BOHR Journal of Material Sciences and Engineering
2023, Vol. 1, No. 1, pp. 20–24
DOI: 10.54646/bjmse.2023.04
www.bohrpub.com

RESEARCH

# Investigating the effect of microwave-assisted method in dyeing 100% cotton fabric using colorants extracted from fresh turmeric

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**Received:** 09 May 2023; **Accepted:** 17 May 2023; **Published:** 02 June 2023

The researchers investigated the curcumin colorant of turmeric, extracted directly from fresh turmeric. Investigating different dyeing conditions such as pH, dye concentration, microwave power, and dyeing time to determine the optimal conditions of a 100% cotton fabric dyeing process using a complementary dyeing method with microwave assistance. Optimal results were obtained with the following parameters: extraction ratio: 1:10, dyeing: pH 2–3, dyeing ratio: 1:30, dye concentration: 100%, microwave power at the level: high, dyeing time: 3 min and using 5% mordant $CuSO_4.5H_2O$. Washing fastness testing is a way of assessing the quality of dyed samples.

**Keywords:** fresh turmeric, extract, natural colorants, cotton fabrics, microwave

## 1. Introduction

Turmeric longa) is an herbaceous perennial plant belonging to the ginger family (Zingiberaceae), with underground tubers (rhizomes). It is native to tropical Tamil Nadu, in southeastern India. Plants are harvested annually for their tubers and propagated from a portion of them the following season. Today, turmeric is cultivated and widely distributed in warm climates, including Southeast Asia, southern China, the Indian subcontinent, New Guinea, and northern Australia. (1, 2) Some species are thought to have been introduced and naturalized in other warm parts of the world, such as tropical Africa, Central America, Florida, and a variety of islands in the Pacific, Indian, and Atlantic Oceans. In Vietnam, turmeric is commonly grown in most provinces. Turmeric is an herbaceous perennial plant, 0.6–1 meter tall. The tree is tall branched, yellow-orange in color, cylindrical, and has fragrant stems and roots. The rhizome is a slightly flattened cylindrical tuber that, when broken or cut, is dark orange-yellow in color. The leaves are alternate and arranged in two rows. They are divided into leaf sheath, petiole, and leaf blade. From the leaf sheaths, pseudo-stems are formed. Leaves are oval, tapered at both ends, smooth on both sides, up to 45-cm long, and up to 18-cm wide. Leaves are sheathed, and inflorescences grow from between the leaves, forming a sparse cone. The petiole is 50–115-cm long. The single-leaf blades are usually 76–115-cm long and rarely up to 230 cm. They are 38–45-cm wide and are oblong or elliptical in shape, narrowing at the tip. Corolla has leaflets, outer petals are pale yellow-green, divided into three panicles, the upper lobe is larger, the inner petal plate is also divided into three panicles, there are two lateral columns upright and flat, lobes upright and straight, and the lower lobe has a deep trough. The genus turmeric includes 1,400 species. (3–5) The key chemical constituents of turmeric are a group of compounds known as curcumin (77%). They are phenolic compounds. Cotton is a natural cellulose fiber, so the chemical properties of cotton and cellulose fibers are similar. The growing process of industrialization causes strong impacts on the environment, resources, and human health. The materials and fuels that are synthesized for the industry have become popular and play an important role in production. (6–8), However, in recent years, the environment has been seriously damaged. In particular, the textile industry uses a lot of sources of raw materials, energy, and chemicals, as well as color additives. The researchers have pointed out that "The textile industry is the industry with the second highest level of environmental pollution compared to other industries globally". The use of products derived from nature is a trend to solve the above situation. Therefore, this study has used a microwave oven to replace the traditional dyeing method because of its quickness and convenience. All processes and results are detailed in this research paper.

## 2. Research elaborations

### 2.1. Dyeing materials and chemicals

Untreated cotton fabric is 100% woven; warp density is Pd = 25 ± 1 threads/cm; and weft density is Pn = 19 ± 1 threads/cm. Fabric weight is 180 $g/m^2$. The fabric after purchasing is washed with NaOH, soap, and $H_2O_2$ to remove the chemicals left in the pre-treatment on the fabric. Then, the fabric was cut into pieces weighing 1 ± 0.005 g (about 5.5 × 7 cm in size).

