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Volume 4, Issue 6, June – 2019 International Journal of Innovative Science and Research Technology

ISSN No:-2456-2165

Dyeing Cotton with Natural Dye Extracted from *Syzygium cordatum* Bark

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Abstract:- The growing awareness of environmental issues and damage has generated renewed interest in the use of eco-friendly natural dyes for natural fibres such as cotton. With that in mind, the dyeing of cotton fabrics with *Syzygium cordatum* natural dye using two organic electrolytes as mordants was investigated. Dyeing was carried out by either pre-mordanting, post mordanting or simultaneous mordanting. A reddish brown colour was obtained from the plant and it showed good colourfastness to washing rubbing and perspiration.

***Keywords*:-** *Natural dyes, Syzygium cordatum, Colourfastness.*

I. INTRODUCTION

With the ever increasing interest in "green" (i.e. ecofriendly) products, low carbon- footprint and environmentally friendly consumerism, there is an increasing interest in natural environmentally friendly products, including natural dyes (Kaldoph, 2008; Dayal, 2006), research on dyeing shifting from synthetic to natural dyes extracted from plant and animal sources that are renewable and sustainable (Kulkarni *et al.*, 2011:135). The use of natural dyes is of utmost importance, as they are generally eco-friendly, non-allergic and harmonized with nature (Prabhu and Bhute, 2012; Patel, 2011; Kumar and Barati, 1998). Natural dyes can offer almost all colours, and produce shades that are soft, lustrous, soothing to the eye, and their preparation involves very little potential for harmful chemical reactions. They are not harmful to health, and reportedly even have curative effects. (Prabhu and Bhute, 2012) Also, the use of natural dyes does not cause problems with regard to disposal of the product (Patel, 2011). Although a fair amount of research has been undertaken on natural dyes and their sources, only a few sources have been used on a commercial scale due to various factors such as the complexity of the dyeing process, lack of appropriate technologies and standardized procedures as well as reproducibility of shades, limited shades, and inadequate fastness properties (Rai *et al.*, 2010; Kulkarni *et al.*, 2011).

In exploring potential sources of natural dyes, the *Syzygium cordatum* plant was selected as a dye source due to its availability in Swaziland and given its current usage by handcrafters in making attractive wall hanging cotton motifs which are particular sought after by tourists. Although this plant is widely used by the "Tie dye" women in Swaziland, the dye application condition (recipes and procedures) is not standardized to produce the same colour shades within and between dye batches. Colour fastness is also a challenge with cotton products which reduces dyed products lover's aesthetic appeal and serviceability within a short period successfully. Addressing the above concerns will be of great benefit particularly to SMEs in the handicraft sector.

Optimization of the dye extraction process was described in an earlier paper by Gamedze *et al.* (2018). The objectives of the present study were to: optimize the dyeing of cotton fabric using dye extracted from *Syzygium cordatum* derived from the above study. With this in mind, the effectiveness of organic electrolyte mordanting in improving dye fixation, colour fastness and yield as well as its effect of organic electrolyte mordanting on fabric physical properties were investigated.

II. MATERIALS AND METHODS

A. Material

Two organic electrolytes namely N, N-dimethylformamide (DMF) and trisodium nitrilo triacetate (trisodium NTA) were used, each at three different concentrations namely 1, 2 and 3 grams of electrolyte per Litre of dye liquor and temperatures namely 50, 60 and 70^{0}c.

Bleached plain weave 100% cotton fabric (poplin) was used as the substrate. The bark of *Syzygium cordatum* was collected for the extraction of dye. Analytical reagents used were: Methanol, Sodium carbonate (Na_2Co_3), ECE formulation non-phosphate reference detergent, and Tannic acid.

B. Methods

Dye was extracted under optimized conditions as described previously by Gamedze *et al.* (2018). As pre-treatment, cotton fabric was scoured for 4 hours in a boiling solution, containing 5 g/L of sodium carbonate and 3 g/L of non-ionic detergent, after which the fabric was thoroughly rinsed in distilled water and dried at room temperature.

Scouring was done to remove sizing and other impurities which could adversely affect dye uptake.

A primary mordant with tannin was done on the cotton fabric, as they do not have an affinity for metallic mordants. Once treated with tannins, cotton can readily absorb all types of metallic mordants. However, it does not change the colour of the fabric and can be used for pale and brighter colours. The fabric was immersed in a 4 % (o.w.f) solution of tannic acid in water for at least 4-5 hours, then squeezed and dried at room temperature (Srivasta *et al.*, 2008).

Part of the primary treated fabric was dyed in the absence of a mordant as a control using a liquor ratio of 1:20. For the control dyeing was carried out in stainless canister in the Rotary dyeing machine, Model M2288, equipped with a programmable control of treatment temperature and time. Dyeing was done at 60°C and dyeing continued for 1 hour, according to the procedure by Kumaresan *et al.* (2013). For the actual dye optimization trials, the treated fabric was dyed applying organic electrolyte in three different ways namely, pre-mordant, simultaneous mordant and post mordant as illustrated in figures 1, 2 and 3.

