Waste from Eucalyptus Wood Steaming as a Natural Dye Source for Dyeing Cotton

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Abstract

Textile Industry is increasingly researching for Cleaner Production improvements, such as new processes and materials. Natural dyes are gaining interest due their expected low risk to human health and the environment. In this study, the potential for using colored liquid waste produced in the steam treatment of eucalyptus wood as a natural coloring matter for textile cotton was investigated. Specifically, eucalyptus wood extract from waste eucalyptus wood steaming was used to dye cotton in an exhaust dyeing process without the addition of traditional mordanting agents. The resulting dyed fabrics were evaluated for color fastness. It was found that wash fastness of waste dyed fabrics was very good, while light fastness was typical of natural dyes. It ws also found excellent rubbing fastness ratings. In this regard, the waste from eucalyptus wood steaming is accepted as a new material on Cleaner Production strategies in Textile Industry applications in cotton dyeing.

Keywords: *Textile Industry, natural dyes, cotton, waste, eucalyptus.*

1. Introduction

The Textile Industry is the second largest industry in Brazil. In order to reduce environmental problems, the Textile Industry has adopted strategies such as Cleaner Production (CP) to eliminate the use of toxic raw materials, increasing the efficiency of water use, energy reduction in wastewater treatment and new materials (Bastian and Rocco, 2009, Bechtold et al., 2003; Bechtold et al., 2007; Bechtold and Mussak, 2009). As a result, the increased interest in natural materials and renewable resources has come to the forefront, which motivates the investigation of natural dyes.

Historically, the use of natural dyestuffs has been limited by technical properties required in the Textile Industry, including the ability to conduct dyeing process in existing equipment, reproducibility of fabric shades from batch to batch, and acceptable color fastness properties, i.e., the permanence of dyes under end-use conditions (Bechtold et al., 2003). Among the procedures most often cited in the literature dyes in order to increase the fastness properties and the substantivity of natural dyes is the inclusion of mordants, which are transition metal salts, in the dyeing process (Bechtold et al., 2007, Puntener and Schlesinger, 2000). Regarding light fastness, most natural dyes have poor to moderate color strength (Cristea and Vilarem, 2006). The light fastness is influenced by internal factors of the dye molecules, such as chemical and physical state of the dye and its concentration, the nature and type of fibers and the light source used (Cristea and Vilarem, 2006). Another important requirement for the viability of natural dyes for the Textile Industry is the reliability of their source and the consistency of their composition.

Generally, there are three types of natural dyes for dyeing textiles: 1) Substantive dyes, which bond directly to textile fibers during the dyeing process without adding a mordant (Centeno, 2010); 2) Traditional dyes, which characterize the majority of the natural dyes family. This group requires the formation of a mordant-fiber complex to establish a dye-fiber connection (Freeman and Peters, 2000; Dean, 2010; Vankar, 2007; Rudkin, 2007; Bhattacharya and Shah, 2000; Kamel et al. 2011) and 3) Vat dyes, which include certain water insoluble dyes (Vankar, 2007; Rudkin, 2007; Bhattacharya and Shah, 2000).

More recently, a movement in our society towards sustainability, green and environmentally friendly products, as well as specific market niches (Bechtold et al., 2003; Bechtold et al., 2007) has led to the consideration of eucalyptus as potential source of natural dyes.

Eucalyptus is a widely cultivated plant in Brazil, whose acreage currently is about 4.75 million hectares spread over almost all states. It is estimated that there are approximately 600 sawmills dedicated to processing its timber, which comprised 9.0 million tons of lumber in 2010 and reflected an average annual growth rate of 1.7% (ABRAF, 2011).

The processing of eucalyptus wood includes subjecting the lumber to steam at 95°C in a closed chamber. This process gives the wood a uniform red tone, including the part of the sapwood, which is initially gray to white. In this process, the water in the treatment tank becomes dark brown, providing the colored waste considered for dyeing textiles in this study.

The use of eucalyptus extract as a natural colorant for dyeing cotton has been shown feasible in the study by Rossi et al. (2012). But in this case, the dye originated from the waste from extraction of eucalyptus leaves for oil distillation. The brown aqueous extract gave light brown shades on cotton. In tests of the fastness to washing, the rating was 3-4 for dyebath concentrations of 10 and 50% based on the fabric weight (owf). The multifiber fabric staining ratings were >4 at both concentrations. Light fastness ratings obtained were 2-3 and 3, using dyebath concentrations of 10 and 50% (owf), respectively.

This early success motivated our consideration of waste effluent from steaming eucalyptus wood for dyeing cotton, which forms the overall objective of the present work.

