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Improving dyeability of modified cotton fabrics by the natural aqueous extract from red cabbage using ultrasonic energy

Manel Ben Ticha[a,b,*], Wafa Haddar[a,c], Nizar Meksi[a,b], Ahlem Guesmi[d], M. Farouk Mhenni[a]

[a] Université de Monastir, Faculté des Sciences, Unité Chimie Appliquée – Environnement UR13ES63, Monastir 5000, Tunisia
[b] National School of Engineers of Monastir, 5000 Monastir, Tunisia
[c] Higher Institute of Technological Studies, Ksar Hellal 5070, Tunisia
[d] Chemistry Department, College of Science, IMSIU (Al Imam Mohammad Ibn Saud Islamic University), Riyadh 11623, Saudi Arabia

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ABSTRACT

The concern regarding sustainable utilization of available resources is growing due to its global importance. In this paper, the dyeability of cotton fabrics with natural colorant extracted from red cabbage was improved by applying cationic groups on cotton fibers. Modification of cotton was carried using acid tannic, Rewin Os, Denitex BC and Sera Fast as cationic agents. The dyeing process was done by ultrasonic energy. The effects of the cationising agent amount, the dye bath pH, the dyeing temperature and duration, on the sonicator dyeing quality were studied. The performances of this process were evaluated by measuring the colour yield (K/S) and the dyeing fastness of the coloured cotton. Besides, modified cotton fibers were characterized by morphology analysis (SEM) and Fourier transform infrared (FTIR) spectra and compared to untreated cotton.

Moreover, a two-level full factorial design was employed to optimize the sonicator dyeing process. Mathematical model equation and statistical analysis were derived by computer simulation programming applying the least squares method using Minitab 15. Best dyeing conditions were found to be: 10%, pH 11, 60 min and 100 °C respectively for the Sera Fast amount, dye bath pH, dyeing duration and temperature.

1. Introduction

Environmental awareness aims to understand the weakness of our environment and the significance of its protection. It is a way to participate in creating a brighter future for our children. Promoting environmental awareness affects all fields in our life. Its main objective is to fight all types of pollution.

The synthetic dye industry is one of the world's most polluting industries. Most garment manufacture nowadays takes place in countries where environmental law is weak or largely unenforceable, and so waste water and sludge laced with toxic chemicals are consistently released into watercourses and onto land.

With environmental concerns rising on the utilization of synthetic chemical dyes, natural dyes offers scope for eco-friendly way to dye fibrous materials (Sivakumar, Vijaeeswarri, & Lakshmi Anna, 2011).

The use of natural dyes has developed in the last decade, mainly in foodstuffs and cosmetic products given the very stringent safety and toxicological requirements present in the food, pharmaceutical, and cosmetic industries. Moreover, there has been growing interest in the use of natural dyes in the textile industry (Ebrahimi & Parvinzadeh Gashti, 2016). Using natural dyes contributes to the added value of textiles and also responses to the increasing demand of compatibility with the environment (Kiumarsi & Parvinzadeh Gashti, 2015). In fact, natural dyes may overcome many defects of synthetic dyes such as harmfulness to the human body and water pollution (Miyamatsu, Kawai, Morita, & Kubo, 1993; Smith & Wagner, 1991). Besides, the actual coloring matters used and the methods by which they were so skillfully applied are of considerable interest. Hence, it is necessary to study and introduce new dyes from natural sources for textile industry (Ebrahimi & Parvinzadeh Gashti, 2015; Kiumarsi, Parvinzadeh Gashti, Salehi, & Dayeni, 2016).

Unfortunately, natural dyes show very low dye exhaustion on cotton fiber compared to silk or wool, and no satisfying result has been attained in spite of many experimental efforts of repeating dyeing and mordant treatment.

* Corresponding author at: University of Monastir, Faculty of Sciences of Monastir, Research Unit of Applied Chemistry and Environment, 5000 Monastir, Tunisia.
E-mail address: manel005@hotmail.fr (M. Ben Ticha).

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Today, the world uses more cotton than any other fiber. In fact, it is a major textile fiber and it has a unique combination of properties, including high strength, durability, softness, good dyeability and biodegradability (Parvinzadeh Gashti, 2013). According to the International Year of Natural Fibers (2009) Current estimates for world production are about 25 million tonnes annually.

Cotton structure consists of cellulose, a polymer constructed of monomeric glucose units. Subsequently, cellulose is susceptible to hydrolysis when heated in acidic medium. Dyeing of cotton must be realized at pH values above 4 (Broadbent, 2001). At higher pH values (>8), side chain hydroxyl groups can be ionized, thus increasing the negative surface charge considerably (Rattee, 1995). Hence, cotton mostly shows poor affinity toward anionic dyes due to charge repulsion, leading to low uptake of such dyes (Janhom et al., 2006; Rattanaphani, Chairat, Bremner, & Rattanaphani, 2007).