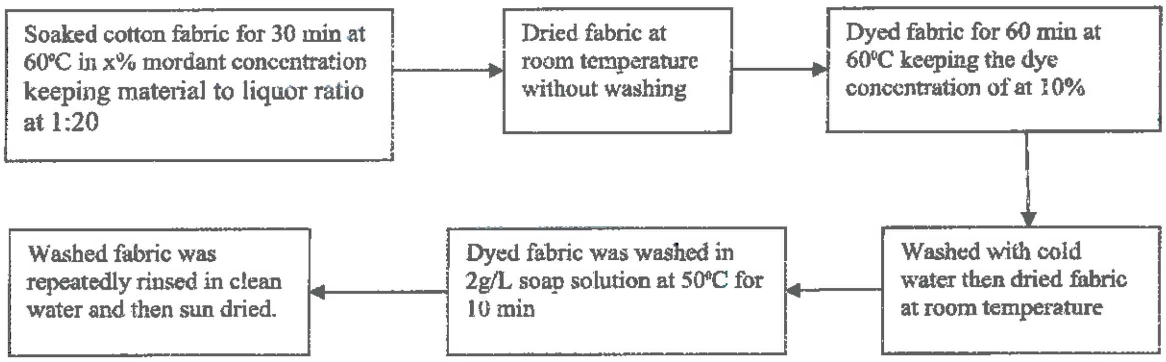

Fig 2:- Pre-mordanting

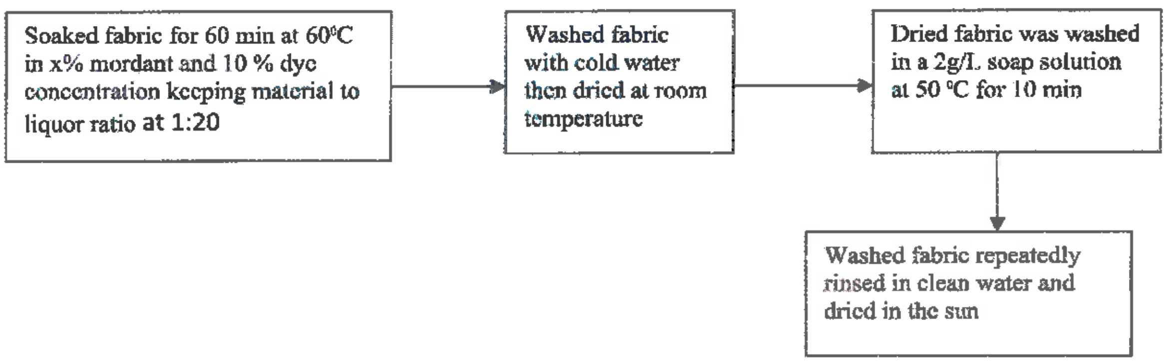

Fig 3:- Simultaneous mordanting

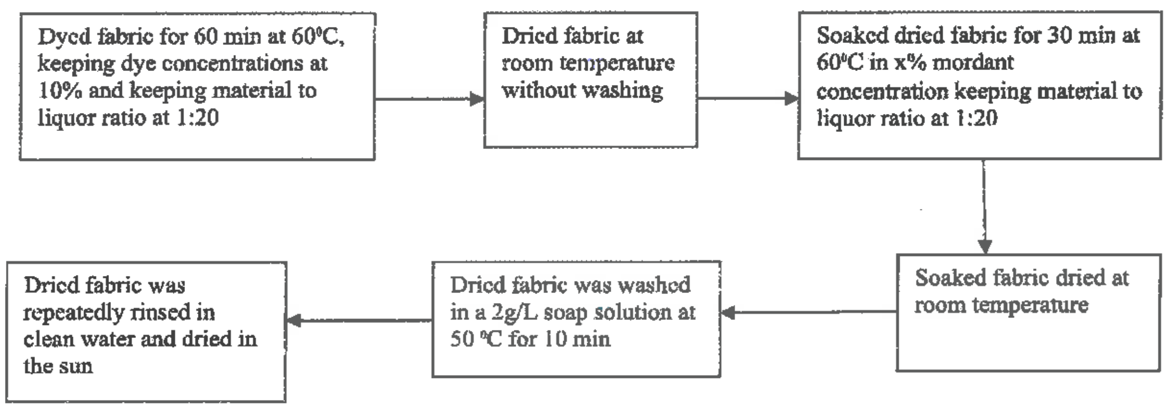

Fig 4:- Post-mordanting

ISSN No:-2456-2165

III. TESTING

A. Colour strength

The reflectance spectra of each dyed fabric was measured by means of a Data Colour 600 Spectrophotometer and Data Colour tool version 20.0, under illuminant D_{65} with a 10^0 standard observer, with the tannic pre-treated undyed fabric used as reference. The reflectance and colour strength (K/S) values were determined for each fabric. The colour strength (K/S value), assessed in triplicate, was calculated, using the Kubelka-Munk equation:

$K/S = (1-R)^2 / 2R,$

Where K is the sorption coefficient, R is the reflectance of the dyed fabric and S is the scattering coefficient.

