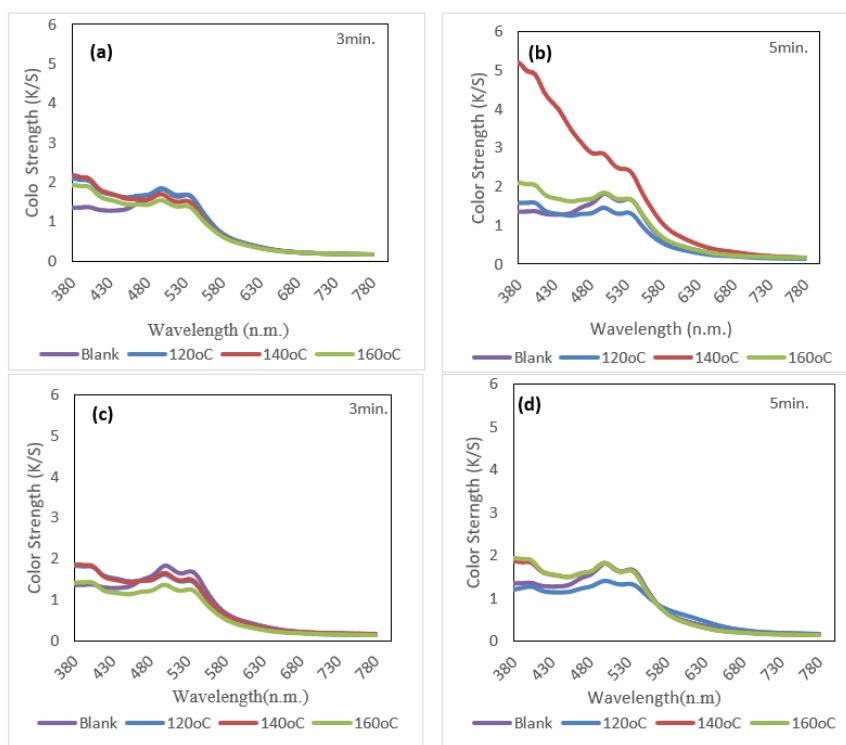


**Figure 5.** FTIR absorbance spectra of the modified and unmodified cotton fabric dyed with madder and catalyst  $(\text{NH}_4\text{Cl})$ .

The presence of bands in the case of dyed modified cotton fabrics compared to that of dyed and undyed unmodified cotton fabrics with madder (as natural dye) conforms to the successful chain bond between dye and modified cotton fabrics with the presence of a catalyst (ammonium chloride and ammonium sulfate), the intensity of peaks increase with increasing time (3 and 5min.) and temperature from 120 to 140 then decrease at 160°C. These important peaks elucidate the structure of dyed unmodified cotton fabrics, undyed unmodified cotton fabrics, and dyed modified cotton fabrics.

### 3.2. Color strength.

All modified cotton fabrics samples in the presence of catalysts that cured at times (3 and 5 min.) and temperatures (120, 140, and 160°C) were then dyed with madder (as natural dye). The color strength of dyed cotton fabrics (modified and unmodified) and the reflectance values (R) were assessed by spectrophotometer (Data color 650 Spectrophotometer with illuminant D65 and 10° observer). Where a measure of its characterized by the absorption in the visible region of the spectrum and can be expressed as a color strength value was used to determine the concentration of dye in the fabric [44] using the reflectance value, then calculating K/S as appear in (eq. 1):



**Figure 6.** Color strength (K/S) of the modified cotton fabric dyed with madder and catalysts  $(\text{NH}_4)_2\text{SO}_4$  in (a),(b), and  $(\text{NH}_4\text{Cl})$  in (c),(d), respectively.

Modification of cotton fabric samples before dyeing can provide an easy and efficient method to improve dye-fiber compatibility, eliminating the need for salt in the dye bath. Cationizing cotton fabrics increase anionic dyes substantively due to the presence of positive charges imparted to the material. Cationisation is the chemical alteration of cotton to create cationic (positive) dyeing sites instead of existing hydroxyl (-OH) sites [45,46]; as appears in my work, the modification of cotton fabrics in the presence of catalysts (ammonium sulfate and ammonium chloride) with curing temperature and time, then dyed with natural anthraquinone colorants extracted from Indian madder roots with liquor ratio (1:40). As shown

in figure 6(a,b), in the presence of ammonium sulfate as a catalyst, we note the color strength (k/S) for all modified cotton fabrics used by using the madder as a natural dye increases with curing at various temperatures from 120 to 140°C then decreased at 160 °C with changing time from 3 and 5 min. , in the presence of ammonium chloride, slight change in K/S with the same conditions as shown in Figure 6(c,d). The graph shows that modified-cotton fabric and dyed fabric have given higher color yield values than the unmodified and dyed cotton fabric.

