



INVESTIGATION OF MICROWAVE-ASSISTED NATURAL DYEING USING HOUSEHOLD FOOD WASTE

Scientific paper
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ABSTRACT: Nowadays, waste management goes beyond being merely an environmental necessity and plays a vital role in achieving sustainable development goals. This has increased the demand for more sustainable production methods, particularly in the textile industry, where water, energy and chemicals are used intensively. In this context, microwave-assisted dyeing has recently emerged as a popular method in sustainable natural dyeing applications due to its eco-friendly, sustainable and cost-effective nature. In this study, onion peel, a domestic food waste product, was used as a dye for 100% cotton woven fabrics. To enhance the efficiency of the dyeing process, alum ($KAl(SO_4)_2 \cdot 12H_2O$), a traditional mordant, was used, whilst pomegranate peel, spurge (*Euphorbia*) and pine cones were employed as bio-mordants. The effect of microwave-assisted dyeing, applied at different durations, on colour properties was investigated in comparison to traditional dyeing. The CIELAB colour parameter values and colour strength (K/S) values of the dyed fabrics were calculated. Principal Component Analysis (PCA) was used to examine the relationship between the parameters in greater detail. It is considered that onion peel can be effectively utilised in sustainable dyeing, particularly in microwave-assisted dyeing processes, and that the biomordants used can make a positive contribution to the dyeing process as environmentally friendly and alternative auxiliary agents. It is anticipated that the findings will contribute to the development of alternative and environmentally friendly processes in the field of natural dyeing.

Keywords: Sustainability, natural dyeing, PCA, microwave, biomordant.

MIKROTALASIMA POTPOMOGNUTO BOJENJE KORIŠĆENJEM OTPADA OD HRANE

APSTRAKT: U današnje vreme upravljanje otpadom prevazilazi samo ekološku potrebu i igra vitalnu ulogu u postizanju ciljeva održivog razvoja. Ovo je povećalo potražnju za održivijim metodama proizvodnje, posebno u tekstilnoj industriji, gde se voda, energija i



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hemikalije intenzivno koriste. U tom kontekstu, bojenje uz pomoć mikrotalasa se nedavno pojavilo kao popularna metoda u održivim procesima bojenja zbog svoje ekološke, održive i isplative prirode. U ovoj studiji, ljuska crnog luka, proizvod od otpada hrane iz domaćinstva, korišćena je kao boja za 100% pamučne tkanine. Da bi se poboljšala efikasnost procesa bojenja, korišćena je stipsa ($KAl(SO_4)_2 \cdot 12H_2O$), tradicionalno sredstvo za močenje, dok su kora nara, mlječika (*Euphorbia*) i šišarke korišćeni kao biomočila. Ispitan je efekat bojenja uz pomoć mikrotalasa, primenjenog u različitim trajanjima, na svojstva boje u poređenju sa tradicionalnim bojenjem. Izračunate su vrednosti parametara boje CIELAB i vrednosti jačine boje (K/S) obojenih tkanina. Analiza glavnih komponenti (PCA) korišćena je za detaljnije ispitivanje odnosa između parametara. Smatra se da se ljuska crnog luka može efikasno koristiti u održivom bojenju, posebno u procesima bojenja uz pomoć mikrotalasa, i da korišćena biomočila mogu pozitivno doprineti procesu bojenja kao ekološki prihvatljiva i alternativna pomoćna sredstva. Očekuje se da će nalazi doprineti razvoju alternativnih i ekološki prihvatljivih procesa u oblasti prirodnog bojenja.

Ključne reči: Održivost, prirodno bojenje, PCA, mikrotalasi, biomočila.

1. INTRODUCTION

Sustainability in the textile industry involves preserving ecological balance, preventing the depletion of natural resources, and ensuring that production does not endanger human lives. Traditional textile dyeing processes pose a serious threat to the environment and human health due to high water and energy consumption, carcinogenic and toxic effects, and the presence of heavy metals. Consequently, the adoption of eco-friendly dyeing practices has accelerated globally [1]. The integration of natural dyes, biomaterials, and advanced technologies in the textile industry aligns directly and strongly with the United Nations Sustainable Development Goals (SDGs) [2].