B. Dye exhaustion

The dye exhaustion % was determined by measuring the absorbance at 650 nm and 700 nm of the dye solution, both before and after dyeing, using Boeco Model S-22 UV-VIS range spectrophotometer. The measurements were in triplicate and the dye exhaustion was calculated as follows:

Dye exhaustion % = $[AO-A_r/AO] \times 100$,
Where AO - is the absorbance before dyeing,
And A_r - is the absorbance after dyeing.

C. Colour fastness to perspiration

Colour fastness to perspiration using, both alkaline and acid, was tested, three times, according to ISO 105-E04, using the grey scales for colour change, with a grade rating of 5 signifying negligible change, and 1 indicating maximum change. The colour change grades for each fibre type of the multifibre test sample were also assessed to provide a measure of staining.

D. Colour fastness to washing

Colour fastness to washing was measured, in triplicate according to ISO 105 C06, evaluation being done using the grey scale, as per ISO-05-A02 for change of shade depth, and ISO-05-A03 for staining, a rating of 5 once again signifying negligible change and 1 indicating maximum change.

E. Colour fastness to crocking

Colour fastness to wet and dry crocking was measured on each test sample, using a manually operated James Heal Crockmaster; visual assessment being according to the AATCC test method 8- 1996, using the grey scales for staining, a rating of 5 signifying negligible change, and 1 indicating maximum change.

F. Fabric tensile strength

For fabric tensile strength a Shumadzu AGX tensile testing machine was used to measure the breaking strength of the fabrics in accordance with ASTM D5035- 95 test standard. In each case, three test specimens were measured for strength, each being obtained from an area of the fabric not represented by the same warp or weft yarns as the other specimen.

IV. RESULTS AND DISCUSSION

A. Effect of the mordanting method, type and level on colour strength (K/S)

The fabric dyed with the dye extract exhibited a light reddish brown to clay brown colour. **Table 1** shows that the highest K/S value, of 6.4, was obtained at 3g/L concentration of trisodium NTA in both simultaneous- and pre-mordanting. In post-mordanting, lower K/S values were generally obtained, irrespective of the mordant used. This is in agreement with the results obtained by Naz *et al.* (2010), who also observed lower colour strength values under post-mordanting conditions, which they associated with the accumulation of the metal dye complex, in the form of clusters. Increasing the mordant concentration increased the dye uptake, resulting in an increase in the K/S values of the dyed fabric. Table 1 shows that the K/S values of the trisodium NTA mordanted dyed samples were consistently higher than those of the dimethylformamide mordanted samples, indicating improved dye uptake by the fabric. There were statistically significant differences between mordant techniques and mordant concentrations.

An even dyeing and uniform colour was observed on the dyed fabric indicating that the methanolic extract used, was appropriate for extraction. The methanol component used in the extraction caused most of the dye extract to dissolve in the liquid, resulting in maximum colour absorption of colourant by the fabric. It also follows from the fact that the *Syzygium cordatum* bark contains colouring material, such as tannins and polyphenols, which are more soluble in a solvent, such as methanol, than in water (Srivastava *et al.*, 2008).

Mordanting Method	Mordant type and concentration	K/S	Mordant type and concentration	K/S
Unmordanted control		2.7a		2.7a
Simultaneous- mordanting	Trisodium NTA 1%	4.8b	Dimethyl Formamide 1%	4.2b
	Trisodium NTA 2%	5.0c	Dimethyl Formamide 2%	4.3b
	Trisodium NTA 3%	6.4d	Dimethyl Formamide 3%	4.5b
Pre-mordanting	Trisodium NTA 1%	4.3b	Dimethyl Formamide 1%	4.2b
	Trisodium NTA 2%	5.0c	Dimethyl Formamide 2%	4.3b
	Trisodium NTA 3%	6.4d	Dimethyl Formamide 3%	4.5b
Post-mordanting	Trisodium NTA 1%	4.1b	Dimethyl Formamide 1%	2.8a
	Trisodium NTA 2%	4.5b	Dimethyl Formamide 2%	2.9a
	Trisodium NTA 3%	5.2c	Dimethyl Formamide 3%	3.1a

Table 1:- K/S values of fabric dyed using different methods, types and concentration of mordant
Means followed by the same letter are not statistically different at $P < 0.05$.

B. Effect of mordanting method, type and level on dyed fabric colour

➢ *Effect on L**

Table 2 shows that when a mordant was introduced in the dye bath, a decrease in L* (lightness) was observed, for 3g/L concentration of trisodium NTA in both for simultaneous and pre-mordanting being lowest (61.7). For pre-mordanting the 2g/L and 3g/L concentrations of trisodium NTA were significantly different from the rest. A lower L* can be attributed to the mordant-dye complex formation within the fabric resulting in a deeper colour. With dimethylformamide as a mordant, a high L* value (77.0) was observed in post-mordanting when using 1g/L. The results obtained here agree with those of Vinod *et al.* (2010), for treatment with tannic acid and alum mordants.