Mordanting chemicals ($FeSO_4.7H_2O$, $CuSO_4.5H_2O$, $KAl(SO_4)_2.12H_2O$, and tannic acid) are used.

### 2.2. Dye extraction from turmeric

Turmeric powder of 5 g with 100 ml of ethanol $96^0$ solution is ensured that turmeric powder is evenly dispersed in the solution with an extraction ratio of 1:10. It heats up from room temperature up to 60°C and stays at that temperature for 60 min. Then, let the mixture cool naturally at room temperature and filter the dye solution twice before starting dyeing.

### 2.3. Dyeing process

Cotton fabric (100%) is dyed with turmeric extract as follow:

Survey 1: Investigate the influence of pH on color intensity with changes in pH (pH = 2–3, pH = 6, and pH≈7–8).

Survey 2: Investigate the effect of dyeing ratios (1:20, 1:30, and 1:40).

Survey 3: Investigate the influence of dye concentrations (25%, 50%, 75%, and 100%)

Survey 4: Investigate the influence of microwave power (low, medium, and high).

Survey 5: Investigate the effect of time (2 min, 3 min, 4 min, and 5 min) without using mordant.

Survey 6: Investigate the influence of four different mordants ($FeSO_4.7H_2O$, $CuSO_4.5H_2O$, $KAl(SO_4)_2.12H_2O$, and tannic acid; each mordant is used with a different concentration of 5% by the simultaneous mordanting method).

After conducting investigations and selecting the optimal dyeing option, test the criteria for washing color fastness.

### 2.4. Color measuring and fastness determination

The following color system is used to assess the color: CIE L*a*b*. Results were examined using a spectrophotometer (Xrite Color i5, USA).

L*: Lightness of color

a*: Color coordinate on red (a*) – green (–a*) axis

b*: Color coordinates on the yellow (b*) – blue (–b*) axis

The level of coloration of the colored cotton fabric samples was determined by using the K/S value.

K/S, a value of color depth degree, is the Kubelka–Munk formula above:

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

Where R is the reflection value, K and S are the absorption and the back scattering values, respectively.

The color fastness to washing and rubbing criteria of the dyed cotton fabric samples were tested on the certificated international standards, ISO 105-X12: 01 and ISO 105-C06 A1S: 2010.

## 3. Results and discussion

### 3.1. Investigate the influence of pH

The color intensity was highest in the dyed samples at pH 2–3 ($K/S_{tb}$ = 19.24), followed by the dyed samples at pH ≈ 6 ($K/S_{tb}$ = 16.21), and the lowest in dyed samples at pH ≈ 7–8 ($K/S_{tb}$ = 14.20). Therefore, according to **Table 1** and **Figure 1**, the pH chosen for the next investigation will be in the range of 2–3.

### 3.2. Investigate the influence of the dyeing ratio

To evaluate the influence of the dyeing ratio on the color absorption ability of 100% cotton fabric according to the

**TABLE 1** | Influence of extraction pH on color parameters.

| Value | | ΔE | | $ΔE_{tb}$ | | K/S (λ = 420 nm) | | $K/S_{tb}$ |
|---|---|---|---|---|---|---|---|---|
| **Raw fabric** | | – | | – | | **0.23** | | **0.23** |
| (pH = 2–3) | 103.38 | 100.58 | 101.58 | 101.82 | 19.33 | 18.97 | 19.52 | 19.24 |
| (pH = 6) | 95.84 | 94.62 | 95.45 | 95.03 | 16.32 | 15.51 | 16.8 | 16.21 |
| (pH = 7–8) | 68.06 | 67.26 | 69.32 | 68.21 | 13.91 | 14.51 | 14.17 | 14.20 |

