Effect of UV radiation on dyeing of cotton fabric with extracts of henna leaves

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Received 31 August 2007; accepted 28 December 2007

Natural dye containing Lawsone that imparts yellowish-green colour on to the cotton fabric has been extracted using water, alum and methanol from non-irradiated and irradiated henna powder through UV source. The effect of treatment time, temperature and salt concentration on the dyeing of cotton fabric has been studied using CIELab system for the optimization of dyeing conditions. Different mordants, such as copper sulphate and ferrous sulphate, have been employed for the improvement in colour fastness properties of the irradiated dyed cotton fabrics. It is observed that the UV radiation not only enhances the colour strength of dye on cotton fabric but also improves the fastness properties of pre-irradiated cotton fabrics.

Keywords: Cotton fabric, Colour fastness properties, Henna powder, Lawsone, UV radiation

IPC Code: Int. Cl. D06P

1 Introduction
In recent past, synthetic dyes have been widely used as compared to natural dyes1 due to their lower prices and wide range of bright shades with considerably improved colour fastness properties. However, recently the concern for the environment has created an increasing demand for natural dyes, which are friendlier to the environment as compared to synthetic dyes.2

Although there are several types of radiations, e.g. ultraviolet (UV) and visible3,4, the treatment of fibres with UV radiations affects the colouration. The photo modification of the fibres allows more dye or pigment to fix on fabric under the normal conditions (e.g. lower temperature), thereby increasing the wettability of hydrophobic fibres to improve depth of shade in printing.5

The present work was, therefore, undertaken to extract colouring component from henna and to study its dyeing effect on cotton fabric before and after being exposed to UV radiation. Attempts have also been made to improve the colour strength of dye on cotton fabric by using extracts of irradiated henna powder and to improve the colour fastness properties of dyed fabrics using irradiated cotton fabric. Henna contains Lawsone (alpha napthoquinone or 2-hydroxy-1, 4-naphthoquinone) that produces yellowish-green colour on cotton.6, 7 The general formula of Lawsone is given below:

![2-Hydroxy-1, 4-naphthoquinon](image)

2 Materials and Methods

2.1 Preparation of Samples
Henna (Lawsonia inermis L.) leaves were collected from the botanical garden of University of Agriculture, Faisalabad, Pakistan, washed with distilled water and then dried at room temperature. The dried leaves were grounded to obtain particles of uniform size. Plain weaved, bleached and mercerized cotton fabrics, purchased from MSC Textile (Pvt), Faisalabad, Pakistan, were used for the dyeing.

2.2 Radiation Processes
UV radiation (245 nm, 180 W) was used for irradiating dye powder and cotton fabrics for 1 h. The extracts obtained from non-irradiated powder were also irradiated in order to observe the effect of radiation on the solution via observing the colour strength of fabric dyed with irradiated solutions.8-10
2.3 Extraction Methods
Extraction of natural dye from the irradiated and non-irradiated henna powder was carried out by the traditional method using water, alum and methanol as solvents. For 1g irradiated and non-irradiated henna powder, 20 mL solvent was used keeping the material-to-liquor (M:L) ratio at 1:20 (ref. 10).

2.4 Optimization of Dyeing Conditions
Different dyeing parameters, such as time, temperature and salt concentration, were optimized. The dyeing was carried out for 1 h using 1:20 M:L ratio. To observe the effect of time, dyeing was carried out for 20, 40, 60, 80, 100 and 120 min. In another experiment, dyeing was performed at 35, 45, 55, 65, and 75°C to observe the effect of temperature. In order to observe the effect of salts (Na2SO4 and NaCl), different salt concentrations such as 2, 3, 4 and 5 % were used.11, 12

2.5 Mordanting Process
Mordanting was carried out at optimized dyeing conditions using copper and ferrous mordants to improve the colour fastness properties. The pre- and post- mordanting experiments were carried out by applying different concentrations of the mordants.10-13

2.6 Evaluation of Colour Strength and Lab Values
Dyed fabrics were subjected to CIELab and LCH system for calculation of \( L^* \), \( a^* \) and \( b^* \) values with the help of Spectra flash spectrophotometer (SF 650).14-18

2.7 Evaluation of Colour Fastness Properties
Fastness to washing, rubbing and light were studied using ISO105-CO 3 for colour fastness to washing, ISO 105 X-12 for colour fastness to rubbing and ISO 105-BO for colour fastness to light.19

3 Results and Discussion
Table 1 shows that the colour strength values slightly change in aqueous, inorganic and organic media, while the Lab values \( (L^*, a^* and b^*) \) indicate that samples dyed with methanolic extracts are mostly higher in strength and yellower in shade than that of samples dyed with alum extract. This might be ascribed to the hydrolytic degradation of Lawson colourant upon the UV treatment, which causes