Mordanting method	Mordant type and concentration	L*	Mordant type and concentration	L*
Unmordanted control		77.1 i		77.1g
Simultaneous- mordanting	Trisodium NTA 1%	62.9d	Dimethyl Formamide 1%	70.0c
	Trisodium NTA 2%	62.4c	Dimethyl Formamide 2%	70.0c
	Trisodium NTA 3%	62.0b	Dimethyl Formamide 3%	69.7b
Pre-mordanting	Trisodium NTA 1%	63.1e	Dimethyl Formamide 1%	70. 7d
	Trisodium NTA 2%	61.9a	Dimethyl Formamide 2%	70.0c
	Trisodium NTA 3%	61.7a	Dimethyl Formamide 3%	69.1a
Post-mordanting	Trisodium NTA 1%	71.3h	Dimethyl Formamide 1%	77.0g
	Trisodium NTA 2%	70.7g	Dimethyl Formamide 2%	76.8f
	Trisodium NTA 3%	69.9f	Dimethyl Formamide 3%	76.3e

Table 2:- Effect of mordant type, concentration and method of application on L* values
Means followed by the same letter are not statistically different at $P < 0.05$. Mean separation by LSD

➢ *Effect on a**

Different mordant, mordant type and concentration produced significant differences in the a* values (Table 3). A 3 % concentration of trisodium NTA, as a pre-mordant, produced the highest a* (12.1) this being significantly higher than the others. An increase in mordant concentration generally resulted in an increase in a*, indicative of a shift towards the red colour, along the red- green axis quadrant of the colour-space diagram. Once again, the trisodium NTA mordant had a significantly greater effect than the dimethylformamide mordant. There were significant differences in mordant techniques and mordant concentrations. With dimethylfomamide when using post-mordanting, it produced a* values lower than cotton fabric which was unmordanted. This means that adding the dimethylformamide mordant first to the fabric had an effect of lowering the dye-bond in the dyeing process.

ISSN No:-2456-2165

Mordanting method	Mordant type and concentration	a*	Mordant type and concentration	a*
Unmordanted control		8.1a		8.1b
Simultaneous	Trisodium NTA 1%	11.3e	Dimethyl Formamide 1%	9.8e
	Trisodium NTA 2%	11.7g	Dimethyl Formamide 2%	9.6d
	Trisodium NTA 3%	11.9h	Dimethyl Formamide 3%	9.8f
Pre-mordanting	Trisodium NTA 1%	11.6f	Dimethyl Formamide 1%	9.3c
	Trisodium NTA 2%	12.0i	Dimethyl Formamide 2%	9.8f
	Trisodium NTA 3%	12.1j	Dimethyl Formamide 3%	10.2g
Post-mordanting	Trisodium NTA 1%	10.3d	Dimethyl Formamide 1%	7.8a
	Trisodium NTA 2%	9.7b	Dimethyl Formamide 2%	8.0b
	Trisodium NTA 3%	9.8c	Dimethyl Formamide 3%	8.0b

Table 3:- Effect of mordant type, concentration and method of application on a* values
Means followed by the same letter are not statistically different at P< 0.05.

➢ *Effect on b**

Mordanting type, concentration and method of application, all had a significant effect on the b* values as can be seen from Table 4. Simultaneous and pre-mordanting in trisodium NTA produced similar b* values, which were higher than those obtained with post-mordanting. Also with the dimethylformamide mordant, similar values of (.8 were observed in simultaneous and pre-mordanting. In virtually all cases, an increase in mordant concentration produced an increase in b*value, with the highest values being obtained with 3% trisodium NTA. An increase in b* value indicates a colour shift towards yellow, along the yellow- blue axis quadrant of the colour-space diagram. Kechi *et al.* (2013) observed similar trends in b* values with the application of alum and iron mordants.

C. Dye exhaustion

Dye exhaustion (%) was based upon the dye liquor absorbance values. Table 5 shows that the highest dye exhaustion of 23.6 % was achieved by pre-mordanting with 3g/L trisodium NTA, and the lowest (7.6) by post-mordanting with 1g/L dimethylformamide. It is also apparent; from Table 5 that dye exhaustion increased with an increase in mordant concentration and was always higher for the trisodium NTA mordant than for the dimethylformamide mordant. Furthermore, pre-mordanting generally produced the highest dye exhaustion, followed by simultaneous-mordanting with trisodium NTA being superior to dimethyl formamide. Kathri *et al.* (2012) obtained reactive dye exhaustion levels, ranging from 36% up to 60%, using higher percentage of trisodium NTA and dimethyl formamide. The relatively low dye exhaustion observed in the present study was attributed to the low concentrations of trisodium NTA which did not provide sufficient alkaline pH conditions and that dimethylformamide was used as a mordant and not as an exhaustion agent, as was the case in the study by Kathri *et al.* (2012). The relatively low levels (maximum 3g/l) of mordant used in the present study were selected because of environmental considerations.

