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Effect of dye bath pH on dyeing and functional properties of wool fabric dyed with tea extract

Yanfei Ren [a, b], Jixian Gong [a, b, *], Fubang Wang [a, b], Zheng Li [a, b], Jianfei Zhang [a, b, **], Ranran Fu [a], Jiangfei Lou [a, b]

[a] School of Textiles, Tianjin Polytechnic University, Tianjin 300387, China
[b] Key Laboratory for Advanced Textile Composites of the Education Ministry of China, Tianjin 300387, China

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A B S T R A C T

This study involved the dyeing of wool fabric with tea natural dye, and focused on the influence of dye bath pH on the color characteristics, fastness, UV protection property and antimicrobial efficacy of dyed wool. Furthermore, the possible mechanism was revealed. The results indicated that the pH value of dye bath had great effects on apparent color and color strength. When the pH value was 5.5, it exhibited the maximum *Integ* value. All dyed fabrics possessed good rubbing and washing fastness but presented growing hyperchromic effect under light with the decrease of pH value. Besides, tea imparted excellent UV protection ability and outstanding antibacterial activity to wool fabric. The antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* decreased under acidic or alkaline dyeing conditions, especially in alkaline dye bath. This research pointed out that the conventional dyeing technology of tea natural dye could impart the color and functional performances to wool.

1. Introduction

In recent years, people have more interest in natural dyes, on the ground of their better biodegradability and compatibility with the environment as well as lower toxicity and allergic reaction [1–3]. In order to meet the growing demand for natural dyes, new pigment plants are being sought [4,5]. In this course, tea has recently been suggested as a promising source of valuable natural pigments [6,7]. Tea plant (Fig. 1a) is grown in south China, southeast Asia, Sri Lanka, Russia and some other regions. In the process of tea planting and production, large amounts of tea dust and other waste will be produced, which provide a rich source of raw materials for natural tea dyes.

Tea could be classified into six sorts: green, yellow, white, oolong, black and dark, according to processing means, fermentation degree as well as oxidation of tea polyphenols. Tea is rich in polyphenols (ranging from 20 to 35%), among which catechins are the principle components. As shown in Fig. 1b, the chemical structures of catechins are determined to be epicatechin (EC), epigallocatechin (EGC), epicatechin gallate (ECG) and epigallocatechin gallate (EGCG) [8]. During tea fermentation or other oxidation process, catechins can be oxidized into theaflavins by cyclization of benzene, and then theaflavins and other substances in tea such as bisflavanol can form thearubigins through oxidative polymerization, and further oxidative polymerization can generate theabrownins with a higher molecular weight. So tea pigments comprise theaflavins, thearubigins and theabrowins, which are the oxidized derivatives of tea polyphenols.

Tea polyphenols have been reported to have many health benefits and functionalities, such as antibacterial activity, anti-oxygenation, anti-carcinogenicity and UV protection performance [9–11]. These properties can bring fabric added value when tea extract is used as dye. Although some papers have reported the tea pigments employed as textile dyes, most of the dyeing procedures need mordants to improve color fastness and change the apparent color [6]. These metallic salts of aluminum, iron, zinc, copper and others are not environmentally friendly. To my knowledge, the functionalities of fabrics dyed with tea and the effect of pH value during dyeing process have rarely been reported.

For the first time, this work studied the influence of dye bath pH on apparent color, color fastness, UV protection and antibacterial

* Corresponding author. School of Textiles, Tianjin Polytechnic University, Tianjin 300387, China.
** Corresponding author. School of Textiles, Tianjin Polytechnic University, Tianjin 300387, China.
E-mail addresses: gongjixian@126.com (J. Gong), zhangjianfei1960@outlook.com (J. Zhang).

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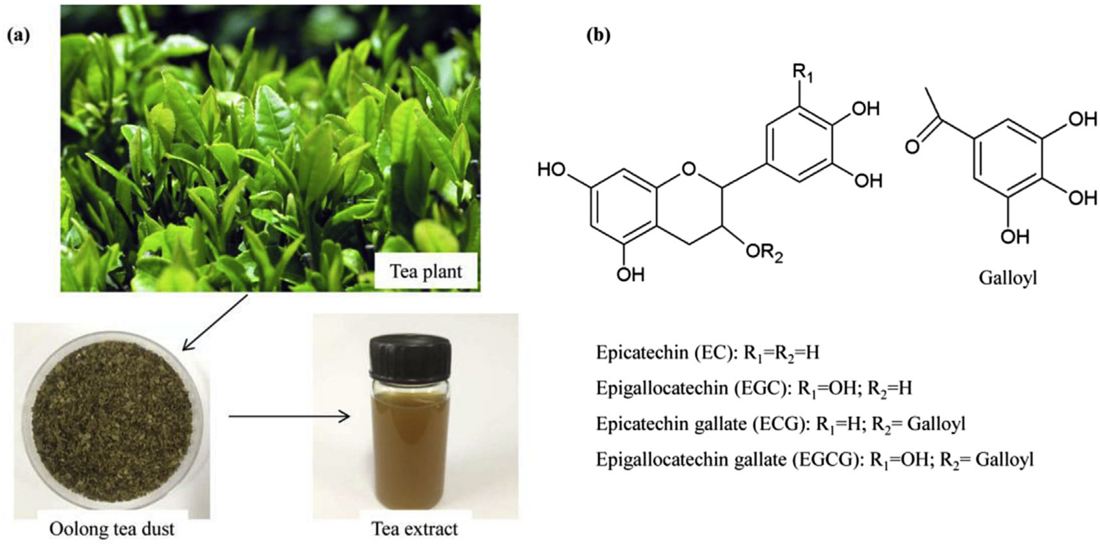