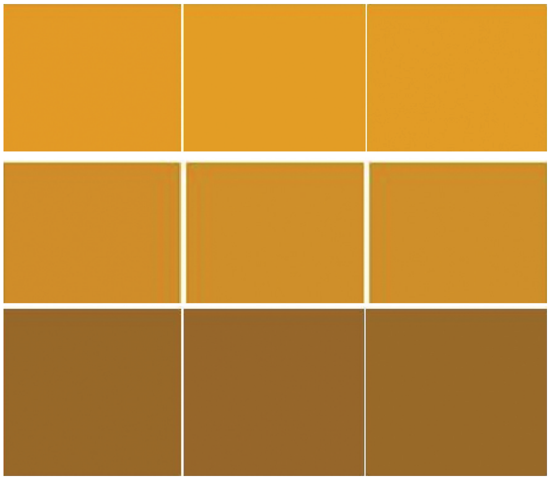

**FIGURE 1 |** Dyeing color on fabric at different pHs (upper: pH = 7–8, middle: pH = 6, bottom: pH = 2–3).

survey pH above with the conditions of microwave-assisted dyeing. The measured values are shown in **Table 2**.

The color intensity was the highest for dyed samples at 1:40 ratio ($K/S_{tb}$ = 19.36), followed by the dyed samples at 1:30 ($K/S_{tb}$ = 19.30), and the lowest for dyed samples at 1:20 ($K/S_{tb}$ = 15.58).

The color difference is the highest for dyed samples at 1:40 ratio ($\Delta E_{tb}$ = 100.46), followed by the dyed samples at 1:30 ratio ($\Delta E_{tb}$ = 99.56), and the lowest for the dyed samples at 1:20 ratio (with $\Delta E_{tb}$ = 81.52).

The change in dye ratio has an influence on the dyeing results, which is reflected in the difference between the K/S and ΔE values among the samples and the increase and decrease in the K/S and ΔE values when increasing the dyeing ratio from 1:20 to 1:30 and 1:40.

In this study, the dye ratio of 1:40 gave the highest K/S results, so the optimal dye ratio in this survey was 1:40. However, the color intensity values in the 1:40 and 1:30 ratios are not much different. So, a 1:30 ratio is selected as the optimal ratio to dye cotton fabric.

## 3.3. Investigate the influence of dyeing concentrations

The experiment is conducted on the concentration of dye solution at the following levels: 25%, 50%, 75%, 100%, high microwave power, 3-min dyeing time, and no mordanting.

The color intensity and color deviation were the highest for samples dyed at 100% concentration (K/S = 20.2 and ΔE = 103.5), followed by the samples dyed at 75% concentration (K/S = 18.16 and ΔE. = 91.59), samples dyed at 50% concentration (K/S = 15.3 and ΔE = 75.61), the lowest value for samples dyed at 25% concentration (K/S = 12.53 and Δ E = 71.45).

Changing the dye concentration affects the color in the results (both in terms of color intensity, color deviation, and visual perception) because when reducing the dye concentration from 100 to 75%, 50%, and 25%, both the values of K/S and ΔE change in a decreasing direction. When the dye concentration decreased from 100 to 75%, the K/S and ΔE values did not change much; however, when the dye concentration decreased from 75 to 50% and 25%, the K/S and ΔE values decreased significantly. The results of this investigation are presented in **Figure 2**. From **Figure 2**, we

**TABLE 2 |** Influence of dyeing ratio.

| Value | ΔE | | | $\Delta E_{tb}$ | K/S (λ = 420 nm) | | | $K/S_{tb}$ |
|---|---|---|---|---|---|---|---|---|
| **Raw fabric** | – | | | – | **0.23** | | | **0.23** |
| 1:20 | 80.48 | 81.79 | 82.30 | 81.52 | 16.12 | 15.51 | 15.13 | 15.58 |
| 1:30 | 99.85 | 100.34 | 98.51 | 99.56 | 19.32 | 18.8 | 19.8 | 19.30 |
| 1:40 | 100.22 | 101.48 | 99.70 | 100.46 | 19.50 | 19.41 | 19.17 | 19.36 |