For natural dyeing, the roots, stems, and leaves of plants, as well as fungi, algae, insects, and various minerals, can be used. In natural dyeing, biomordants – which are entirely biological and environmentally friendly – can serve as alternatives to traditional metal mordants, which help dyes adhere more strongly to fabrics [3]. These natural dyes and biomordants can impart low toxicity, biodegradability, antimicrobial activity, antioxidant properties, and UV-protective effects to the dyed fabrics [1,4–5].

In sustainable natural dyeing processes, the microwave dyeing method can also be used as an alternative to conventional dyeing methods. Microwave dyeing enables processes to be completed in a shorter time by providing high energy efficiency. Due to rapid penetration, high yields can be achieved at lower temperatures and with reduced water usage. In these respects, it supports a sustainable production approach and is fully aligned with the Sustainable Development Goals (SDGs) [6–8].

In this study, 100% cotton fabrics were mordanted using the microwave method with various biomordants and a metal mordant. The mordanted fabrics were dyed using onion peel derived from domestic waste as a dye source, both under microwave energy for varying durations and via the conventional method. The colour properties of the samples



were evaluated using CIELAB parameters and L/B values, and the results were statistically analysed using Principal Component Analysis (PCA).

2. MATERIALS AND METHOD

A 100% cotton plain-weave fabric was used for this study.

2.1 Mordanting process

A pre-mordanting process was used in the study. Pomegranate peel, spurge (*Euphorbia*), pine cone bio-mordant, and the metal mordant aluminium potassium sulphate ($\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$) were used for mordanting. The mordanting process was conducted for 5 minutes using 700 W of microwave energy. The concentration of the mordants was set at 5% by weight of the fabric.

2.2 Dyeing process

Dye concentrations were calculated based on fabric weight; a 50% concentration (o.w.f.) of onion peel waste derived from domestic sources was utilized. The microwave dyeing process was conducted using 700 W microwave energy for 5, 7, and 15 minutes. Additionally, a conventional dyeing process was applied to the fabrics for 15 minutes at boiling temperature.

2.3 Colour measurement

Following the pre-mordanting and dyeing processes, the colour values were measured using an LS175 colourimeter. Measurements were taken under a D65 light source and 10° standard observer conditions. Reflectance (R) values were obtained in the visible range (400–700 nm) and converted to colour strength (K/S) values using the Kubelka–Munk equation (Equation 1).

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

2.4 Principle component analysis

Principal Component Analysis (PCA) was used to evaluate the relationships between the dyeing parameters and the colour characteristics of the fabrics after dyeing. PCA was performed using OriginLab 2024 software to visualise the distribution of the dyed fabrics and the correlations between the variables.

3. RESULTS AND DISCUSSION

Table 1 shows the effects of various mordant types and dyeing methods on the colour properties of fabrics.

Table 1: Colour data for dyed and mordanted fabrics

Samples	L*	a*	b*	C*	h°	λ	K/S
STD	90.46	-0.75	1.60	1.75	115.2	400	0,25
E	88.47	-0.19	5.05	5.05	92.2	400	0,30
A	90.66	-1.10	2.78	2.98	111.5	400	0,29
P	86.03	0.58	7.49	7.51	85.5	400	0,39
5MW	86.08	1.34	10.93	11.01	83.0	400	0,61
7MW	82.44	4.16	17.40	17.89	76.5	400	1,71
15MW	75.33	9.71	21.46	23.55	65.6	400	2,55
15C	81.32	5.04	18.22	18.90	74.5	400	1,65
P5MW	81.57	3.13	17.58	17.84	79.8	400	1,49
P7MW	81.53	3.79	16.02	16.45	76.6	400	1,43
P15MW	78.35	6.67	18.17	19.35	69.8	400	1,85
P15C	80.02	4.28	20.02	20.46	77.9	400	1,89
E5MW	83.51	2.74	15.05	15.28	79.6	400	1,14
E7MW	83.17	2.38	14.99	15.17	80.9	400	1,20
E15MW	75.58	9.61	21.85	23.86	66.1	400	2,82
E15C	77.08	7.93	19.24	20.81	67.6	400	2,18
A5MW	76.30	4.59	45.67	45.90	84.2	400	4,12
A7MW	70.50	9.31	54.94	55.72	80.3	400	8,00
A15MW	67.59	10.86	54.99	56.05	78.8	400	9,64
A15C	72.60	7.30	50.98	51.50	81.8	400	6,09
PC5MW	83.32	2.86	15.27	15.53	79.3	400	1,21
PC7MW	83.19	2.55	15.61	15.81	80.6	400	1,14
PC15MW	74.81	9.65	21.12	23.22	65.4	400	2,71
PC15C	79.54	5.29	18.56	19.29	74.0	400	1,90