Mordanting method	Mordant type and concentration	b*	Mordant type and concentration	b*
Unmordanted control		7.9a		7.9a
Simultaneous	Trisodium NTA 1%	17.9d	Dimethyl Formamide 1%	13.6d
	Trisodium NTA 2%	18.8e	Dimethyl Formamide 2%	13.7d
	Trisodium NTA 3%	20.0g	Dimethyl Formamide 3%	13.8d
Pre-mordanting	Trisodium NTA 1%	17.1c	Dimethyl Formamide 1%	14.3e
	Trisodium NTA 2%	19.4f	Dimethyl Formamide 2%	14.3e
	Trisodium NTA 3%	19.1f	Dimethyl Formamide 3%	15.8f
Post-mordanting	Trisodium NTA 1%	14.3b	Dimethyl Formamide 1%	8.0a
	Trisodium NTA 2%	14.0b	Dimethyl Formamide 2%	8.5b
	Trisodium NTA 3%	14.5b	Dimethyl Formamide 3%	9.1c

Table 4:- Effect of mordant type, concentration and method of application on b* values
Means followed by the same letter are not statistically different at P< 0.05.

Mordanting Method	Mordant type and concentration	Exhaustion %	Mordant type and concentration	Exhaustion %
Unmordanted control		7.61a		7.61a
Simultaneous	Trisodium NTA 1%	16.55c	Dimethyl Formamide 1%	11.69c
	Trisodium NTA 2%	18.97c	Dimethyl Formamide 2%	11.77c
	Trisodium NTA 3%	20.02d	Dimethyl Formamide 3%	12.35d
Pre-mordanting	Trisodium NTA 1%	14.97b	Dimethyl Formamide 1%	11.81c
	Trisodium NTA 2%	17.07b	Dimethyl Formamide 2%	11.837c
	Trisodium NTA 3%	23.56e	Dimethyl Formamide 3%	12.200d
Post-mordanting	Trisodium NTA 1%	8.66a	Dimethyl Formamide 1%	7.61a
	Trisodium NTA 2%	10.21a	Dimethyl Formamide 2%	7.87a
	Trisodium NTA 3%	12.29b	Dimethyl Formamide 3%	8.14b

Table 5:- Effect of mordant type, concentration and method of application on dye exhaustion (%)Means followed by the same letter are not statistically different at P< 0.05.

D. Effect of mordanting, type, method and level on dye colour fastness to perspiration

➢ *Staining resistance*

Using trisodium NTA as a mordant and of the three methods of mordanting, in both the acid and alkaline perspiration fastness tests, was consistently better than the commercially acceptable grade of 3 as seen in Table 6. With the fastness to alkaline perspiration test, the fabrics mordanted in trisodium NTA appeared darker than the originally dyed samples. This may be attributed to that natural dye is composed of tannins and phenolic compounds which favour alkaline conditions. Some dye particles could also be attracted to the fabric due to ionic attraction, and then fixed on the fabric while it is soaked in the perspiration, thus resulting in the observed darker shade.

Using dimethylformamide as a mordant, and in all three mordanting methods, 3g/L gave staining grades above the commercially acceptable grade of 3. The dimethyl formamide mordant generally produced better resistance to staining in an alkaline medium than in an acid medium, with a concentration of at least 1g/L being required to reach an acceptable grade of 3. With reference to resistance to staining, under acidic conditions, colour fastness to staining at 1g/L and 2g/L concentrations was generally below grade 3, which is an indication of poor complex dye formation within the fibre. The results show that at least 3g/L dimethylformamide is generally required to produce commercially acceptable resistance to staining in an acid perspiration test.

Mordanting method	Mordant type and concentration	Staining grade		Mordant type and concentration	Staining grade	
		Acid	Alkaline		Acid	Alkaline
Unmordanted control		2.8a	3.0a		2.8	3.0a
Simultaneous	Trisodium NTA 1%	3.7a	3.8a	Dimethyl Formamide 1%	2.7a	3.0a
	Trisodium NTA 2%	4.0a	4.1a	Dimethyl Formamide 2%	3.3a	3.3a
	Trisodium NTA 3%	4.3a	4.3a	Dimethyl Formamide 3%	3.7a	3.8a
Pre-mordanting	Trisodium NTA 1%	3.3a	3.1a	Dimethyl Formamide 1%	2.8a	3.2a
	Trisodium NTA 2%	3.7a	3.5a	Dimethyl Formamide 2%	2.8a	3.5a
	Trisodium NTA 3%	3.8a	3.7a	Dimethyl Formamide 3%	3.2a	3.8a
Post-mordanting	Trisodium NTA 1%	3.2a	3.2a	Dimethyl Formamide 1%	2.3a	3.1a
	Trisodium NTA 2%	3.8a	3.6a	Dimethyl Formamide 2%	2.8a	3.3a
	Trisodium NTA 3%	4.2a	4.0a	Dimethyl Formamide 3%	3.3a	3.5a
Significance		NS	NS		NS	NS

Table 6:- Effect of mordant type, concentration and method of application on the colour fastness to staining in alkaline and acid perspiration, Means followed by the same letter are not statistically different at P< 0.05.