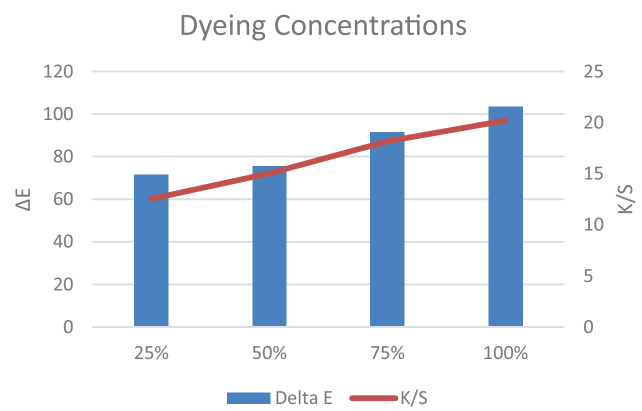


**FIGURE 2 |** Influence of dye concentration on coloring.

**TABLE 3 |** Influence of microwave power on the color of dyeing materials.

| Value | ΔE | | | $\Delta E_{tb}$ | K/S (λ = 420 nm) | | | $K/S_{tb}$ |
|---|---|---|---|---|---|---|---|---|
| **Raw fabric** | – | | | – | **0.23** | | | **0.23** |
| Low | 85.15 | 86.85 | 84.21 | 85.4 | 16.5 | 15.89 | 17.11 | 16.5 |
| Medium | 92.22 | 91.89 | 90.48 | 91.53 | 17.8 | 18.15 | 17.8 | 17.91 |
| High | 100.58 | 100.78 | 99.15 | 100.17 | 21.5 | 21.89 | 20.21 | 21.2 |

**TABLE 4 |** Influence of time on the color of dyeing materials.

| Value | ΔE | | | $\Delta E_{tb}$ | K/S (λ = 420 nm) | | | $K/S_{tb}$ |
|---|---|---|---|---|---|---|---|---|
| **Raw fabric** | – | | | – | **0.23** | | | **0.23** |
| 2 min | 90.15 | 90.52 | 92.21 | 90.96 | 18.15 | 17.89 | 18.11 | 18.05 |
| 3 min | 100.52 | 103.89 | 99.48 | 101.29 | 21.8 | 20.15 | 22.5 | 21.48 |
| 4 min | 102.85 | 102.11 | 100.15 | 101.7 | 19.55 | 20.11 | 21.15 | 20.27 |
| 5 min | 100.61 | 102.78 | 101.15 | 101.51 | 21.17 | 20.89 | 20.18 | 20.74 |

TABLE 5 | Influence of mordants to color of dyeing materials.

| M?u | ΔE | | | $\Delta E_{tb}$ | K/S (λ = 380 nm) | | | $K/S_{tb}$ |
|---|---|---|---|---|---|---|---|---|
| M?u cotton ch?a nhu?m | – | | | – | 5.23 | | | 5.23 |
| Non-mordant | 98.26 | 100.87 | 101.28 | 100.13 | 20.50 | 20.25 | 21.1 | 20.61 |
| 5% Tannic acid | 102.30 | 101.90 | 100.32 | 101.5 | 19.10 | 20.68 | 21.89 | 20.55 |
| 5% $CuSO_4.5H_2O$ | 105.89 | 103.98 | 106.21 | 105.36 | 22.5 | 21.99 | 21.23 | 21.9 |
| 5% $FeSO_4.7H_2O$ | 72.45 | 71.61 | 70.77 | 71.6 | 14.21 | 14.52 | 15.11 | 14.61 |
| 5% $KAl(SO_4)_2.12H_2O$ | 99.85 | 98.77 | 101.85 | 100.15 | 14.21 | 15.27 | 15.95 | 15.14 |

can see that 100% concentration is the optimal concentration because the highest K/S value is 20.2.

## 3.4. Investigate the influence of microwave power

The color intensity and color difference were the highest for samples dyed at high microwave power ($K/S_{tb}$ = 21.2 and $\Delta E_{tb}$ = 100.17), samples dyed at medium microwave power (K/S = 17.91 and ΔE = 91.53), and the lowest for samples dyed at low microwave power (K/S = 16.50 and Δ E = 85.4).

Priority is to choose the optimal condition based on the K/S value, so to select the microwave power, it is chosen to be high power because the largest K/S value is 21.2. All results are listed in Table 3.

## 3.5. Investigate the influence of dyeing time

The color intensity was the highest for samples dyed with a dyeing time of 3 min ($K/S_{tb}$ = 21.48), followed by the samples dyed with a dyeing time of 5 min ($K/S_{tb}$ = 20.74), followed by the samples dyed with a dyeing time of 4 min ($K/S_{tb}$ = 20.27), and the lowest for samples dyed with a dyeing time of 2 min ($K/S_{tb}$ = 18.05).