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Sample code</th>
<th>Colour strength, %</th>
<th>( L^* )</th>
<th>( a^* )</th>
<th>( b^* )</th>
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<tbody>
<tr>
<td>Water</td>
<td>nrp/nrc</td>
<td>100.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<td>0.28</td>
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<td>0.78</td>
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<td>0.77</td>
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<td>-0.01</td>
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<tr>
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<td>rs/rc</td>
<td>109.84</td>
<td>-0.72</td>
<td>1.10</td>
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<tr>
<td>Alum</td>
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<tr>
<td>Alum</td>
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<td>-1.66</td>
<td>-0.29</td>
<td>6.85</td>
</tr>
<tr>
<td>Alum</td>
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<td>-2.66</td>
<td>-0.11</td>
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<tr>
<td>Alum</td>
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<td>-2.58</td>
<td>-0.41</td>
<td>8.69</td>
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<tr>
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<td>-2.76</td>
<td>-0.47</td>
<td>8.56</td>
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<tr>
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<td>-2.83</td>
<td>-0.35</td>
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<tr>
<td>Methanol</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<td>Methanol</td>
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<td>117.36</td>
<td>-1.55</td>
<td>0.68</td>
<td>-0.14</td>
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</table>

\( L^* \)—Lighter/darker, \( a^* \)—Redder/greener, \( b^* \)—Yellower/bluer, Nrp—Non-irradiated powder, nrc—Non-irradiated cloth, rc—Irradiated cloth, rp—Irradiated powder and rs—Irradiated solution.
significant sorption of degraded products on cotton fabrics.

As Lawsone is slightly soluble in water, it tends to attach to the cotton fibre, thereby causing darker shades. In aqueous media containing alum, the extraction of the colourant is better, probably due to the formation of metal-dye complexes and the nature of bonding between metal and dye. In aqueous media, the role of some insoluble impurities is dominant and unevenness in shade is observed due to low colour strength values, which is clear from the $L^*$, $a^*$ and $b^*$ values and colour strength values as given in Table 1. The $Lab$ values show that the dyed samples are darker, redder and bluer, when water is used as a solvent.

The anthraquinone type Lawsone is more soluble in organic media. When such extracts are used for dyeing, more colour strength is obtained. This is because the dye is absorbed more and more on cotton fabric and other insoluble component either got mixed with media or scattered during dyeing. The $Lab$ values show that the dyed samples are mostly darker, redder and yellower in shades.

The radiation treatment of cotton fabric with UV radiation shows that the irradiated cloth has maximum affinity for the dye substrate to attach on it as compared to non-irradiated sample. The results of irradiated cloth dyed with aqueous filtrates of non-irradiated and irradiated henna powder show darker shades which might be ascribed to the oxidation of cellulose, resulting in carboxylic acid groups. The UV treatment of cellulose fibres creates spaces between fibres linings, and as a result the interaction between the dye and the cellulose fabric becomes more significant. The dye molecules rush rapidly on the fabric along with some impurities and as a result either unevenness or low colour strength is obtained. The same trend is observed in dyeing of irradiated and non-irradiated cotton fabrics using inorganic and organic media.

More colour strength and good $L^*$, $a^*$ and $b^*$ values (Table 1) show that the extraction of dye should be carried out with irradiated henna powder and the dyeing should be carried out using irradiated cotton fabric in order to get more colour strength and acceptable $L^*$, $a^*$ and $b^*$ values. When cellulose fibres are treated with a dye for sufficiently long time, the dye molecules enter into the fibre structure and are generally distributed in the interior of the fibres, while they remain mainly on the surface, when dyed for a short time.

It is shown in Fig. 1 that with the increase in dyeing time, more colour strength is observed. The less strength might be due to incomplete dyeing when insoluble impurities compete with the colourant to sorb onto cotton fabric rather than colourant. As the time of dyeing increases from moderate to high, more and more colour strength is obtained even for 120 min dyeing. This might be because of the fact that the colourant significantly gets adsorbed and then absorbed. But when dyed for 120 min, the unevenness is observed. This is because of the dye aggregates, which continuously accumulate on the surface of fabric and gather there as bunch. When dyeing starts, equilibrium is established between the solvent and the fabric. It means that the number of dye molecules going towards fabric is equal to that going back to the solvent. The possibility of shifting colorant towards fabric might exist between solvent and fabric up to certain limit of time. Therefore, 100 min dyeing having maximum colour strength is selected (Fig.1) as the optimum dyeing time.

Temperature also plays a significant role in dyeing.

Too low temperature causes incomplete dyeing while too high may cause degradation of components. Hence, dyeing should be done at moderate

![Fig. 1— Effect of dyeing time, temperature and salt concentration on the colour strength of irradiated cotton fabric with methanolic extract of irradiated henna powder](image-url)
temperatures. The dyestuff is present in water as single molecules (ionized) as well as clusters of many molecules (aggregates). Aggregates are too large to enter the interior of fibres at a given temperature. Raising the temperature leads to the breaking down of aggregates. So, the number of single molecules existing in the solution increases. When a single molecule is absorbed by the fabric, additional monomers deliberate from the aggregates, which are, in turn, taken up by the fabric, resulting in a complete dyeing.