2. Material and Methods

2.1 Eucalyptus extract from wood steaming waste

Eucalyptus liquid waste from lumber steaming was supplied by Depinus, located in the city of Curiuva, Paraná. The timber subjected to steaming was Eucalyptus grandis Hill Ex. Maiden. A 40 liter sample was collected for evaluation and sent to the Integrated Laboratories of Chemistry, Pulp and Energy (LQCE), the Escola Superior de Agricultura "Luiz de Queiroz" (ESALQ/USP) in Piracicaba, São Paulo, Brazil.

The analyses performed on the residue were pH, total solids (TS) and condensed tannins (CT). The TS was determined by drying the material in the oven at 103 ± 2°C to remove water and quantitative assessment of the solids. The determination of CT was performed using the method of Stiasny (Paes et al., 2006). Three repetitions were performed for each analysis.

2.2 Dyeing fabrics with eucalyptus extract

Textile dyeing employing the liquid residue was carried out in the Textile Laboratory at the Escola de

Artes, Ciências e Humanidades (EACH/USP), using an HT Mathis machine for exhaustion dyeing. The knitted fabrics used was cotton 98% with 2% of elastane.

Dye baths were prepared according to Rossi et al. (2014) and the dyeing was performed without addition of metal salts. The dye concentration used was 1%, 10% and 20%, based on the fabric weight. Dye bath contained NaCl (20 g/L) and the liquor ratio was 10:1.

The mass of the colorant to be used in the dye bath was determined using the equation (1):

$$Mc = (Cc \times Mf) / 100 \times (100/TS) \quad (1)$$

wherein:

Mc = mass of the colorant from eucalyptus to be applied to the fabric (g);
Cc = target concentration of colorant on the fabric (%);
Mf = mass of the fabric (g);
TS = total solids of the colorant (%).

After dyeing, the fabrics received a wash with 1 g/L of neutral detergent in distilled water for 10 min at 30ºC. After this, the fabrics were washed in running water and dried at low temperature for 30 min. Two repetitions were performed for each dye concentration.

2.3 Color assessments

X-Rite Colorimetric analysis was used to measure the color strength in terms of L*, a*, b* and K/S value, both to the eucalyptus waste and the dyed samples. The operating conditions of the equipment were scanning from 360 to 700 nm, CIE illuminant D65, and observer angle of 10º.

K/S values were calculated using the Kubelka-Munk equation, as in (1):

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

where R represents the reflectance, and was obtained directly from the spectrophotometer at λ_{max} (360nm) of dyed fabrics.

2.4 Fastness properties

The color fastness to washing of dyed samples was determined according to NBR ISO 105-C06 AIS: 2006 (ABNT, 2006), in Golden Química Industry in Guarulhos, São Paulo, Brazil. The difference obtained between the control fabric and the multi-fiber, before and after washing, was visually compared with the gray scale to obtain the color change and the staining, according to the ABNT (2006).

For light fastness, AATCC Test Method 16-2004 (Option 3) (DING, 2013) was used and this assessment was conducted in the College of Textiles, North Carolina State University, USA. The exposure was conducted with irradiation of 55 W/m², relative humidity of 50%, temperature of the black body of 63ºC and temperature in the chamber of 30ºC at 5, 10 and 20 hours. The difference obtained between the control fabric and the exposed fabrics, were visually compared with the gray scale to obtain the color change, according to the ABNT (2006).

The fastness to rubbing were also conducted at the College of Textiles at North Carolina State University, North Carolina, USA, using a "crockmeter" following the ABNT / NBR 105-X12 (ABNT, 2007). The tissue evaluations were performed following the ABNT 2006 standard, the grayscale staining.

3. Results and Discussion

The results of the physicochemical evaluations, presented in Table 1, revealed an aqueous extract with acidic pH, dark brown coloration and with ~1% of condensed tannins. Compared with the residue from eucalyptus leaves reported by Rossi et al. (2012), which had 0.6% of tannins, and a total solids content of 3.4%, the residue of this study contained a content of tannins about 1.5 times greater and 50% less total solids.

Table 1. Physico-chemical analysis of the residue from steaming eucalyptus wood.

Analysis		Average
pH		5.1
Total solids content (%)		2.2
Condensed tanins content (%)		0.9
Color	L*	24.3
	a*	0.4
	b*	0.2

The color strength of the dyed cotton fabrics is presented in Fig. 1 and Table 2. Fastness properties to washing, light and rubbing are shown in Tables 3 to 5, respectively.