L * Lightness (0 = black, 100 = white), ; a* ± Red/green, ; b* ± Yellow/blue, C * To vividness-dullness (100 = vivid, 0 = dull),

A: aluminium potassium sulphate ($KAl(SO_4)_2 \cdot 12H_2O$) mordant P: Pomegranate peel biomordant E: *Euphorbia* biomordant PC: Pine cone biomordant MW: Microwave dyeing C: Conventional dyeing

A decrease in L* values was observed after application, except for the aluminium-mordanted and unpainted sample. The lowest brightness value was recorded in the A15MW sample. There is an inverse relationship between application time and brightness values. Microwave dyeing caused a greater reduction in brightness than conventional dyeing over the same period. Among the mordant types, the lowest brightness was found in samples mordanted with aluminium potassium sulphate (A).

The a* values of the samples shifted towards the red region after the dyeing process. The sample with the reddest hue is coded A15MW. Samples dyed using a microwave for the same duration show higher a* values. The highest a* values are found in the samples



coded A. The b^* value, which represents the yellow and blue hue, increased in the yellow region after the mordanting and dyeing process. As with the a^* value, the highest b^* values are found in the samples coded A, with the highest value in the sample coded A15MW. The positive effect of microwave application is also evident in this value. Regarding C^* chroma values, the saturation of the samples increased after the mordanting and dyeing process. While samples mordanted with natural mordant yielded similar results, those mordanted with aluminium potassium sulphate ($KAl(SO_4)_2 \cdot 12H_2O$) (A) exhibited higher values than the other samples. When the samples are examined in terms of hue values (h°), it is evident that, except for those coded STD, E, and AL (in the yellow region), the samples fall within the orange-yellow region. The K/S value is known as colour strength. In terms of colour strength values, the dyed samples have higher values than the undyed samples, and it is generally observed that colour strength values increase with longer microwave application times. Additionally, as with other values, the best colour strength values are observed in the samples coded A, with the highest value in the A15MW sample.

In samples treated with natural mordant, the highest values are found in those labelled 'E'. The CIE $L^*a^*b^*$ chromaticity diagram clearly shows the differences in L^* and b^* values among samples without mordant, those treated with natural mordant, and those treated with aluminium mordant (Figure 1).

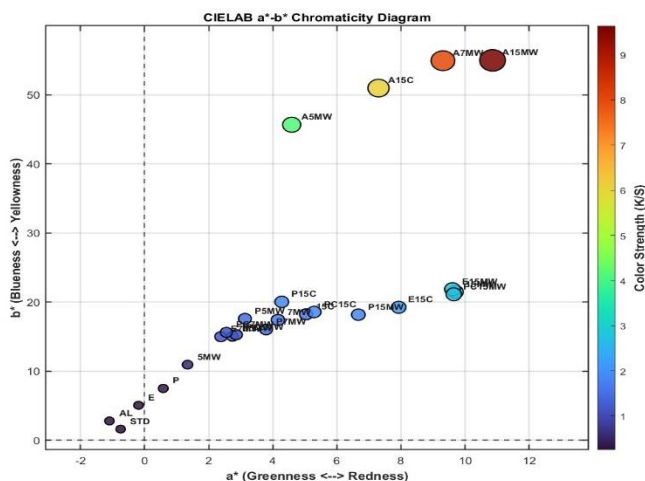


Figure 1: Cielab a^*b^* Chromaticity Diagram

The Lightness vs. Chroma Distribution graph clearly demonstrates the inverse relationship between lightness and chroma, while the clustering of the A-coded samples indicates that they have the highest chroma and lowest lightness values (Figure 2).