➢ *Colour change*

It can be seen from Table 7, in all cases, both mordanting types improved the colour change fastness to both acid and alkaline perspiration, and gave levels equal to, or better than, the commercially acceptable grade of 3, at all mordant concentration levels. It is also apparent that the colour fastness generally improved with an increase in mordant concentration with simultaneous-mordanting

ISSN No:-2456-2165

performing best, and trisodium NTA being superior to dimethylformamide. The colour fastness to alkaline perspiration was generally better than in acid perspiration. Good colour fastness to perspiration was also observed by Dayal *et al.* (2006), who found that the colour change and staining in acid and alkaline media varied between grades 4-5, when dyeing with *Lantana camara* leave extracts and using potassium dichromate as the mordant. They found that, with copper sulphate as a mordant, the colour fastness varied between 3- 5, indicating that different mordants have different effects of insolubilizing the dye, to make it colour fast.

Mordanting method	Mordant type and concentration	CC grade		Mordant type and concentration	CC grade	
		Acid	Alkaline		Acid	Alkaline
Unmordanted control		2.8a	3.0a		2.8a	3.0a
Simultaneous	Trisodium NTA 1%	3.8a	4.3a	Dimethyl Formamide 1%	3.2a	3.5a
	Trisodium NTA 2%	4.2a	4.5a	Dimethyl Formamide 2%	3.7a	3.8a
	Trisodium NTA 3%	4.3a	4.6a	Dimethyl Formamide 3%	3.8a	4.0a
Pre-mordanting	Trisodium NTA 1%	3.2a	4.0a	Dimethyl Formamide 1%	3.2a	3.5a
	Trisodium NTA 2%	3.6a	4.3a	Dimethyl Formamide 2%	3.2a	3.7a
	Trisodium NTA 3%	4.0a	4.5a	Dimethyl Formamide 3%	3.7a	3.8a
Post-mordanting	Trisodium NTA 1%	3.3a	3.5a	Dimethyl Formamide 1%	3.0a	3.5a
	Trisodium NTA 2%	3.8a	3.7a	Dimethyl Formamide 2%	3.0a	3.7a
	Trisodium NTA 3%	4.1a	4.1a	Dimethyl Formamide 3%	3.7a	3.9a

Table 7:- Effect of mordant type, concentration and method of application on colour change fastness to alkaline and acidic perspiration test Means followed by the same letter are not statistically different at P< 0.05.

E. Colour fastness to washing

The colour fastness to washing is one of the most important criteria for dye quality and acceptability. Table 8 gives the washing test results for staining onto adjacent fabric, while Table 9 gives the results for colour change (CC) in shade of the dyed fabric, the grade of 5 being excellent and of 1 being very low. As can be seen from Table 8, both mordants improved the resistance to staining significantly, with mordant concentration not having a consistent effect; the trisodium NTA was generally superior to the dimethylformamide mordant. The method of mordanting did not have a major effect, although pre- and simultaneous-mordanting performed better than post-mordanting. Similar trends were observed for the colour fastness of the dyed fabric to washing (Table 9).

Mordanting method	Mordant type and concentration	Staining grade		Mordant type and concentration	Staining grade	
		Acid	Alkaline		Acid	Alkaline
Unmordanted control		2.8a	3.0a		2.8	3.0a
Simultaneous	Trisodium NTA 1g/l	3.7a	3.8a	Dimethyl Formamide 1g/l	2.7a	3.0a
	Trisodium NTA 2g/l	4.0a	4.1a	Dimethyl Formamide 2g/l	3.3a	3.3a
	Trisodium NTA 3g/l	4.3a	4.3a	Dimethyl Formamide 3g/l	3.7a	3.8a
Pre-mordanting	Trisodium NTA 1g/l	3.3a	3.1a	Dimethyl Formamide 1g/l	2.8a	3.2a
	Trisodium NTA 2g/l	3.7a	3.5a	Dimethyl Formamide 2g/l	2.8a	3.5a
	Trisodium NTA 3g/l	3.8a	3.7a	Dimethyl Formamide 3g/l	3.2a	3.8a
Post-mordanting	Trisodium NTA 1g/l	3.2a	3.2a	Dimethyl Formamide 1g/l	2.3a	3.1a
	Trisodium NTA 2g/l	3.8a	3.6a	Dimethyl Formamide 2g/l	2.8a	3.3a
	Trisodium NTA 3g/l	4.2a	4.0a	Dimethyl Formamide 3g/l	3.3a	3.5a

Table 8:- Effect of mordant type, concentration and method of application on the fastness to staining during washing Means followed by the same letter are not statistically different at P< 0.05.