### 3.3. Color parameters.

Based on the madder root's external color. That outer color was measured using Data Color 650 Spectrophotometer with standard D65 and 10° observer illuminant. , And the color space of CIE-Lab. Three readings were conducted for each color measurement to get an average of the three readings (L \*, a \*, and b \*). The colorimetric coordinate (a\*) was the same as the Green-red axis, with negative values linked to green color and the orange and red positive values (-60 black, +60 Red) Red. The (b\*) corresponded to the blue-yellow axis, where the negative values were associated with the blue color and the positive values were associated with the Yellow (- 60 blue, +60 purple) color. Coordinate (L\*) (0 = black, 100 = white) calculated the brightness and put it on the z-axis, with the coordinates (a\*and b\*) placed on the XY color planes. The (a\*) coordinate was associated with the red color content of the madder root. The values of the Hue angle (arc tan b\*/a \*) were also used.

**Table 2.** Color parameters of the unmodified and modified cotton fabric with (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> as a catalyst and dyed with madder.

Temp.	Time	L*	a*	b*	c*	h*
120°C	Blank	57.18	20.52	8.39	22.17	2.31
	3min.	58.29	18.97	12.5	22.72	1.29
	5 min.	61.76	19.06	12.89	23.01	1.25
140°C	3min.	59.67	19.90	14.15	24.42	1.16
	5min.	62.74	20.31	19.48	28.14	0.70
160°C	3min.	59.60	19.75	14.10	24.27	1.15
	5min.	62.70	20.20	19.40	28.01	0.70

From (Table 2), the effect of dyeing modified cotton fabrics in the presence of ammonium sulfate as a catalyst; all samples used was cured at different temperatures and times before dyeing, and the relative brightness (L\*) shows an increase in their values of cotton fabrics from unmodified to modified, from the temperature at 120 to 140°C then slightly decrease at 160°C for the dyed modified cotton fabrics and also, with an increasing time from 3 to 5 minutes, we note the values of (L\*) increase which means that the fabric becomes fader firstly in color then becomes more brightness. And also, we note the values of the color constant (a\*), decrease in their values from unmodified to modified cotton fabrics which display an increase in their values of modified cotton fabrics from 120 to 140°C, then slightly decrease at 160°C for the dyed of modified cotton fabrics with an increasing time from 3 and 5 minutes, this indicates that the red component decreases first rather than the green component then the red component increases instead of the green component. And also, the same color constant (b\*) value increases in both dyed (unmodified and modified) cotton fabrics under the same conditions, which indicates that there is an increase in the yellow component instead of the blue component, followed by an increase in a blue component instead of yellow component. Finally, all values of C\* and H\* for all samples depend on values of a\* and b\* of color scales.

As appear in (Table 3), the effect of color parameters of dyed modified cotton fabrics in the presence of a catalyst (ammonium chloride), we note an increase in color parameters



properties at different temperatures from 120 to 140 °C and then decrease at 160 °C with a change of time from 3 and 5 minutes by comparing to unmodified dyed cotton fabric, we note, it takes the same trend of other catalyst used (ammonium sulfate) but in lower values. Furthermore, the strong interactions intermolecular bond of the dye and cationization modified cotton fabrics that allowed for dyeing without any additional electrolyte. It gave a higher value to the color effect [47].

**Table 3.** Color parameters of the dyed unmodified, and modified cotton fabric with (NH<sub>4</sub>)Cl as a catalyst.

Temp.	Time	L*	a*	b*	c*	h*
	Blank	57.18	20.52	8.39	22.17	2.31
120°C	3min.	57.30	20.61	13.90	24.86	1.25
	5 min.	59.54	23.74	16.52	28.92	1.20
140°C	3min.	58.34	20.85	14.50	25.40	1.20
	5min.	62.30	23.89	18.11	29.98	1.06
160°C	3min.	58.20	20.80	14.40	25.30	1.21
	5min.	62.27	23.70	18.00	29.76	1.05

### 3.4. Fastness properties.

The change of washing fastness properties generally for all samples (Unmodified and modified cotton fabrics) for dyeing with natural dye (a madder) were moderate to fine; we note an increase in washing fastness properties [48] at different temperatures from 120 to 140 °C and then decrease at 160 °C with a change of time from 3 and 5 minutes, we note the washing fastness properties for samples in the presence of ammonium sulfate more than with ammonium chloride as a catalyst at 140°C for 5 minutes compared to others conditions used that showed less staining due to the structure of the madder dye as shown in (Figure 1). Therefore its removal during washing showed higher staining for wool and cotton. This is due to the high affinity of the dye to modified cotton, as in (Table 4).

**Table 4.** Washing fastness properties for dyed unmodified, and modified cotton fabrics in the presence of (NH<sub>4</sub>)Cl and (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> as catalysts.