Several studies have been carried out on cotton using chemical and physical modification methods to improve its dyeability, including, treatment with enzymes, bacteria and reagents, grafting of monomers, application of supercritical carbon dioxide in the scouring and dyeing,micro-encapsulation techniques, corona discharge treatment, UV irradiation, ultrasound vibration and plasma functionalization of cellulose fibers (Kalia, Thakur, Celli, Kiechel, & Schauer, 2013; Parvinzadeh Gashti, Pournaserani, Ehsani, & Parvinzadeh Gashti, 2013). However, sometimes these methods may cause some physical, chemical, and mechanical damage to the textile fibers (Parvinzadeh Gashti, Katozian, Shaver, & Kiumarsi, 2014). Other studies have been conducted on applying cationic agents in the form of secondary, tertiary and quaternary amine compounds (Ben Ticha, Meksi, Drira, Kechida, & Mhenni, 2013; Burkinshaw, Lei, & Lewis, 1989; Eorn, Shin, & Yoon, 2001; Haddar, Ben Ticha, Guesmi, Khoffi, & Durand, 2014; Janhom, Griffiths, Watanesk, & Watanesk, 2004; Lewis & Lei, 1991; Pisitsak et al., 2016). Results have been shown that these compounds could improve the dyeability and the colour fastness of the cotton fabrics.

Furthermore, to ensure a better dyeing quality of cotton, it is recommended to use the ultrasonic energy instead of the conventional dyeing process. In fact, many studies have been elaborated to compare ultrasonic and conventional dyeing techniques and shown the priority of the ultrasonic way (Guesmi, Ben Hamadi, Ladhari, & Sakli, 2013; Haddar et al., 2015). Ultrasonic energy could accelerate both physical and chemical reactions (Gogate, 2008). The use of ultrasound in chemical reactions in solution offers specific activation founded on a physical phenomenon: acoustic cavitation (Hu, Zou, Wub, & Shi, 2012). The ultrasound energy provides rise to acoustic cavitations in the dye bath. The cavitations happening near to a solid surface make microjets, which enable the liquid to move with a high speed and provide rise to an increased diffusion of dye molecules inside the fabric's pores, thus producing development in dye uptake under less energetic conditions (Guesmi et al., 2013).

The present study reports a systematic investigation of a sonicator cotton dyeing. Cotton was treated by cationic agents to improve its dyeability. Dyeing was achieved with natural dye extract from red cabbage.

The red cabbage is a sort of cabbage, also known as purple cabbage. It is distinguished by its coloring, texture and flavor. Like green cabbage it is rounded and wrapped in tightly wound waxy leaves. The leaves are more violet and burgundian versus true red. Their flavor is far more bold, cruciferous and peppery versus green cabbage.

Red cabbage's origins are strictly European. The round-headed form is the oldest of the hard types of cabbage and is the only one described first during the 16th century. The first description of red cabbage dates back to 1570 England, though it was introduced to all of Europe by the Romans during the 14th century, during which it was used primarily by peasant families as food for both human and livestock consumption. Red cabbage first appeared in an aristocratic culinary setting in the 18th century. It is now internationally grown and traded throughout all hemispheres.

Before being thought of as a food, red cabbage was valued for medicinal purposes in treating headaches, gout, diarrhea and peptic ulcers (Cheney, 1950). Further, juice of red cabbage could be used as a pH indicator, turning red in acid and green in basic solutions. Indeed, this plant changes its colour according to the pH value of the soil, due to a pigment belonging to anthocyanins (flavins). Anthocyanins are natural dyes responsible for the red and blue colours of many flowers, fruits and leaves (Arapitsas, Sjoberg, & Turner, 2008; Kong, Chia, Goh, Chia, & Brouillard, 2008).

Anthocyanins are the largest group of water-soluble pigments in the plant kingdom which are present in the skin of eggplant. They are also responsible for most of the red, purple and blue colours exhibited by flowers, fruits and other plant tissues and have found applications in the food industry as natural colorants. This group of pigments is proved to be antioxidants with anti-cancer properties (Parvinzadeh Gashti, 2009). They occur in all tissues of higher plants, including leaves, stems, roots, flowers and fruits. They belong to a parent class of molecules called flavonoids synthesized via the phenylpropanoid pathway (Andersen Oyvind, 2001).

2. Materials and methods

2.1. Plant material

The red cabbage (*Brassica oleracea* L. var. capitata f. rubra) was gotten from a local supermarket in (Tunisia). The fresh sample was instantly, without storage, squeezed to juice by an electrically operated grinder.

2.2. Materials and chemicals used

Commercially bleached cotton fabric with the following specifications was provided from SITEX, Tunisia: plain weave; ends per cm, 83.87; picks per cm, 96.77; warp count, 10.5 Open End; weft count, 15 Open End; weight, 204 g/m^2.

Tannic acid is laboratory reagent grade and is used without further purification. Sera Fast GMT (CPM, Tunisia), Rewin Os (Bezema AG, Switzerland), Denitex BC 200% (Denisul, Spain) were used as cationic agents. They are polymers product soluble in water, precisely aliphatic polyamine, which works by anionicity on the cellulosic fibers, forming then a long polymer chain.

2.3. Extraction of natural dyes

30 g of red cabbage was mixed with 100 mL of water as solvent for dye extraction. The bath temperature was retained at 80 °C for 60 min at pH 9, and then the solution was divided from the plant tissue on a Büchner funnel with a filter paper.

2.4. Cotton modification

Cotton samples were modified using a specific preparative bath. The suggested method consists of treating cotton before the step of dyeing in a bath containing an appropriate amount of a cationising agent during 60 min at 50 °C. After that, cotton was dried at the room temperature.

2.5. Sonicator dyeing process description

The dyeing process was done by ultrasonic energy. The dye bath was maintained at pH 9. The used concentration of the colorant is 30 g. The temperature was raised to 80 °C and maintained at this level for 60 min. Cotton was modified by each cationising agent studied.