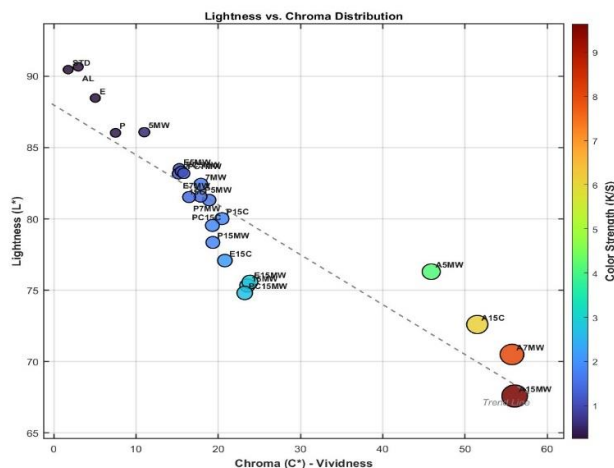


Figure 2: Lightness vs. Chroma Distribution

The visual representation of the Trend of Colour Strength across Heating Methods and Mordants also demonstrates the superiority of aluminium mordant and microwave application (Figure 3).

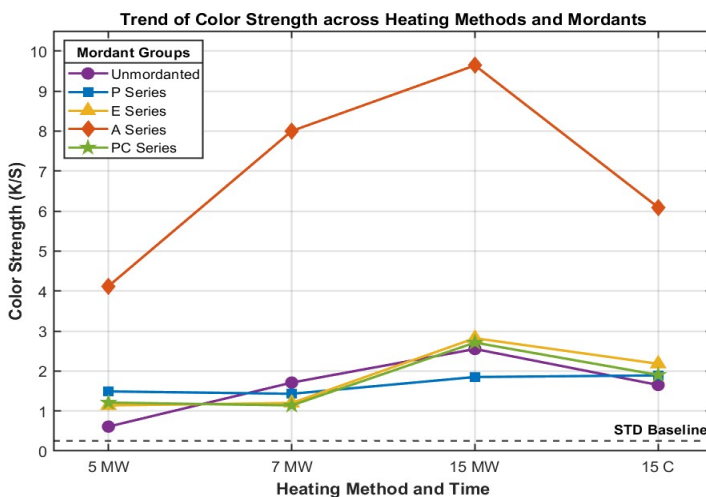


Figure 3: Trend of colour Strength across Heating Methods and Mordants

The eigenvalue plot shows that the values of PC1 and PC2 are greater than 1, indicating that the relationships between these two dimensions and the parameters can be explained (Figure 4). The PC1 and PC2 plot shows that PC1 (63.83%) and PC2 (18.49%) together

A line graph with 'Principal Component Number' on the x-axis (ranging from 0 to 10) and 'Eigenvalues' on the y-axis (ranging from 0 to 6). The graph shows a steep decline in eigenvalues for the first two components, followed by a more gradual decline. The first component has an eigenvalue of approximately 5.7, the second is approximately 1.7, and the third is approximately 0.8. From the fourth component onwards, the eigenvalues are very low, close to zero.

Principal Component Number	Eigenvalue
1	5.7
2	1.7
3	0.8
4	0.5
5	0.3
6	0.1
7	0.1
8	0.1
9	0.1

[illegible]

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4. CONCLUSION

This study has shown that the microwave method produces faster and more effective results than the traditional method when dyeing 100% cotton fabrics with onion peel waste. The analyses revealed that fabrics dyed with aluminium potassium sulphate (A) achieved the highest colour strength (K/S) and saturation values, resulting in the deepest and most vivid colour tones, especially with a 15-minute microwave application (A15MW). It was observed that as the microwave duration increased, brightness (L*) decreased while colour saturation increased. Statistical data (PCA) confirmed the strong correlation between these parameters. In conclusion, the combination of aluminium mordant and microwave energy can be considered a sustainable, efficient and high-performance alternative method for using natural waste in textile dyeing.

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