Temp.	Time	Types	NH <sub>4</sub> Cl			(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>		
			Alteration	Staining		Alteration	Staining	
			wool	Cotton	Wool	Wool	Cotton	wool
120°C	3min.	U	3-4	4	3-4	3-4	4	3-4
		M	3-4	3-4	3-4	3-4	4-5	3-4
5 min.	3-4		3-4	3-4	3-4	4-5	3-4	
140°C	3min.		4	4	3-4	4-5	4-5	3-4
	5 min.		4	4	3-4	4-5	4-5	3-4
160°C	3min.		3-4	4	3-4	3-4	4-5	3-4
	5 min.		3-4	4	3-4	3-4	4-5	3-4

Note: U and M represent unmodified and modified fabric samples, respectively

Lightfastness of many natural colors, almost all natural colorants fade after daylight exposure [49]. This is what's relevant to Natural dye's disadvantages and usability. Lots of papers indicated that some natural colorants had poor luminosity values. In that work, for all the dyed samples with madder as a natural dye, the samples have good to excellent light fastness. The modified cotton fabric has shown better light fastness results than the unmodified fabric. The electron arrangement of the dye molecules in the chromophore can withstand the degrading effect of light while being exposed to light for an extended time. Furthermore, Cationized fabric showed better results because the number of coloring molecules in the samples was higher than those present, as shown in (Table 5).

Colorfastness to crocking [50] of the dry crocking fastness of all the modified and unmodified samples was good, and wet crocking fastness was moderate; modified fabric samples showed a slightly lower rating than unmodified ones. (Table 5), shows the color speed to crock with different shades from the unmodified and modified samples with both ammonium chloride and ammonium sulfate catalyst. The dry crocking speed of all the modified with ammonium-sulfate and ammonium-chloride was good, and the wet crocking speed was moderate. However, modified fabric samples showed a slightly lower rating for some shades than unmodified ones.

**Table 5.** Colorfastness to rub and light for the dyed unmodified, and modified cotton fabric in the presence of  $(\text{NH}_4)\text{Cl}$ ,  $(\text{NH}_4)_2\text{SO}_4$  as catalysts.

Temp.	Time	Types	$\text{NH}_4\text{Cl}$		$(\text{NH}_4)_2\text{SO}_4$		Light Fastness
			Wet	Dry	Wet	Dry	
		U	3-4	4	3-4	4-5	3
120°C	3min.	M	3-4	3-4	3-4	4	3-4
	5 min.		3-4	3-4	3-4	4	3-4
140°C	3min.		3-4	4	4	4-5	4
	5 min.		3-4	4	4	4-5	4
160°C	3min.		3-4	4	4	4	4
	5 min.		3-4	4	4	4	4

Note: U and M represent unmodified and modified fabric samples, respectively

Tables 6 and Table 7 indicate the change in (acid and base) perspiration [51] fastness properties of both modified and unmodified cotton fabrics dyed with (the madder) that shows no remarkable variation for all studied samples ranging between excellent (5) to very good (4) at Gray Scale.

**Table 6.** Colorfastness to perspiration for the dyed unmodified, and modified cotton fabrics in the presence of  $(\text{NH}_4)_2\text{SO}_4$  as catalysts.

Temp.	Time	Types	Alteration		Staining			
			acid	Base	Cotton		Wool	
					acid	Base	acid	base
		U	3	3-4	3	3-4	3	3-4
120°C	3min.	M	4	4-5	4-5	4-5	4	4
	5 min.		4	3-4	4	4	4-5	4
140°C	3min.		4-5	4-5	4	4-5	4-5	4-5
	5 min.		4-5	4-5	4-5	4	4-5	4-5
160°C	3min.		3-4	4	3-4	4	4-5	4-5
	5 min.		4	4	4-5	4	4-5	4-5

Note: U and M represent unmodified and modified fabric samples, respectively

**Table 7.** Colorfastness to perspiration for the dyed unmodified, and modified cotton fabrics in the presence of  $(\text{NH}_4)\text{Cl}$  as catalysts.

Temp.	Time	Types	Alteration		Staining			
			Acid	base	cotton		Wool	
					acid	base	acid	base
		U	3	3-4	3	3-4	3	3-4
120°C	3min.	M	3	3-4	4	4	4	4
	5 min.		3-4	4	4-5	4-5	4-5	4
140°C	3min.		4	4	4	4	4-5	4
	5 min.		4-5	4	3-4	4	3	4
160°C	3min.		4	4	4	4	4	4
	5 min.		4	4	4	4	4	4

Note: U and M represent unmodified and modified fabric samples, respectively

## 4. Conclusions

This study used FTIR analysis to investigate the groups formed while dyeing modified cotton fabrics with madder as a natural dye. The presence of bands in dyed modified cotton fabrics, when compared to dyed unmodified cotton fabrics with madder dye, indicates a successful chain bond between dye and modified cotton fabrics. These significant peaks shed light on the structure of dyed unmodified, and modified cotton fabrics; this was done under various conditions, including time, temperature, and catalyst type. Based on the results, the dyed samples were evaluated by monitoring the color strength (K/S), color parameters (such as L\*, a\*, b\*, and  $\Delta E^*$ ), and fastness properties. On dyed modified cotton fabrics, madder extract is very effective. In terms of washing and rubbing, the color quality was excellent.

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## Conflicts of Interest

The authors declare no conflict of interest.

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