Characterization of colour from some dye-yielding plants in Uganda

P. A. G. Wanyama¹,²*, B. T. Kiremire², P. Ogwok¹ and J. S. Murumu².

¹Department of Chemistry, Kyambogo University, Kampala, Uganda.
²Department of Chemistry, Makerere University, Kampala, Uganda.

Dyes from nine (9) selected dye-yielding plants namely Albizia coriaria (bark), Vitellaria paradoxa (bark), Curcuma longa Linn (roots), Indigofera arrecta (leaves), Syzygium cordatum (bark), Morinda lucida (bark), Morinda lucida (roots), Rubia cordifolia (roots), Mangifera indica (bark) and Justicia betonica (leaves), collected from Jinja, Kampala, Luweero, Mbarara, Mbale, Mukono, Pallisa, Arua and Wakiso districts of Uganda were evaluated for colour absorption and fastness on cotton fabrics. Colours were evaluated based on the CIELab colour order system. The highest and lowest values of chroma (C) were 68.34 in respect of C. longa Linn and 10.66 for J. betonica respectively. Spectral reflectance curves for the dyed fabrics were indicative of yellowish-green to red colour shades between 550 and 700 nm. J. betonica, however, reflected about 65% of violet-blue light between 410 to 495 nm. The colour co-ordinates in colour space diagram were found to lie in the yellow-red quadrant for R. cordifolia, M. lucida, S. cordatum, C. longa L, M. indica, V. paradoxa and A. coriaria; in the yellow-green quadrant for I. arrecta and M. lucida (roots) and in the red-blue quadrant for J. betonica. A. coriaria, V. paradoxa, M. lucida and S. cordatum had fairly good fastness ratings of 3 to 4. Lightness values varied from 58.57 for A. coriaria to 77.63 for I. arrecta. Results of this study demonstrate that dyes obtained from selected dye-yielding plants in Uganda can be good sources of natural dyes for the textile industry.

Key words: Plants, colour characterization, fastness, colour, lightness, chroma, Uganda.

INTRODUCTION

Plants contain natural colours ranging from yellow to black (Siva, 2007). The colour of dyed fabrics depends on the nature of the chromophores as well as the substituent functional groups, the auxochromes, of the dye molecular species (Padma, 2000; Siva, 2007). Chromophores and auxochromes are considered the most important chemical constituents of dyes responsible for textile colouration (Trotman, 1993; Foulds, 1995). Dye-yielding plants, unlike synthetic dyes, may contain more than one chemical constituent, each exhibiting a different colour and properties, operating singly or in combination with the different groups, depending on their chemical structure and composition (Siva, 2007; Bechtold et al., 2007; Samanta and Agarwal, 2009).

The fading of dyestuffs by light radiation is a major factor influencing the useful life span of dyed clothings (Kunio and Patricia, 2003). A high-quality coloured fabric possesses an acceptable amount of colour fastness rating of at least 3.0 on a five-point grey scale (Kadolph, 2005; Papita and Siddharta, 2008). Depth of colour on a fabric depends on absorption levels of dyes by the fibres and its distribution coefficient between the dyebath solution and the fibres (Kadolph, 2005). The amount of dye present on the substrate is therefore very critical in determining the fastness property (Guinot et al., 2006; Samanta et al., 2006).

Traditionally, plants were used for colouring silk, wool and cotton fibres but gradually were replaced by cheaper synthetic dyes (Anna and Christian, 2003). However, since the beginning of the 1990s, there has been a growing interest in the re-introduction of natural dyes and dye-yielding plants for textile application (Anna and Christian, 2003). The reasons for this new scientific interest in natural dyes are based on the growing awareness to find sustainable and non-toxic alternatives.

*Corresponding author. E-mail: aaronwanyama@gmail.com. Tel: +256779 520 747. Fax: 0414 288492
to synthetic dyes, a growing market for naturally dyed textiles and the search for additional, economically viable alternative crops for farmers (Anna and Christian, 2003; Bhuyan and Saikia, 2005). Recently, over 40 plants with potential of yielding dyes of good characteristics for application in the textile industry were identified in Uganda (Wanyama, 2010). In this paper we report results on characterization of the colour produced from nine selected dye-yielding plants for textile colouration.

