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Antimicrobial activity of wool fabric treated with curcumin

Shinyoung Han[a], Yiqi Yang[a,b,*]

[a]Department of Textiles, Clothing & Design, University of Nebraska-Lincoln, 234 HE Building, Lincoln, NE 68583-0802, USA
[b]Department of Biological Systems Engineering, University of Nebraska-Lincoln, 234 HE Building, Lincoln, NE 68583-0802, USA

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Abstract

Curcumin, a common natural dye used for fabric and food colorations, was used as an antimicrobial finish due to its bactericidal properties on dyed textiles. A common dyeing process, either batch or continuous, could provide textiles with colour as well as antimicrobial properties. The relationship between the sorption of an interesting natural colorant onto wool and the antimicrobial ability of the dyed wool were investigated. Relations between the bacterial inhibition rate and curcumin concentration, and inhibition rate and K/S value were developed. Antimicrobial activity of wool fabric finished with curcumin can be predicted without antimicrobial testing based on the developed relationships. Durability of antimicrobial activity to laundering and to light is also discussed.

Keywords: Curcumin; Antimicrobial ability; Antimicrobial finishing; Dye sorption; K/S; Wool

1. Introduction

Application of natural antimicrobial agents on textiles dates back to antiquity, when the ancient Egyptians used spices and herbs to preserve mummy wraps. Natural antimicrobials were used to inhibit the growth of bacteria and mould in the fabric [1,2]. The prevention of microbial attack on textiles has become increasingly important to consumers and textile producers; therefore, interests in antimicrobial fabric finishing have steadily increased over the last few years. The major classes of antimicrobial agents for textiles include organo-metallics, phenols, quaternary ammonium salts, and organo-silicones. To be successful in the marketplace, these finishes should be durable and have selective activity towards undesirable organisms [3]. Safety, non-toxicity and biodegradability are required for antimicrobial agents, and the active ingredients used in antimicrobial finishes need to be registered after they have been demonstrated effective and safe to use [4]. Due to the fact that natural dyes can often inhibit the growth of microorganisms without toxicity, the study and application of these dyes have gained attention [5–9]. Pharmacological studies have demonstrated that curcumin used in traditional medicine results in anti-inflammatory, antifungal, and antitumour activities [10,11].

Curcumin (1,7-bis(4-hydroxy-3-methoxyphenyl)-1,6-heptadiene-3,5-dione) is an active ingredient in turmeric (*Curcuma longa* L.) which is widely used as a food colorant. It is called C.I. Natural Yellow 3; WHO (World Health Organization) and FAO (Food and Agriculture Organization) committees have approved it as a food additive [12]. Its structure was elucidated in 1910 and it was in fact the first known diarylheptanoid, a class of compounds containing a 7-carbon chain flanked by an aromatic ring on either side as shown in Fig. 1 [13]. It also exhibits many interesting and useful pharmacological properties. Curcumin has a unique conjugated structure including two methoxylated

* Corresponding author. Tel.: +1 402 472 5197; fax: +1 402 472 0640.
E-mail address: yyang2@unlnotes.unl.edu (Y. Yang).

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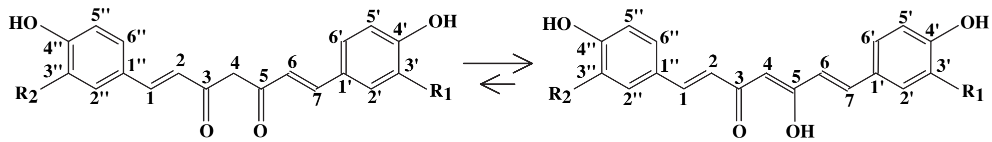

$R_1 = R_2 =$ OMe: curcumin
$R_1 =$ OMe, $R_2 =$ H: demethoxycurcumin
$R_1 = R_2 =$ H: bisdemethoxycurcumin

Fig. 1. Chemical structure of curcumin.

phenols and the enol form of β-diketone. It exists in a keto–enol tautomerism with equilibrium strongly favouring the enol form (Fig. 1). The enol structure enables curcumin to form additional inter- and intramolecular hydrogen bonds [14,15]. The mechanism for the antimicrobial activity of curcumin is not completely understood. However, the existence of methoxyl and hydroxyl groups is believed to be responsible for the antimicrobial activity [16–22].