The dyeing was performed using optimized extract of irradiated henna powder at various temperatures. It is found that the colour strength values rise with the increase in temperature up to 65°C and then decrease due to both photodecomposition and thermal decomposition of the colourant (Fig. 1).

Dyeing at low temperature causes incomplete sorption of the colourant on fabric, whereas temperature above 65°C either causes breakdown of the colourant or destroys the efficiency of dye bath. When direct dyes are applied on cellulosic fibres, the amount of the dye taken up (the uptake of the dye) is considerably less than that in the cases when a salt such as sodium chloride or Glauber’s salt is also present in the dye bath. Therefore, the salt is called an exhausting agent.

When a cellulosic fibre is immersed in water, it acquires a negative electrical charge. As a result, the negatively charged fibre surface repels negatively charged dye ions present in the dye bath solution. When salts are added to dye bath, they try to neutralize or reduce the negative charge of fibre, thereby facilitating the approach of the dye anions into the range of hydrogen bond formation or of the formation of other bonds between the dye and the fibre.

For optimization of salt concentration, different concentrations of salts (Na₂SO₄ and NaCl) were used. Colour strength values indicate that the sodium chloride shows better results than sodium sulphate. It is shown in Fig.1 that the colour strength increases as the salt concentration increases to some extent then decreases with further increases in salt concentration. Hence, the optimum condition is found to be 3% NaCl.

A mordant can be defined as a polyvalent metal ion which forms coordination complexes with certain dyes. The chelate formed by a mordant dye and a metal is called a lake. After the optimization of extraction and dyeing conditions, the mordants copper sulphate and ferrous sulphate were applied. The colour was obtained from light brown to light green. Mordanting was done before and after dyeing the fabric.

In case of pre-mordanting with CuSO₄ at 65°C, the colour strength values increase with the increase in mordant concentration (Fig. 2). This is due to the more complex concentration gathered on the fabric which causes darker but dull shades with unevenness. Figure 2 shows that 4% CuSO₄ gives not only good colour strength but also excellent shade. This might be due to metal-dye chelate formation. Greater concentrations result in greater colour strength, but at 8% shade of mordant (CuSO₄), unevenness is observed. So, the optimized mordant concentration is 4% CuSO₄.

Post-mordanting is a process in which mordant is applied after completion of dyeing. Figure 2 shows no significant changes in shades of dyed fabrics by small increase in mordant concentration, but maximum colour strength is obtained, when maximum

![Fig. 2—Effect of pre-mordanting (a) and post-mordanting (b) with CuSO₄ and FeSO₄ on the colour strength of irradiated cotton fabric with methanolic extract of henna powder](image-url)
concentration of mordant is used. So, the optimized condition should be 8% CuSO₄. It is also clear from Fig. 2 that the colour strength increases as the concentration of mordant increases but at 8% concentration of FeSO₄, unevenness is observed. On the whole, the fabrics pre-treated with 4% copper sulphate give better results. So, in order to get good results pre mordanting with copper sulphate is significant rather than that of post-mordanting with copper sulphate.

It is revealed from Table 2 that UV radiation has improved the colour fastness properties from moderate to good if irradiated powder was used for dyeing. The cotton fabric dyed with irradiated extract might have more affinity towards fabric and more stability of colourant to light, rubbing and detergent used.

4 Conclusions
The role of UV radiation on the colour strength of fabrics dyed with the extracts of henna leaves and its colour fastness properties is found to be prominent.

4.1 The irradiated fabrics dyed with the extracts of irradiated henna powder shows better colour strength than that of non-irradiated fabric dyed with the extract of non-irradiated henna powder.

4.2 For obtaining better results by employing UV radiation, the optimum dyeing conditions are found to be 65°C temperature, 3% sodium chloride (exhausting agent), 120 min dyeing time and 4% copper sulphate (pre-mordant). Under these conditions not only good colour strength could be obtained, but also good colour fastness properties could also be observed.

4.3 The study shows that the UV radiation improves the colour fastness properties of the cotton fabric dyed with methanolic extract of henna leaves. The colour fastness of the fabric improves when methanolic extracts obtained from irradiated powder of henna leaves is applied onto irradiated cotton fabric under the optimized dyeing conditions.

4.4 In ordinary application of dyes under the influence of modern techniques such as UV radiation, the dyer can achieve better results (colour depth/strength and shades ) by the selection of plant material, the amount of dyestuff and the amount of mordant used.

Industrial Importance: The technique used in this study not only improves the colour strength but also enhances the colour fastness properties of the irradiated fabric dyed with extracts of irradiated powder.

Acknowledgement
The authors are thankful to Prof. Reda M Elshishtawy, National Textile Centre, Doki, Cairo, Egypt, and to Prof. M L Gulrajani, IIT-Delhi, India, for helpful discussion. The authors also express their sincere thanks to Mr. Mudassar Riaz, Dyeing Manager and Mr. Waqas, Manager QA/QC, MSC Textile (Pvt), for providing the Spectraflash spectrophotometer and Fastener tester for the evaluation of dyed samples.

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