**MATERIALS AND METHODS**

**Plant materials and fabrics**

Fresh plant materials were collected from Mukono, Wakiso, Kampala, Luweero, Arua, Jinja, Mbale, Pallisa and Mbarara districts of Uganda between 2004 and 2008. The plant parts were cut into small pieces, spread on clean polythene material and left to dry in open air. The dried samples were ground to powder using a metallic mortar and pestle and kept in sealed plastic containers. The fabrics made of scoured and bleached 100% cotton fabric (plain weave, 23 × 24/cm, 27 g/m², 0.01 mm thickness) were purchased from a local trader in Kampala.

**Extraction of colour components**

Dried and pulverized plant parts (10 g each) of Albizia coriaria (bark), Vitellaria paradoxa (bark), Curcuma longa Linn (roots), Indigofera arrecta (leaves), Morinda lucida (bark and roots), Rubia cordifolia (roots), Justicia betonica (leaves), Syzygium cordatum (bark) and Mangifera indica (bark) were soaked in distilled water (400 ml beaker) for four hours. The soaked plant materials were heated at 60°C for 30 min and temperature gradually raised to between 85 and 90°C and then maintained at the boiling temperature (90°C) for one hour to yield a dye extract. The dye extract was left to stand for 30 min at ambient temperature and then filtered. The coloured crude dye solution (150 ml) was diluted with distilled water (50 ml) and immediately used for dying.

**Dyeing of cotton fabrics**

Cotton fabrics were dyed by a simultaneous mordanting method as described by Katy (1997). Fabrics (8 × 10 cm) weighing approximately 1.41 g were dyed in a beaker (250 ml) containing 10% on weight of fabric (o.w.f) of alum (potassium aluminium sulphate) mordant and 20% o.w.f of sodium sulphate. The pH of each dye solution was maintained between 6.5 and 7.5 with 2 - 5% w/w of acetic acid (40% solution) monitored by test papers during the dyeing process. A material to liquor ratio (LR) of 1:200 was used in all dyings.

**Colour measurements and analysis**

Colour development and dye absorption potential of cotton fabrics were evaluated in terms of CIELab colour coordinates; L (lightness), a (redness or greenness of colour), b (yellowness or blueness of colour), C (chroma) and H (hue angle), and K/S (colour strength) values as described by Sule (1997). The L, a, b, C and H colour values were determined using a Datacolour Spectrastash (SF) 600 double beam reflectance spectrophotometer, interfaced to a digital PC under illuminant D65 with a 10° standard observer with o/d (illumination/viewing) geometry. The largest aperture of 30 mm was used for colour measurements, with the UV component and specular reflection component included. Dyed fabrics were folded to form four layers and an average of two duplicate readings was taken. A plot of a and b coordinate values in a colour space diagram was done for each of the dyed fabrics, thus defining precisely the colour of each dyed specimen by the L, a and b values, specified according to Sule (1997) and Shah (1998).

**Colour fastness to light**

The fastness test was carried out according to International Standards Organization (ISO) test methods. The British Standard (BS) 1006 (1978) test was used (Trotman, 1993). Dyed cotton fabrics were subjected to daylight exposure, alongside standard dyed wool controls of light fastness in the range of 1 to 8 for a minimum of 6 hours per day for 30 days until sufficient fading occurred. Half of each coloured specimen and standard sample was covered with a piece of cardboard during the exposure. Colour change was evaluated by comparison between dyed fabrics with the standard blue scale woolen samples used for this test. The change in colour between the exposed and covered parts of the test specimen was compared with that for the standard sample. The fastness rating of the standard sample showing the same change as the test specimen was the light fastness grade of the fabric.

**Colour fastness to washing**

Dyed fabrics were tested for washing fastness according to the method described by Foulds (1995), using the relevant grey scale. A dyed piece of fabric to be tested (5 × 5 cm) was placed between two pieces of undyed cotton fabrics of similar dimensions and stitched round the edges. The composite specimen was treated in a beaker (100 ml), containing a solution of detergent (5 g/l), at 40°C for 30 min. Sufficient quantity of soap solution was used to give a liquor ratio of 50:1.

**Colour fastness to rubbing**

Dyed fabrics were tested for rubbing fastness according to the BS 1006 No. X12: 1978 standards method as described by Trotman (1993). Dry and wet rubbing fastness properties were determined using a manual crockmeter (James H. Heal and Co Ltd, United Kingdom). In the dry-rubbing test, the finger covered with the bleached fabric was moved back and forth along a track of 10 cm long on the dry fabric for 20 times making ten complete turns of the crank at the rate of about one turn per second. In the wet-rubbing test, the same procedure was used, with a fresh dry specimen and undyed cloth which had been wetted with distilled water and squeezed between two sheets of filter paper. Staining of bleached white cotton fabric by dyed fabrics was assessed with standard grey scale obtained from Equiptex Co. Ltd, Bronte Works, Bradford, United Kingdom.