Fig. 1. (a) Tea plant, oolong tea dust and tea extract; (b) Chemical structures of catechins.

property of wool fabric dyed with oolong tea without mordants. We analysed the possible mechanism effected by the pH.

2. Materials and methods

2.1. Materials

2.1.1. Plant material

Dust of oolong tea, grown in Fujian (Region of China), was harvested on June 22, 2015.

2.1.2. Textile material

The scoured and bleached wool fabric (warp 205 dtex, weft 205 dtex; warp density 97 yarns per inch, weft density 66 yarns per inch; weight 177.0 g/m^2; thickness 0.46 mm) was bought from Jiangsu Huaxi wool spinning mill in China.

2.1.3. Chemical and reagents

Sodium hydroxide, hydrochloric acid and epicatechin were of analytical reagent grade and used as received.

2.2. Dye extraction

The dust of oolong tea was washed, dried and powdered. 50 g of powder was added to 1 L of distilled water with liquor ratio 1:20 and boiled for 1 h. Then the filtered extract was diluted with water to 1 L, and its concentration was confirmed to be 50 g/L. The extract obtained (Fig. 1a) was applied for the dyeing experiment.

2.3. Dyeing procedure

The pH value of the tea extract was recorded with Jenco pH meter, which was weakly acidic (pH 5.5). The pH of the dye baths were adjusted to 3.5, 5.5, 7.5, 9.5 with 1 M NaOH and 1 M HCl solutions. Dyeing process was carried out in an Aliba Easydye infrared dyeing machine (Datacolor company, USA) with liquor ratio 1:20. The dyeing temperature was 100 °C with a holding time of 90 min, which started from 40 °C with a raise velocity of 2 °C/min. After dyeing process, the fabrics were washed under running water, followed by drying at 70 °C. The dyed wool fabrics were marked as sample 1, 2, 3 and 4 corresponding to the different dye bath pH values of 3.5, 5.5, 7.5 and 9.5, respectively.

2.4. Measurements

2.4.1. FTIR analysis

FTIR spectrometer (Nicolet iS50, Thermo fisher, USA) was used to confirm the structure of tea extract and dyed fabrics. For each sample 32 scans at 4 cm^{-1} resolution (400–4000 cm^{-1}) was gathered in the transmittance (for tea extract) or ATR (for wool fabric) mode. The IR spectrum of tea extract was obtained by method of KBr pellet.

2.4.2. UV–Vis analysis

The absorption spectra as well as the absorbance of tea extract and the epicatechin solutions with a certain concentration gradient were measured by a Shimadzu UV-2401PC UV/visible spectrophotometer. The absorbance/concentration relationship at the λ_{max} (276 nm) of the epicatechin solution was established, and then the concentration of polyphenols in tea dust extract could be calculated.

2.4.3. Color characteristics

The CIE L^*, a^*, b^*, C^*, h (a^* presents redness-greenness and b^* presents yellowness-blueness) as well as color strength (*Integ*) of dyed fabrics were tested using a Datacolor 600 spectrophotometer (Datacolor company, USA) under illuminant D65, by a 10° standard observer. The test result was the average of observed values from eight different positions. The *Integ* value was calculated by Eq. (1):

$$\mathrm{Integ} = F(X) + F(Y) + F(Z) \tag{1}$$

where *F(X)*, *F(Y)* and *F(Z)* are the pseudo tristimulus values.

2.4.4. Color fastness

The rubbing, washing and light fastness of dyed fabrics were tested in the light of ISO 105-C01, ISO 105-X12, ISO 105-B02, respectively.

2.4.5. Ultraviolet protection ability

The ultraviolet (UVA, UVB) transmittance and ultraviolet protection factor (UPF) of wool samples were measured by Camspec