The color deviation was the highest at 4 min ($\Delta E_{tb}$ = 101.7), followed by dyeing at 5 min ($\Delta E_{tb}$ = 101.51), followed by dyeing at 3 min ($\Delta E_{tb}$ = 101.29), and the lowest for the samples dyed at 2 min ($\Delta E_{tb}$ = 90.96). According to the K/S values in Table 4, dyeing time was chosen to be 3 min because the largest K/S value is the most suitable to get dyeing efficiency.

## 3.6. Investigate the influence of mordanting to dyed color

The purpose of the survey is to test the influence of mordant on color intensity, thereby investigating the optimal mordant. Carrying out the reaction using mordants: $FeSO_4.7H_2O$, $CuSO_4.5H_2O$, $KAl(SO4)_2.12H_2O$, tannic acid, and no mordant.

The color intensity was the highest for samples dyed with $CuSO_4.5H_2O$ (K/S = 21.9), followed by the non-mordant (K/S = 20.61), followed by the tannic acid mordant (K/S = 20.55), followed by the samples dyed with mordant $KAl(SO_4)_2.12H_2O$ (K/S = 15.14), and the lowest with samples mordanted with $FeSO_4.7H_2O$ (K/S = 14.61).

The color difference was the highest for samples dyed with $CuSO_4.5H_2O$ mordant (ΔE = 105.36), followed by the samples dyed with tannic acid mordant (ΔE = 101.5), followed by the samples dyed with $KAl(SO_4)_2.12H_2O$ mordant (ΔE = 100.15), followed by the samples dyed without mordant (ΔE = 100.13), and the lowest for the samples dyed with $FeSO_4.7H_2O$ mordant (Δ E = 71.6).

Therefore, from Table 5, we can choose $CuSO_4.5H_2O$ as the mordanting chemical because the best value was achieved.

## 3.7. Determining fastness to washing on dyed fabric

Color fastness is tested many times by international standards in textiles. The grade ranges from very poor to excellent (1–5). Table 6 shows the color durability to washing of cotton fabric. Results show that mordanted cotton fabric achieved levels 3–4 of fading and staining to help improve the durability of samples.

TABLE 6 | Color fastness to washing and color of cotton fabrics.

| No mordant | | | Mordant with $CuSO_4.5H_2O$ 5% | | |
|---|---|---|---|---|---|
| Fading | | 1 | Fading | | 3–4 |
| Staining | Acetate | 1–2 | Staining | Acetate | 1–2 |
| | Cotton | 12 | | Cotton | 1–2 |
| | Nylon | 1–2 | | Nylon | 1 |
| | Polyester | 3 | | Polyester | 2 |
| | Acrylic | 3–4 | | Acrylic | 3 |
| | Wool | 2–3 | | Wool | 2 |

## 4. Conclusion

Through the process of researching, calculating, and investigating the method of dyeing cotton fabric with fresh turmeric extract using the microwave auxiliary method, we have obtained the following results: optimal conditions for natural dyeing of 100% cotton fabrics by the microwave supplement method with fresh turmeric extract with a extraction ratio 1:10 are: pH 2–3, 100% concentration, 1:30 liquor ratio, high power, 3 min, 5% $CuSO_4.5H_2O$ mordant. With minimal fading and staining, 100% cotton fabric dyed with the fresh turmeric extract using the microwave heating has a high washing fastness. This demonstrates that the ability to form a bond between colorant molecules and cotton fabric exists. Microwave-assisted dyeing technology for dyeing natural dyes hopes to be more widely applied to save energy and protect our living environment.

## Author contributions

HK has written all the content in this article. QT has checked all the formats again. Both authors contributed to the article and approved the submitted version.

## Acknowledgments

We thank to colleagues and students in Department of Textile Garment, Ho Chi Minh City University of Technology in Vietnam is used for engineering experiments, as is Thanh Cong Textile Garment in that country's capital for supporting.

## Conflict of interest

The authors declare that the article was conducted in the absence of any commercial or financial relationships that could be thought of as a conflict of interest between parties.

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