**Colour absorption and reflectance measurements**

Reflectance values were measured at 10 nm intervals between 400 and 700 nm, the range commonly covered in textile applications (Sule, 1997) and from these values, the corresponding K/S (colour concentration absorption) values were calculated. Plots of reflectance values against wavelength were made for the coloured fabric samples resulting into spectral reflectance curves, a fingerprint record of reflectance characteristics of the natural dyes in this study.
Table 1. The CIELab colour coordinates of cotton fabrics dyed with crude dye extracts from selected dye-yielding plants in Uganda.

<table>
<thead>
<tr>
<th>Selected dye-yielding plants</th>
<th>L</th>
<th>a</th>
<th>b</th>
<th>C</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albizia coriaria</td>
<td>58.57</td>
<td>13.26</td>
<td>21.28</td>
<td>25.70</td>
<td>58.08</td>
</tr>
<tr>
<td>Morinda lucida (root)</td>
<td>76.24</td>
<td>-0.77</td>
<td>37.52</td>
<td>37.52</td>
<td>91.17</td>
</tr>
<tr>
<td>Morinda lucida (bark)</td>
<td>69.05</td>
<td>3.35</td>
<td>37.92</td>
<td>38.07</td>
<td>84.96</td>
</tr>
<tr>
<td>Syzygium cordatum</td>
<td>60.13</td>
<td>8.29</td>
<td>14.72</td>
<td>16.89</td>
<td>60.02</td>
</tr>
<tr>
<td>Justicia betonica</td>
<td>67.80</td>
<td>8.10</td>
<td>-6.94</td>
<td>10.66</td>
<td>319.42</td>
</tr>
<tr>
<td>Rubia cordifolia</td>
<td>76.45</td>
<td>20.74</td>
<td>4.39</td>
<td>21.20</td>
<td>11.97</td>
</tr>
<tr>
<td>Curcuma longa L.</td>
<td>74.68</td>
<td>10.18</td>
<td>67.58</td>
<td>68.34</td>
<td>81.43</td>
</tr>
<tr>
<td>Mangifera indica</td>
<td>69.80</td>
<td>3.37</td>
<td>30.85</td>
<td>31.03</td>
<td>83.76</td>
</tr>
<tr>
<td>Vitellaria paradoxa</td>
<td>59.43</td>
<td>13.27</td>
<td>19.16</td>
<td>23.31</td>
<td>55.31</td>
</tr>
<tr>
<td>Indigofera arrecta</td>
<td>77.63</td>
<td>-2.86</td>
<td>20.04</td>
<td>20.24</td>
<td>98.13</td>
</tr>
</tbody>
</table>

L = lightness; a = red - green coordinate; b = yellow - blue coordinate, C = chroma; H = hue angle.

The colour absorption values (K/S) of the dyed cotton fabrics were evaluated by light reflectance measurements using the Data colour SF600 double beam spectral reflectance spectrophotometer. The (K/S) values were calculated from reflectance values using the Kubelka-Munk equation, K/S = (1 - R)^2/R, where R is the surface reflectance at wavelength of maximum absorption, , K is the coefficient of absorption and S is the coefficient of scatter (Ratanaphol and Tharapong, 2007, Changyong and Jae-Woon, 2006).

RESULTS AND DISCUSSION

Dyes from I. arrecta, C. longa L., M. lucida (roots) and R. cordifolia produced the lightest (L > 70) shades. Materials dyed with crude natural extracts from M. indica and M. lucida (bark) had L values of 69.80 and 69.05, respectively. Dye extracts from S. cordatum, A. coriaria and V. paradoxa produced medium dark brown colours characterized by L values of 60.13, 58.57 and 59.43 respectively (Table 1). Yellow and orange shades were developed by M. lucida, C. longa L and M. indica plant species (Table1).

Yellow shade from C. longa L. exhibited the highest degree of colour saturation on cotton fabric with the highest C value of 68.34. The net effect of its high value of chroma and lightness is reflected in its high brilliance appearance. The bluish–violet shade from J. betonica exhibited the lowest degree of saturation with a low value of C (10.66). It was also characterized by the highest value of hue angle H (319.42) while Rubia cordifolia had the lowest value of H (11.97). M. lucida, with “a” value of -0.77 and I. arrecta, with “a” value of -2.86 presented the only negative values (Table 1). J. betonica, had a negative “b” value of -6.94 (Blueish) and a positive value of “a” of 8.10 (redness). The two different values of “a” and “b” placed the dyed fabric with J. betonica extract in the blue-red quadrant of the colour space diagram. C. longa L. gave the highest “b” value (67.58) (yellowness) and R. cordifolia gave the lowest “b” value of 4.39. R. cordifolia species, on the other hand, gave the highest value “a” of (20.74) (redness) followed by V. paradoxa (13.27) and A. coriaria (13.26) (Table 1).

