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Antimicrobial Activity of Cotton Fabrics Treated with Curcumin

Narendra Reddy,[1] Shinyoung Han,[1] Yi Zhao,[1] Yiqi Yang[1,2,3]

[1]Department of Textiles, Clothing & Design, University of Nebraska-Lincoln, Lincoln, Nebraska
[2]Department of Biological Systems Engineering, University of Nebraska-Lincoln, Lincoln, Nebraska
[3]Nebraska Center for Materials and Nanoscience, University of Nebraska-Lincoln, Lincoln, Nebraska
Correspondence to: Y. Yang (E-mail: yyang2@unl.edu)

ABSTRACT: Curcumin, a yellow pigment known to have various biological activities, was applied onto cotton as an antimicrobial agent. Curcumin could provide both color and antimicrobial activity to cotton and can be dyed using a batch or continuous process. However, curcumin and cotton have low affinity and therefore the ability of curcumin to impart durable antimicrobial activity on cotton needs to be studied. In this research, the ability of curcumin dyed onto cotton fabrics to inhibit the growth of *Escherichia coli* and *Staphylococcus aureus* was studied. Relationships that can predict the rate of inhibition based on the curcumin concentration or shade depth (*K*/*S* values) were developed without the need for an antimicrobial test. Durability of antimicrobial activity to laundering and to light was also studied. Curcumin was more effective in inhibiting *S. aureus* than *E. coli*. The reduction of bacteria and durability of antimicrobial activity of curcumin to laundering was inferior on cotton fabrics compared with wool. © 2012 Wiley Periodicals, Inc. J. Appl. Polym. Sci. 000: 000–000, 2012

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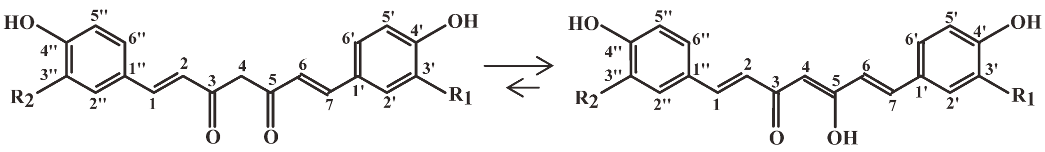
INTRODUCTION

The prevention of microbial attack on textiles has become increasingly important to consumers and textiles producers. Therefore, interests in antimicrobial fabric finishing have steadily increased over the last few years. 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 major classes of antimicrobial agents for textiles include organometallics, phenols, quaternary ammonium salt, and organosilicones. These finishes should be durable and have selective activity toward undesirable organisms.[3] In addition, antimicrobial agents should be nontoxic and biodegradable and the active ingredients used in antimicrobial finishes should be approved by federal agencies as safe chemicals for humans.[4] Several natural dyes have been reported to be effective antimicrobial agents. Tannin-rich extract from *Quercus infectoria* was found to have good activity against gram-positive and gram-negative bacteria.[5] Color extracted from onion pulp and onion skin were grafted onto cotton fabrics and the antimicrobial activity was evaluated. It was reported that the onion skin and pulp were effective against *Staphylococcus aureus*.[6] Eleven different natural dyes were evaluated for their antimicrobial activity against gram negative bacteria. It was found that seven of the 11 natural dyes evaluated had good antibacterial effect.[7]

Curcumin had been used in the Eastern and Western part of the world as a vegetable dye for coloring silk and cotton and also as an essential part of many medicines to treat certain diseases.[8] Many properties that have been attributed to curcumin in pharmacological studies have demonstrated that curcumin used in traditional medicine possess anti-inflammatory, antifungal, antitumor activities, and also as a cancer chemopreventive agent.[8–10]

Curcumin (1,7-*bis*(4-hydroxy-3-methoxyphenyl)-1,6-heptadiene-3,5-dione) is an active ingredient in turmeric (*Curcuma longa L.*), which has been used in the native medicine of East India for thousands of years. It is designated as C.I. Natural Yellow 3 that is insoluble in water, yet soluble in alcohols.[11] Its structure was elucidated in 1910 and it has many interesting and useful pharmacological properties.[10,12] Curcumin is essentially nontoxic and WHO (World Health Organization) and FAO (Food and Agriculture Organization) committees have approved it as a food additive.[11,13] Curcumin has a unique conjugated structure including two methoxylated phenols and enol form of β-diketone. It exists in a keto-enol tautomerism with