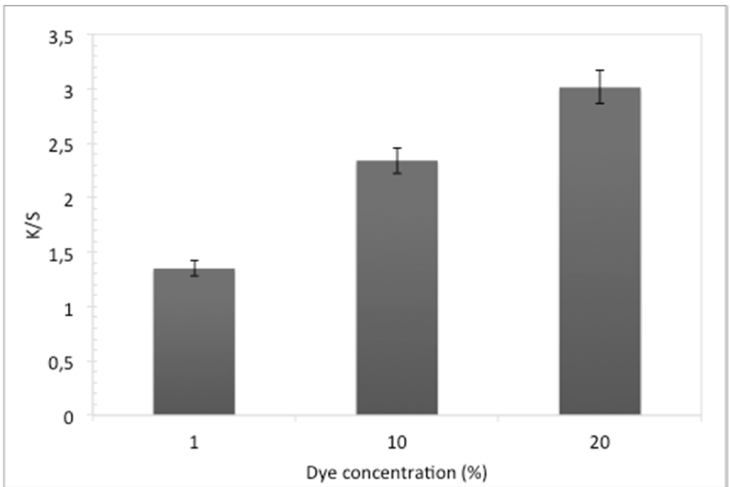

Fig. 1. Color strength (K/S) for dyed cotton fabrics as a function of dye concentration of eucalyptus extract.

The dyed samples had yellowish, brown and beige shades in general. The color strength was 1,35 to 1% dye concentration; 2,34 to 10% dye concentration and 3,01 to 20% dye concentration.

Table 2. L*a*b* results from the dyed cotton fabrics with eucalyptus extract.

Dye concentration (%)	Color properties L*	a*	b*
1	73.97	5.85	10.42
10	62.79	7.76	14.33
20	59.58	8.29	15.14

Table 3. Color fastness to washing based in ABNT NBR ISO 105-C06 AIS:2007.

Dye concentration (%)	Colour change	Colour staining of adjacent fibers					
		Acetate	Cotton	Nylon	Poliester	Acrylic	Wool
1	4	5	5	5	5	5	4-5
10	3	5	4-5	4-5	5	5	5
20	3	5	4-5	5	5	5	4-5

The color change results from fabric washing are considered acceptable, with ratings between 3 and 4. The lowest dye concentration gave the best wash fastness. Regarding the staining ratings, 4,5 to 5, means that were very good to excellent. In practical application, the dyed cotton does not stain other fibers. The final products could mix other fibers without staining one another.

Table 4. Colour fastness to light based AATCC Test Method 16-2004 (Option C).

Dye concentration (%)	Colour change Exposition (Hours) 5	10	20
1	2-3	2	1-2
10	3	2	1-2
20	3	3	2

Light fastness results showed, in general, low light fastness in all dye concentrations at the 20 h exposure level. The characteristic of eucalyptus extract as a colorant indicates finals uses as lingerie and men's underwear, because of the shades obtained in the fabrics, such yellowish, brown and beige. Such shades are frequently present in color charts of all collections of all brands, being a basic color of this segment. For these final uses, light fastness is not important, while wash fastness is important.

Table 5. Colour fastness to rubbing based ABNT NBR ISO 105-X12 (2007)

Dye concentration (%)	Colour staining Dry	Wet
1	5	4-5
10	5	3-4
20	5	2-3

The fastness to rubbing evaluations revealed excellent fastness to rubbing dry with higher rating, 5, at all concentrations of the residue. Dry friction ratios were greater than wet dyed fabric. One possible explanation for this is the low diffusion of dye molecules within the fiber, due to its large size (Burkinshaw; Kumar, 2008). This reveals that the deposit of waste in the textile fiber may be occurring at the periphery of the fiber. Thus, the eucalyptus extract molecules in the surface binding to each other in larger concentrations instead of binding to the fiber, resulting in less rubbing fastness.

The fastness results showed the eucalyptus waste could be a source of natural dye for dyeing cotton for final applications that required low light fastness and excellent fastness to dry rubbing and good fastness to washing.

In terms of Cleaner Production strategies, the waste from wood steaming eucalyptus can be a new dye material for dyeing cotton.

In future studies it is encourage the dyeing and fastness evaluation of others textile fibers to provide a wider range of options to be applied in Textile Industry.

4. Conclusions

It has been found that the liquid waste generated from steaming eucalyptus wood is a potential source of natural dye for dyeing cotton. In this regard, the results from coloristic assessments indicate yellowish, beige and brown colors and K/S in the 1,4-3 range. Good wash fastness was obtained with light fastness typical of natural dyes. Excellent fastness to rubbing was found, witch dry rubbing rates were greater than wet. In this regard, the eucalyptus waste is accepted as a new material on Cleaner Production strategies in Textile Industry.

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