The values of “b” (yellowness-greenness) were greater than those of “a” (yellowness-redness) in dyed fabrics using A. coriaria, M. lucida, S. cordatum, C. longa L., M. indica, V. paradoxa and I. arrecta extracts, indicating that the shades were more yellowish than red in appearance. Values of “a” and “b” were generally low for all colours in this study. Hue (H) angles lay between 55.31 and 98.13 for all plants except for R. cordifolia (11.97) and J. betonica (319.42). This implies that the shades for the majority of the dye-yielding plants were closer to yellow than red. These are represented by sample codes A,B,J,H and G in the colour space diagram as indicated in Figure 1. Shades from M. lucida with H values of 91.17 and 84.96 for root and bark extracts, respectively, C. longa L. with H value (81.43) and M. indica with value of H (83.76) were more yellowish compared to those from A. coriaria, S. cordatum, V. paradoxa and I. arrecta plant species on the basis of the value of b. The hue angle (H = 319.42) perceived from dyed cotton fabrics with crude extract from J. betonica was bluish-violet based on the values of a (8.10) and b (-6.94) (Table 1). The shade developed from J. betonica appeared more red than blue on account of the value of “a” being less than that of “b”.

Good fastness to light of grade four was observed in crude dye extracted from the bark of A. coriaria, the roots of M. lucida, the bark of S. cordatum and the bark of V. paradoxa. The crude dye extracts from C. longa L., I. arrecta, R. cordifolia and M. indica gave poor light fastness on cotton fabrics with the rating of less than three in terms of colour change (Table 2). None of the dyes tested had a fastness greater than four of the standard dyed wool controls of light fastness 1 to 8, respectively. Poor light fastness can partly be attributed to the level of dyeing bath ratio and weak interaction between dye and textile material. All the yellow-orange dyed fabrics had poor light fastness rating of less than
two (Table 2). Notably, the presence of alum mordant did not improve the light fastness of the yellow-orange dyes making them less stable under the influence of light radiation (Patricia, 1982). The amount of dye present in the cotton fabric is critical for determining the light fastness property of dyes (Guinot et al., 2006). Light fastness characteristics of dyes is influenced by the mordanting method and fibres used (Samanta and Agarwal, 2009). In addition, light fastness depends on the chemical structure of dye molecule and the nature of the dye-yielding plant (Anna and Christina, 2003; Bechtold et al., 2007; Siva, 2007). Various tests of light fastness of natural plant based dyes have shown that the majority have a maximum rating of four (4) (Tim and Sheila, 1966;
Table 3. Rubbing fastness of selected dye-yielding plants in Uganda.

<table>
<thead>
<tr>
<th>Local plant name</th>
<th>Botanical name</th>
<th>Plant part used</th>
<th>Rubbing fastness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muga</td>
<td>Albizia coriaria</td>
<td>Bark</td>
<td>4-5</td>
</tr>
<tr>
<td>Mubajansali</td>
<td>Morinda lucida</td>
<td>roots</td>
<td>5</td>
</tr>
<tr>
<td>Mugavu</td>
<td>Morinda lucida</td>
<td>Bark</td>
<td>4-5</td>
</tr>
<tr>
<td>Nakunguli</td>
<td>Vitellaria paradoxa</td>
<td>Bark</td>
<td>4-5</td>
</tr>
<tr>
<td>Muzukizi</td>
<td>Justicia betonica</td>
<td>leaves</td>
<td>4-5</td>
</tr>
<tr>
<td>Kasalabakesi</td>
<td>Rubia cordifolia</td>
<td>roots</td>
<td>4-5</td>
</tr>
<tr>
<td>Omusoroza</td>
<td>Indigofera arrecta</td>
<td>leaves</td>
<td>4-5</td>
</tr>
<tr>
<td>Kanzironziro</td>
<td>Syzygium cordatum</td>
<td>bark</td>
<td>3-4</td>
</tr>
<tr>
<td>Mayembe</td>
<td>Mangifera indica</td>
<td>bark</td>
<td>3-4</td>
</tr>
<tr>
<td>Binzaali</td>
<td>Curcuma longa L.</td>
<td>roots</td>
<td>4-5</td>
</tr>
</tbody>
</table>

Patricia, 1982; Kunio and Patricia, 2003; Patricia, 1987). Results of this study therefore conform to the minimum performance requirements for application in textile industry (Kadolph, 2005).