$R_1 = R_2 =$ OMe: curcumin

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

$R_1 = R_2 =$ H: bisdemethoxycurcumin

Figure 1. Chemical structure of curcumin.

equilibrium strongly favoring the enol form (Figure 1). The enol structure enables curcumin to form additional inter and intramolecular hydrogen bonds.[14,15] The mechanism for the antimicrobial activity of curcumin has not been completely understood. However, the existence of methoxyl and hydroxyl groups is believed to be responsible for the antimicrobial activity of curcumin.[16,17]

Some reports are available on using curcumin as a dye and/or antimicrobial agent. We have shown that curcumin-treated wool fabrics had antimicrobial activity that was semi-durable to home laundering and light exposure.[18] The treated fabrics had inhibition rates of 45% and 30% for *S. aureus* and *Escherichia coli* even after 30 home launderings.[18] However, treating cotton fabrics with curcumin for antibacterial activity is different than treating wool fabrics, especially in terms of the durability of the antimicrobial activity. This is because wool has positive charges and curcumin has negative charge. Because of the opposite charges, there will be strong affinity between wool and curcumin and the curcumin-treated fabrics will have good durability to laundering. However, both cotton and curcumin will have negative charge and therefore, the affinity between cotton and curcumin will be low. It is therefore interesting and useful to know if curcumin can be applied to cotton fabrics and if the antimicrobial activity of curcumin is durable to laundering.

Some studies have been conducted to understand the potential of using curcumin as a dye and antimicrobial agent on cellulosics. The fastness properties of cellulosic fibers dyed with two natural dyes (curcumin and bixin) were evaluated.[18] It was reported that curcumin-dyed fibers had average wash and light fastness rating (2.8 of 5), which was attributed to the stability of curcumin structure.[19] The antimicrobial activity of aloe vera, chitosan, and curcumin on cotton, wool, and rabbit hair was evaluated. It was found that curcumin-treated cotton fabrics had lower number of bacterial colonies but higher number of fungal colonies than curcumin-treated wool fabrics at similar concentrations of curcumin.[19] However, the type of bacteria and fungi used for the study were not reported. In addition, the durability of the antimicrobial activity of curcumin on cotton fabrics was not studied. As seen from the earlier-mentioned reports, although the antimicrobial ability on curcumin on textiles has been reported, the ability of curcumin to impart antibacterial activity to cotton fabrics is not clear. The purpose of this research is to investigate the ability of curcumin to impart antimicrobial activity onto cotton fabric and to study the relation of curcumin concentration and its antimicrobial activity on cotton. Because curcumin is a yellow dye, the possibility of using simple color measurement to predict the antimicrobial activity of the finished fabric is explored. The durability of antimicrobial activity of curcumin dyed cotton to laundering and light exposure is also examined.

EXPERIMENTAL

Materials

Natural curcumin in pure form was purchased from Tokyo Kasei Kogyo, Co., Tokyo, Japan. Standard cotton fabric (Style 400) was purchased from Test Fabrics, Inc. Chemicals necessary for the study (ethyl alcohol, sodium chloride, and acetic acid) were reagent grade chemicals purchased from VWR International, Bristol, CT. Curcumin was dissolved in ethanol and the pH of the solution was adjusted using acetic acid. AATCC Standard Reference Detergent without optical brightener (WOB) was used for the laundering test.