The purpose of this research is to study the antimicrobial activity of wool fabric treated with curcumin. The relation of curcumin concentration and its antimicrobial activity on wool was investigated. Since curcumin is a yellow dye, the possibility of using simple colour measurement to predict the antimicrobial activity of the finished fabric was also explored. The durability of antimicrobial activity of curcumin-dyed wool to laundering and light exposure was also examined.

2. Methods

2.1. Materials

Pure natural curcumin was purchased from Tokyo Kasei Kogyo Co., Tokyo, Japan. The standard wool fabric (Style #541, Test Fabrics, Inc.) was used for the antimicrobial finishing. Ethyl alcohol supplied by EM Science (MERK, KGaA, Darmstadt, Germany) was used for dissolving the curcumin. Acetic acid from EMD Chemical Inc. was used for pH adjustment in wool dyeing (USA). AATCC 1993 Standard Reference Detergent without optical brightener (WOB) was used for the laundering tests.

2.2. Apparatus

Batch dyeing was carried out in the ATLAS Launder-Ometer, an AATCC Standard Instrument. Pad-dyeing was performed using an EVAC padding machine (L. & W. machine works, McConnells highway, SC). A washing machine (Kenmore, Heavy duty 70 series) and a tumble dryer (Kenmore, Heavy duty 70 series soft heat) was used for washfastness tests. Spectrophotometer measurements were performed by an Ultrascan XE HunterLab (Hunter Associates Laboratory, Inc.). ATLAS Xenon Weather-Ometer ATLAS Ci65a from ATLAS was used for the lightfastness test.

2.3. Curcumin application

Three grams of curcumin was dissolved in 100 ml of ethanol and then diluted in distilled water to a 1 L stock solution. To study the relationship between dye concentration and antimicrobial activity, fabrics were padded with 0.001, 0.005, 0.05, 0.1, 0.2 and 0.3% (w/w) of dye at a wet pick up of 100% and dried at 90 °C in a forced air oven. To investigate the relationship of antimicrobial activity and K/S and to test the durability of antimicrobial activity after colour fastness tests, wool fabrics were batch dyed with 2% (owf) of curcumin. The material-to-liquor ratio was 1:20 and temperature was raised to 90 °C over 30 min and maintained at 90 °C for 30 min at pH 5. Dyed fabric was rinsed with cold water and dried.

2.4. Antimicrobial test

AATCC Test Method 100-1999 was used to determine the antimicrobial activity of the treated wool. *Escherichia coli* (*E. coli*), a gram-negative bacterium, was selected due to its popularity of being selected as a test organism and its resistance to common antimicrobial agents [3]. *Staphylococcus aureus* (*S. aureus*), a pathogenic gram-positive bacterium, was used because it was the major cause of cross-infection in hospitals and it is the most frequently evaluated species. The gram-negative *E. coli* KCTC 1039 and the gram-positive *S. aureus* KCTC 1928 were supplied by the Korean Collection for Type Cultures in Korea. These cultures were used to test the antimicrobial effectiveness of curcumin on 3 swatches of treated wool per jar. The dilution medium was nutrient broth and the neutralizer was 1 N sodium hydroxide. To evaluate curcumin's antimicrobial activity on wool fabric, we compared the reduction in colony number between the treated and untreated fabrics after incubation. The results are expressed as percent reduction of bacteria (R) by Eq. (1).

$$R(\%) = 100(A - B)/A \quad (1)$$

where A and B are the numbers of bacteria recovered from the untreated and curcumin-treated wool fabric swatches, respectively after inoculation and incubation.

2.5. Colour fastness test

The treated samples were washed under condition III A of the AATCC Test Method 124-2001 to determine the colour change and the antimicrobial effect of fabrics after laundering. Lightfastness tests were carried out according to AATCC Test Method 16 E-1998. The fabrics were exposed to 5, 10, 20 and 40 AFUs (AATCC Fading Unit) to determine the colour change and the antimicrobial effect of fabrics after lightfastness testing.

3. Results and discussion

3.1. Dye sorption and antimicrobial activity

Fig. 2 illustrates the relation between curcumin concentration on wool and the antimicrobial activity of the treated fabric against *E. coli* and *S. aureus*. As shown, less than 0.01% of curcumin inhibits 70% *S. aureus* growth. Effective inhibition of *E. coli* required a higher concentration of curcumin. For an inhibition rate of 70% against *E. coli*, 0.05% of curcumin was necessary. An inhibition rate of more than 95% was obtained against both *S. aureus* and *E. coli* when 0.2% of curcumin was applied to the fabric. Curcumin concentration higher than 0.2% was not necessary, because the inhibition rate of both microorganisms did not improve notably with further increase in curcumin concentration.