Mordanting method	Mordant type and concentration	CC grade		Mordant type and concentration	CC grade	
		Acid	Alkaline		Acid	Alkaline
Unmordanted control		2.8a	3.0a		2.8a	3.0a
Simultaneous	Trisodium NTA 1g/l	3.8a	4.3a	Dimethyl Formamide 1g/l	3.2a	3.5a
	Trisodium NTA 2g/l	4.2a	4.5a	Dimethyl Formamide 2g/l	3.7a	3.8a
	Trisodium NTA 3g/l	4.3a	4.6a	Dimethyl Formamide 3g/l	3.8a	4.0a
Pre-mordanting	Trisodium NTA 1g/l	3.2a	4.0a	Dimethyl Formamide 1g/l	3.2a	3.5a
	Trisodium NTA 2g/l	3.6a	4.3a	Dimethyl Formamide 2g/l	3.2a	3.7a
	Trisodium NTA 3g/l	4.0a	4.5a	Dimethyl Formamide 3g/l	3.7a	3.8a
Post-mordanting	Trisodium NTA 1g/l	3.3a	3.5a	Dimethyl Formamide 1g/l	3.0a	3.5a
	Trisodium NTA 2g/l	3.8a	3.7a	Dimethyl Formamide 2g/l	3.0a	3.7a
	Trisodium NTA 3g/l	4.1a	4.1a	Dimethyl Formamide 3g/l	3.7a	3.9a

Table 9:- Effect of mordant type, concentration and method of application on colour change fastness to washing
Means followed by the same letter are not statistically different at P< 0.05.

F. Colour fastness to crocking

Table 10 gives the wet rubbing tests results for staining on adjacent fabric while Table 11 gives the dry rubbing tests results for staining onto adjacent fabric of the dyed fabrics, the grade of 5 being excellent and 1 being very low. As can be seen from Table 10, both mordants improved the staining resistance. With the resistance to staining improving with increases in mordant concentration, the two mordants produce similar results. Similar trends were observed for the dry rubbing test results (see Table 11). The ANOVA for both mordants showed that the mordanting type did not have a statistically significant effect while mordant concentration had a statistically significant effect on fabric colour fastness to both dry and wet crocking. It is also evident from the findings that there was no statistically significant interaction between the mordant type and concentration. The above results were very similar to those obtained by Khatri *et al.* (2012), who also used an organic electrolyte which proved to be compatible with reactive dyes.

Mordanting method	Mordant type and concentration	Resistance to staining grade	Mordant type and concentration	Resistance to staining grade
Unmordanted control		4.1a		4.1a
Simultaneous	Trisodium NTA 1%	4.3a	Dimethyl Formamide 1%	4.2a
	Trisodium NTA 2%	4.6a	Dimethyl Formamide 2%	4.7a
	Trisodium NTA 3%	5.0a	Dimethyl Formamide 3%	5.0a
Pre-mordanting	Trisodium NTA 1%	4.5a	Dimethyl Formamide 1%	4.3a
	Trisodium NTA 2%	4.6a	Dimethyl Formamide 2%	4.7a
	Trisodium NTA 3%	4.9a	Dimethyl Formamide 3%	5.0a
Post-mordanting	Trisodium NTA 1%	4.5a	Dimethyl Formamide 1%	4.2a
	Trisodium NTA 2%	4.7a	Dimethyl Formamide 2%	4.8a
	Trisodium NTA 3%	4.9a	Dimethyl Formamide 3%	5.0a

Table 10:- Effect of mordant type, concentration and method of application on the resistance of the dyed fabric to staining during wet rubbing, Means followed by the same letter are not statistically different at P< 0.05.

ISSN No:-2456-2165

Mordanting method	Mordant type and concentration	Resistance to staining grade	Mordant type and concentration	Resistance to staining grade
Unmordanted control		4.5a		4.5a
Simultaneous-mordanting	Trisodium NTA 1%	4.7a	Dimethyl Formamide 1%	4.7a
	Trisodium NTA 2%	5.0a	Dimethyl Formamide 2%	4.8a
	Trisodium NTA 3%	5.0a	Dimethyl Formamide 3%	5.0a
Pre-mordanting	Trisodium NTA 1%	4.8a	Dimethyl Formamide 1%	4.8a
	Trisodium NTA 2%	4.8a	Dimethyl Formamide 2%	4.8a
	Trisodium NTA 3%	5.0a	Dimethyl Formamide 3%	5.0a
Post-mordanting	Trisodium NTA 1%	4.8a	Dimethyl Formamide 1%	4.7a
	Trisodium NTA 2%	5.0a	Dimethyl Formamide 2%	5.0a
	Trisodium NTA 3%	5.0a	Dimethyl Formamide 3%	5.0a

Table 11:- Effect of mordant type, concentration and method of application on the resistance of the dyed fabric to staining during dry rubbing, Means followed by the same letter are not statistically different at $P< 0.05$.

It can be concluded that the dyed fabrics had good colour fastness to wet/dry rubbing, the results being similar to those obtained by other researchers (Saravanan *et al.*, 2012; Kulkarni *et al.*, 2011; Kechi *et al.*, 2013; and Vankar *et al.*, 2009) when using natural dyes on cotton, and very similar to those obtained by Khatri *et al.* (2012), who also used an organic electrolyte which was comparable with reactive dyes. The values obtained here, prove that the two organic electrolyte mordants can be used in relatively low concentrations to achieve good, and commercially acceptable, rubbing fastness.