*A. coriaria, V. paradoxa and S. cordatum* showed a rating to washing fastness of four. The yellow-orange shades of *M. lucida, C. longa L. and I. arrecta*, showed significant alteration in colour after washing. Dyes from these plants therefore have poor washing characteristics and are likely to be easily washed out of the dyed textile material. This could be resulting from lack of strong metal coordination complexes formed inside the internal fibre structure between the mordant and dye fibres (Deo and Roshan, 2004; Jothi, 2008). However, there was no significant staining observed on the adjacent undyed cotton fabrics. Washing developed the true fastness properties and colour of the natural dyes in this study.

Dry and wet rubbing fastness ratings observed in *A. coriaria, V. paradoxa, M. lucida* (root and bark), *J. betonica, R. cordifolia* and *I. arrecta* crude extracts were good with ratings above four (Table 3). On the contrary, wet rubbing fastness ratings for crude dye extracts of *M. indica* and *C. longa L.* were below four (Table 3). Good rubbing fastness indicates that there are no unfixed dyes left on the fibre surface after soaping and washing. Dyes from plants with good fastness penetrate well into the amorphous regions of the fibres, associated with ionic interactions or hydrogen bonding or by complexation with mordant or with functional groups of dyes (Anna and Christian, 2003).

Colour absorption values (K/S) for all the crude dye extracts showed a gradual decrease with increase in wavelength from the violet to the red end (450 to 700 nm) of the visible spectrum (Figure 3). The highest colour absorptions were obtained with *Mangifera indica* bark extract followed by *Morinda lucida* bark extract using potassium aluminium sulphate (alum) as mordant. The reflectance values between 550 to 700 nm and with values of H < 70 indicated the colour of the dyed fabric samples being orange to red in the case of *A. coriaria, S. cordatum, V. paradoxa and R. cordifolia*. The strong coordination tendency and interaction between alum and *M. indica* could have been responsible for the high dye uptake between 400 and 450 nm (Figure 3) represented by curve H. The main spectral colour for *J. betonica* occupied the wavelength bands between 450 for violet and 480 for blue (Figure 2). The same was observed for *R. cordifolia* but with higher spectral reflectance values.

Reflectance resulted in characteristic mixture of yellowish to reddish colours of dyed fabrics. Light reflected from *C. longa L.* had more than 50% spectral colours occupying the yellow to red wavelength bands. This was also observed in the spectral reflectance curves for *I. arrecta, M. indica, V. paradoxa, A. coriaria and S. cordatum* whose spectral reflectance values (between 550 to 700 nm) indicate colours of dyed fabrics to be yellowish-orange to red in hue and occupy over 65% of the yellow-red wavelength bands (Figure 3).

**Conclusion**

*A. coriaria, M. lucida, S. cordatum, V. paradoxa and M. indica* are good sources of natural dyes. Dyes from these plants exhibited good colour absorption on cotton fabrics and met the minimum performance standards for colour fastness to light, washing and rubbing. The above test results have strongly indicated that the Dyes from selected plants in Uganda have a great potential in textile colouration.

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Reflectance curves with alum used as mordant

Figure 2. Spectral reflectance curves of cotton fabrics dyed with crude dyes extracted from selected dye-yielding plants. Curves indicated by A, B, C, D, E, F, G, H, I and J sample codes are values measured for *M. lucida* (roots) (A), *M. lucida* (bark) (B), *S. cordatum* (C), *J. betonica* (D), *R. cordifolia* (E), *A. coriaria* (F), *C. longa* L (G), *M. indica* (H), *V. paradoxa* (I) and *I. arrecta* (J) dye-yielding plants.

K/S Values with alum used as mordant

Figure 3. K/S values obtained from selected dye-yielding plants. K/S values indicated by A, B, C, D, E, F, G, H, I, J sample codes for *M. lucida* (roots). (A), *M. lucida* (bark) (B), *S. cordatum* (C), *J. betonica* (D), *R. cordifolia* (E), *A. coriaria* (F), *C. longa* L (G), *M. indica* (H), *V. paradoxa* (I) and *I. arrecta* (J) selected dye-yielding plants.

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