Methods

Batch dyeing was carried out in an ATLAS Launder-O-meter, using sealed canisters. Pad-dyeing was performed using an EVAC padding machine (L. & W. machine works, McConnells highway, SC). Laundering was done on an automatic washing machine (Kenmore, Heavy duty 70 series) and a tumble dryer

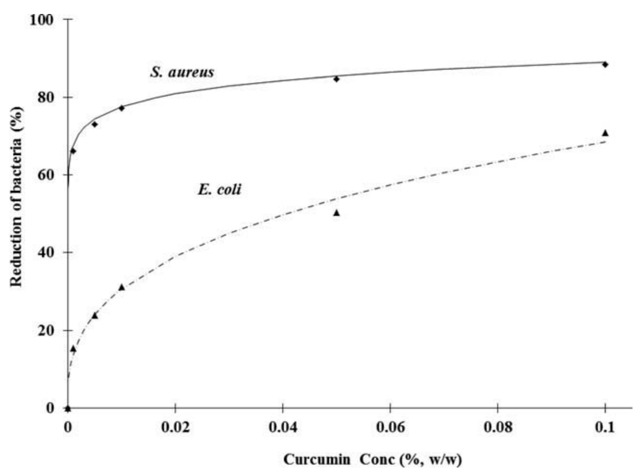


Figure 2. Relationships between curcumin concentration and antimicrobial activity of cotton fabric treated with curcumin against *S. aureus* and *E. coli.*

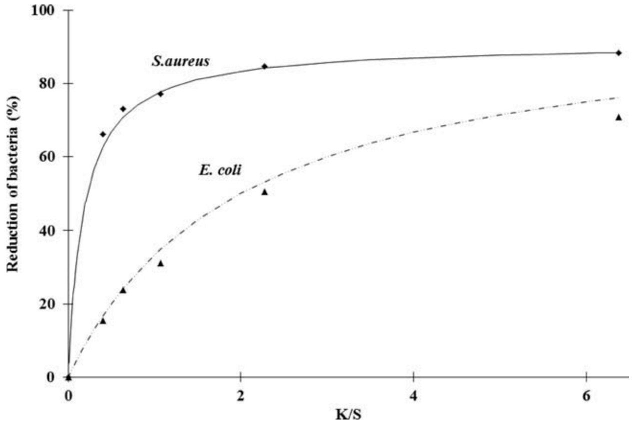


Figure 3. Relationships between *K*/*S* and antimicrobial activity of cotton fabric treated with curcumin against *S. aureus* and *E. coli*.

(Kenmore, Heavy duty 70 series) using soft heat. Spectrophotometer measurements including the specular components were performed by an Ultrascan XE HunterLab (Hunter Associates Laboratory, Inc.) using D65 and 10° illuminator with a viewing area of 1 inch. At least three samples were measured for each condition in the warp, filling and bias direction and the average and ± 1 SD was calculated. An ATLAS Xenon Weather-Ometer (ATLAS Ci65a, ATLAS electric device company) was used to evaluate the light fastness of the curcumin-treated fabrics according to AATCC standard 16 E-1998.

Curcumin Application

Three grams of curcumin were dissolved in 100 mL of ethanol and then diluted in distilled water to prepare a 1 L stock solution. To study the relationship between dye concentration, shade depth (*K*/*S*) 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. The durability of antimicrobial activity after color fastness tests was determined on cotton fabrics that were batch dyed with 2% (owf) of curcumin using a 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 using 20 g/L NaCl as a catalyst. Dyed fabrics were rinsed with cold water and dried under ambient conditions.

Antimicrobial Test

The antimicrobial activity of the treated cotton fabrics was tested according to AATCC Test Method 100-1999. *E. coli*, a gram-negative bacterium was selected due to its popularity and its resistance to common antimicrobial agents.[3] *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* Korean Collection for Type Cultures (KCTC) 1928 were supplied by KCTC in Korea. They were used to test the antimicrobial effectiveness of curcumin on four swatches of treated cotton per jar. The dilution medium was nutrient broth and the neutralizer was 1*N* sodium hydroxide. To evaluate the reduction rate of treated fabric, reduction in the number of colonies between the treated and untreated fabrics after incubation were determined. The results are expressed as percent reduction of bacteria (*R*) by eq. (1).

$$R\,(\%) = \left(\frac{A-B}{A}\right) \times 100 \qquad (1)$$

where *A* and *B* are the numbers of bacteria recovered from the untreated and curcumin-treated cotton fabric swatches, respectively, after inoculation and incubation in a jar over the desired contact period.