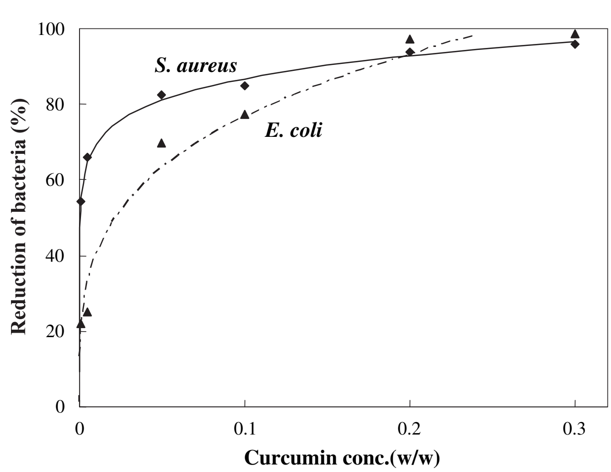

Fig. 2. Relationships between curcumin concentration and antimicrobial activity of wool fabric treated with curcumin against *S. aureus* and *E. coli*.

The curves in Fig. 2 represented the non-linear regression results of experimental data points according to Eq. (2). The satisfactory r^2 values indicated that the antimicrobial activity can be predicted from the curcumin concentration according to Eq. (2) without antimicrobial testing. Since curcumin is a colorant, the well-established methods for dye concentration measurement could be used to obtain curcumin concentration on fabric, and therefore, the antimicrobial ability of the treated fabric. The measurement of K/S value is apparently the simplest method.

$$R(\%) = aC^b \quad (2)$$

where R = % reduction of bacteria, C = % curcumin concentration, a = 146.5, b = 0.281 for *E. coli* (r^2 = 0.9724); and a = 108.6, b = 0.097 for *S. aureus*, (r^2 = 0.9919).

Fig. 3 shows the relationship of antimicrobial activity and K/S value of curcumin treated wool fabric against *E. coli* and *S. aureus*. The relationship between antimicrobial ability and K/S value obtained from experiments (data points) could be well expressed by Eq. (3), as expressed by the curves. The relatively high r^2 value demonstrated that the antimicrobial activity of curcumin finished wool could be predicted by K/S value of finished fabric.

$$\frac{1}{R} = a' + \frac{b'}{K/S} \quad (3)$$

where R = % reduction of bacteria, a' = 0.0100, b' = 0.00380 for *E. coli*, (r^2 = 0.9993) and a' = 0.0101, b' = 0.00083 for *S. aureus* (r^2 = 0.98456).

3.2. Durability to laundering and light exposure

Durability of antimicrobial activity to washing and light exposure is one of the major concerns of textile

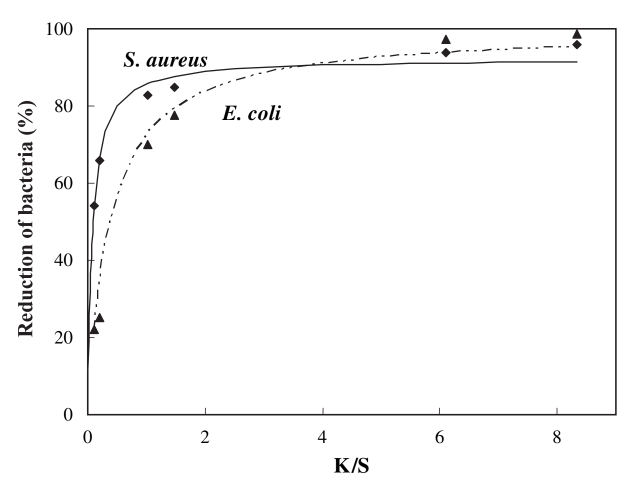

Fig. 3. Relationships between K/S and antimicrobial activity of wool fabric treated with curcumin against *S. aureus* and *E. coli*.

researchers and users because textiles are subjected to frequent laundering and light exposure. Fig. 4 depicts the durability of antimicrobial ability after repeated home launderings. As shown, the antimicrobial activity reduced with increased number of washing cycles, but no decrease after the first washing was observed. The inhibition rate of *E. coli* was reduced more than that of *S. aureus* after laundering. This result was consistent with the fact that a lower curcumin concentration was necessary for the inhibition of *S. aureus* than that of *E. coli* as shown in Fig. 2. The fabric still retained about 50% and 30% of its inhibition to *S. aureus* and *E. coli*, respectively, after 30 cycles of laundering.