G. Fabric Tensile strength

Table 12 gives the fabric tensile strength results, from which it can be seen that trisodium NTA tended to increase the fabric tensile strength, with the tensile strength increasing slightly with increasing mordant concentration, the highest tensile strength being obtained with 3g/L trisodium NTA in simultaneous-mordanting.

Mordanting method	Mordant type and concentration	Tensile strength (N)	Mordant type and concentration	Tensile strength (N)
Unmordanted control		287.3a		287.3i
Simultaneous-mordanting	Trisodium NTA 1g/l	288.3b	Dimethyl Formamide 1g/l	286.3g
	Trisodium NTA 2g/l	290.1d	Dimethyl Formamide 2g/l	284.9f
	Trisodium NTA 3g/l	310.4g	Dimethyl Formamide 3g/l	271.0b
Post-mordanting	Trisodium NTA 1g/l	287.3a	Dimethyl Formamide 1g/l	286.9h
	Trisodium NTA 2g/l	288.5b	Dimethyl Formamide 2g/l	283.1d
	Trisodium NTA 3g/l	290.5e	Dimethyl Formamide 3g/l	278.4c

Table 12:- Effect of mordant type, concentration and method of application on fabric tensile strength
Means followed by the same letter are not statistically different at $P< 0.05$.

H. Interrelationships between various parameters

The linear correlations between the various parameters were determined and are presented in the form of a Pearson correlation matrix in Table 13.

As expected, dye exhaustion was highly correlated with colour strength, particularly for the dyeing involving the dimethylformamide mordant, where the coefficient of determination (R^2x 100) was 0.99^2 x 100 = 98.0 %. Dye exhaustion was also highly correlated with hue (b*), the correlation coefficient being 0.86 and the coefficient of determination (R^2x 100) was 0.86^2 x 100 = 74 %. This indicates that 74% of the variation in hue was associated with differences in dye exhaustion. Colour strength (K/S) was highly and negatively correlated with (L*) lightness index, the correlation coefficient being -0.97 and the coefficient of determination (R^2x 100) was 94.1 %. The negative correlation shows that an increase in colour strength (KS) was associated with a decrease in lightness index.

Parameter	A	B	C	D	E	F	G	H
A	1.00							
B	0.89**	1.00						
C	0.86**	0.80**	1.00					
D	0.86**	0.81**	1.00	1.00				
E	0.99**	0.93**	0.84**	0.84**	1.00			
F	0.68**	0.81**	0.65**	0.65**	0.73**	1.00		
G	-0.96**	-0.87**	-0.71**	-0.71**	-0.97**	-0.65**	1.00	
H	-0.96**	-0.87**	-0.71**	-0.71**	-0.97**	-0.65**	1.00	1.00

Table 13:- Pearson correlation coefficient matrix

A= dye exhaustion % for dimethylformamide mordant
B = dye exhaustion % for trisodium NTA
C = hue b* with dimethylformamide mordant
D = hue b* in trisodium NTA mordant
E = K/S with dimethylformamide mordant
F = K/S with trisodium NTA mordant
G = L* with dimethylformamide mordant
H = L* with trisodium NTA mordant
** Significance

V. CONCLUSION AND RECOMMENDATIONS

Syzygium cordatum bark solvent dye extraction method when used on cotton fabric, it had a superior performance with trisodium NTA organic electrolyte mordant. Dye exhaustion increased with an increase in trisodium NTA mordant concentration when applied as pre-mordanting. The recommended concentration of the trisodium was due to environmental considerations, when disposing the waste water after dyeing. Furthermore, at the recommended concentration of the trisodium, the highest colour yield value was obtained in both simultaneous and pre-mordanting processes. Trisodium NTA using all three methods of mordanting in both acid and alkaline perspiration, had stain resistance better than the commercially accepted grade of 3 and had a darker colour shade. Colourfastness to alkaline perspiration was the best with trisodium NTA and improved with increased simultaneous mordanting.

There was no significant difference across fabrics on colourfastness to washing, although fabric swatches simultaneously and pre-mordanted with trisodium NTA performed better than post-mordanted ones. On colour fastness to crocking, both mordants produced similar results with increased concentration and had good resistance to crocking. Fabric strength increased with simultaneous mordanting using 3g/L trisodium NTA. There was a high correlation between dye exhaustion and colour strength. In general, pre- and simultaneous mordants were better than post-mordanting, and trisodium NTA was a better performing organic electrolyte mordant compared to dimethylformamide.

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Dyeing Cotton with Natural Dye Extracted from *Syzygium cordatum* Bark

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HAS BEEN PUBLISHED IN

Volume 4 | Issue 6 | June - 2019

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HAS BEEN PUBLISHED IN

Volume 4 | Issue 6 | June - 2019

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