Color Fastness Test

The treated samples were washed under condition III A of the AATCC Test Method 124-2001 to determine the color change and the antimicrobial effect of fabrics after laundering. Light fastness test was carried out according to AATCC Test Method 16 E-1998. The fabrics were exposed to 5, 10, 20, and 40 AFU (AATCC Fading Unit) in the weather-Ometer to determine the color change and the antimicrobial effect of fabrics after exposure to light.

RESULTS AND DISCUSSION

Dye Sorption and Antimicrobial Activity

The relationship between the curcumin concentration and antimicrobial activity of the treated fabrics for the two bacteria are shown in Figure 2. As seen from the Figure, even a low curcumin concentration of 0.01% inhibited 77% of *S. aureus* but effective inhibition of *E. coli* required higher concentration of curcumin., A minimum concentration of 0.1% (10 times higher than that required to inhibit *S. aureus*) of curcumin was necessary to obtain a inhibition rate of 70% against *E. coli*. Increasing the concentration of curcumin increased the rate of inhibition for both the bacteria. Almost 90% of inhibition rate was obtained against *S. aureus* when 0.1% of curcumin was applied to the fabric. Increasing concentration of curcumin could further improve the inhibition rate but it should be noted that a very low concentration (0.01%) of curcumin could inhibit 77% of *S. aureus*. Similar results were also observed for curcumin-

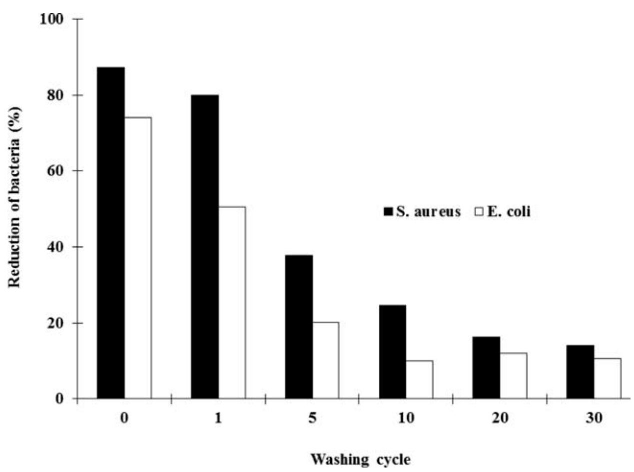


Figure 4. Durability of antimicrobial activity of cotton fabric finished with curcumin against *S. aureus* and *E. coli* to repeated home laundering.

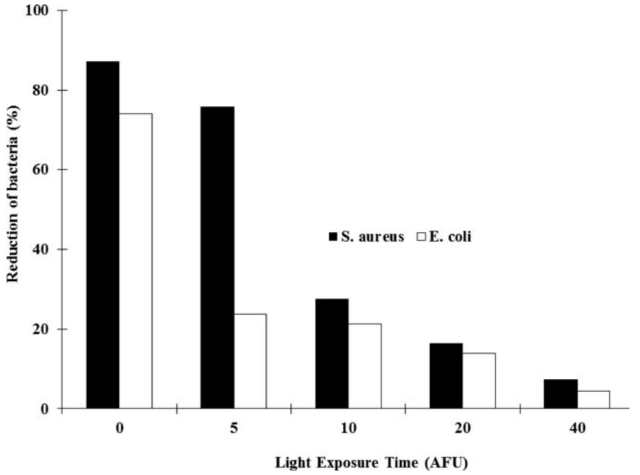


Figure 5. Durability of antimicrobial activity of cotton fabric finished with curcumin against *S. aureus* and *E. coli* to light exposure.

treated wool fabrics. Less than 0.01% of curcumin inhibited 70% of *S. aureus* but at least 0.05% of curcumin was necessary to inhibit 70% of *E. coli.*[18]

The curves in Figure 2 obtained using eq. (2) were the non-linear regression results of the experimental data points. The satisfactory R^2 values (0.9724 for *E. coli* and 0.9984 for *S. aureus)* indicated that the antimicrobial activity can be predicted from curcumin concentration without the need for an antimicrobial test. Because 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.

$$R\,(\%)\ = a\ \times\ C^b \tag{2}$$

where R = % Reduction of bacteria, C = % curcumin concentration, $a = 153.5$, $b = 0.35$ for *E. coli*, ($R^2 = 0.9724$); and $a = 102.3$, $b = 0.06$ for *S. aureus* ($R^2 = 0.9984$).