The results in Fig. 4 demonstrate that curcumin had a relatively strong affinity to wool. Such affinity was considered to be due to the ionic and van der Waals attractions between curcumin and wool. The hydroxyl groups of curcumin had weak acidity because of the easy transfer of electrons to the other parts of the molecule, due to the p-π conjugation after the dissociation of the hydrogen ions. This dissociation provided negative charges to curcumin, and therefore ionic attraction to the positively charged amine groups of wool protein under acidic dyeing conditions. Once curcumin was on the wool, van der Waals forces played an important role. The existence of dipoles, induced dipoles and π–π interactions among the conjugated systems are considered to contribute to the van der Waals attraction between curcumin and wool.

Curcumin had poor resistance to light. Its yellow colour faded away after 5-AFU exposure, with the lightfastness class of L1 according to AATCC Test Method 16E-1998. However, the faded fabric still showed antimicrobial activity against *E. coli* and *S. aureus* (Fig. 5). The reduction of antimicrobial activity against *S. aureus* was evident after 5-AFU light exposure with a slight reduction from 91% to 80%. A substantial reduction to 33% was observed after 10-AFU light exposure. However, the antimicrobial activity against

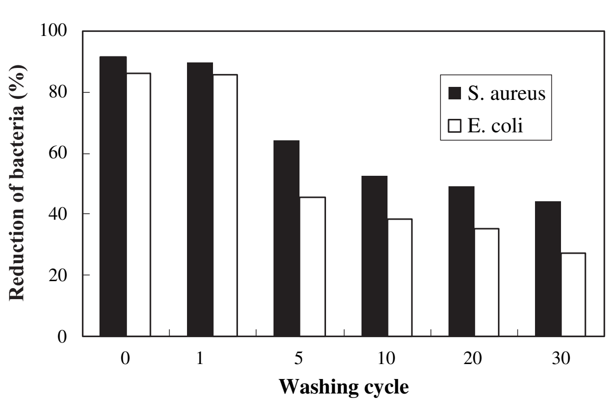

Fig. 4. Durability of antimicrobial activity of wool fabric finished with curcumin against *S. aureus* and *E. coli* to repeated home laundering.

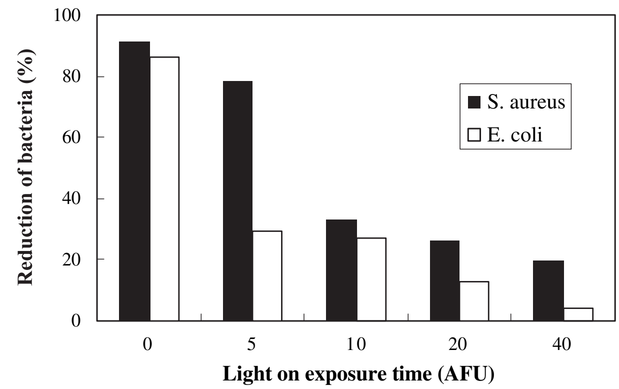

Fig. 5. Durability of antimicrobial activity of wool fabric finished with curcumin against *S. aureus* and *E. coli* to light exposure.

E. coli was dramatically decreased from 86% to 30% after 5-AFU light exposure.

Similar to laundering resistance, curcumin-treated wool had better *S. aureus* inhibition after light exposure than *E. coli* inhibition. However, the loss of more than 58% of its antimicrobial ability after exposing to 10-AFUs indicates that the antimicrobial durability of curcumin-treated wool to light was poor.

4. Conclusions

Curcumin, a common non-toxic natural dye used in textiles and food, has antimicrobial ability on wool. A common dyeing process, either pad or batch, provides wool with colour and antimicrobial properties. The antimicrobial ability of curcumin finished wool is semi-durable, more durable to home laundering than to light exposure. The inhibition rates against *S. aureus* and *E. coli* were 45% and 30%, respectively, after 30 cycles of home laundering. The inhibition rate against *S. aureus* was almost 80% after 5-AFU light exposure but started to decrease substantially after 10-AFU. The *E. coli* inhibition against light was poor. After 5-AFU exposure, the fabric retained only 30% of its original antimicrobial ability.

Quantitative relations between the inhibition rate and curcumin concentrations and K/S values of the treated wool were established. Based on these relations, antimicrobial activity of wool fabric finished with curcumin can be predicted on the strains of *S. aureus* and *E. coli* examined without antimicrobial testing.

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