Because curcumin is a yellow dye, the measurement of K/S value is probably the simplest method to determine the concentration of curcumin. The possibility of using simple color measurement to predict the antimicrobial activity of the finished fabric was explored. Figure 3 shows the relationship of antimicrobial activity and K/S value of curcumin-treated cotton fabric against *E. coli* and *S. aureus.* The relation between antimicrobial ability and K/S value obtained from experiments (data points) could be well expressed by eq. (3), as shown by the curves. The relatively high R^2 value ($R^2 = 0.9950$) demonstrated that the antimicrobial activity of curcumin finished cotton could be predicted by measuring the K/S value of finished fabric.

$$\frac{1}{R} = a + \frac{b}{[K/S]} \tag{3}$$

where R = % reduction of bacteria, $a = 0.01$, $b = 0.02$ for *E. coli*, ($R^2 = 0.9950$) and $a = 0.011$, $b = 0.002$ for *S. aureus* ($R^2 = 0.9898$).

Durability of Curcumin to Laundering and Light Exposure

The antimicrobial activity of the curcumin-treated cotton fabrics after laundering and light exposure is shown in Figure 4. As shown, the antimicrobial activity decreased even after one laundering cycle and the decrease was more pronounced for *E. coli* than *S. aureus.* The fabrics retained ~ 40% of and 20% of its inhibition to *S. aurues* and *E. coli*, respectively, after five cycles of laundering. Inhibition rate of *E. coli* reduced more than that of *S. aureus* after laundering. This result was consistent with the fact that lower curcumin concentration was necessary for the inhibition of *S. aureus* than that of *E. coli* as shown in Figure 2. Because curcumin is very sensitive to the alkaline condition, cotton dyed with curcumin turned red when washed with alkaline soap. Alkaline conditions during the laundering will remove the curcumin from the dyed fabric.[19]

Curcumin had poor resistance to light and the dyed fabrics faded just after 5-AFU exposure and were therefore classified as having a light fastness class of L1 according to AATCC Test Method 16E-1998.However, the faded fabric still showed antimicrobial activity against *E. coli* and *S. aureus* (Figure 5). The % reduction of antimicrobial activity against *S. aureus* decreased to 76% from 87% after a light exposure of 5 AFU. A substantial reduction to 30% was observed after 10-AFU light exposure. However, the antimicrobial activity against *E. coli* was drastically decreased from 73% to 25% after 5-AFU light exposure.

Similar to laundering resistance, curcumin-treated cotton had better *S. aureus* inhibition after light exposure than *E. coli* inhibition. However, the loss of more than 60% of its antimicrobial ability after 10-AFU indicated that the antimicrobial durability of curcumin-treated cotton to light was not very good. Curcumin-treated wool fabrics had higher inhibition rates for both *S. aureus* and *E. coli* after 30 laundering cycles and 40 AFU light exposure indicating that curcumin had relatively stronger affinity to wool than cotton.[18]

CONCLUSIONS

Curcumin-treated cotton fabrics showed good antimicrobial activity to both *E. coli* and *S. aureus.* However, the inhibition was more pronounced for *S. aureus* than *E. coli* both before and after washing and exposure to light. A very low curcumin concentration of 0.01% was able to inhibit 77% of *S. aureus* whereas at least 0.1% of curcumin was necessary to observe noticeable inhibition for *E. coli.* The antimicrobial activity of curcumin decreased to 40% and 20% after five laundering cycles for *S. aureus* and *E. coli,* respectively. Curcumin had poor light fastness and the % of colonies reduced decreased to 30% after 10 AFU exposure to light. The antimicrobial activity showed a direct relationship to the concentration of curcumin. This relationship can be used to impart the desired antimicrobial activity based on the concentration of curcumin without the need for an antimicrobial test. Overall, curcumin-treated cotton fabrics showed better antimicrobial activity to *S. aureus* than *E. coli* and the antimicrobial activity was more resistant to washing than exposure to light.

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