Full paper

Eco-Friendly Dyeing of Wool Yarns with *Allium cepa* Peel Extract Using an Onal-1 Mordant System

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Abstract

Some vegetable dyestuffs exhibit low affinity for natural fibers such as wool, cotton, and leather, which reduces their coloring efficiency. To enhance color uptake, transition metal salts such as copper sulfate ($CuSO_4 \cdot 5H_2O$), iron sulfate ($FeSO_4 \cdot 7H_2O$), alum ($AlK(SO_4)_2 \cdot 12H_2O$), and tin chloride ($SnCl_2$) are commonly used as mordants, which act as stabilizers. However, dyeings produced with these salts often show limited light and washing fastness. In this study, we report the dyeing of wool yarns using Onal-1 mordant, based on bovine urine, and Allium cepa peel extract, which increases color efficiency (K/S). The main components of bovine urine – urea (H_2NCONH_2), ammonia (NH_3), and calcium oxalate (CaC_2O_4) – were analyzed. The mordanting effects of individual components, binary mixtures, and ternary mixtures were evaluated experimentally, revealing that the most effective formulation was a ternary mixture of 3% urea (v/v H_2O), 3% ammonia (v/v H_2O), and 3% calcium oxalate (g/v H_2O). This Onal-1 mordant system was applied to wool yarns, and the K/S values of pretreated fibers were found to be higher than those of untreated fibers. Among all mordants tested, the highest K/S value (K/S = 29.27) was achieved using the post–mordanting method with $CuSO_4$.

Keywords wool yarn, color efficiency, dyeing, Onal-1 mordant

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1. Introduction

Natural dyes were the primary source of colorants for textiles and other materials until the advent of synthetic dyes in 1856. Historically, extracts obtained from plant parts such as roots, barks, seeds, peels, and fruits, as well as from animal tissues and microorganisms, were applied to dye fibers and fabrics using simple aqueous extraction methods [1]. Traditional dyeing practices often involved boiling plant materials to release colorants and immersing textiles directly in the resultant dye baths, without precise control over parameters such as liquor ratio or process conditions. Additionally, natural substances such as stones, soils, and clays were used as rudimentary mordants to improve dye fixation on protein fibers like wool [2, 3].

In recent decades, there has been renewed interest in natural dyes driven by concerns over the environmental and health impacts of synthetic dyes, which contribute significantly to industrial pollution and may pose toxicological risks [4]. Natural dyes are generally biodegradable, ecologically benign, and non-toxic, offering a sustainable alternative for textile applications. However, many plant-derived colorants display poor affinity for fiber substrates and limited resistance to external factors such as light and washing, resulting in suboptimal color fastness [5]. To address these limitations, traditional and modern mordanting techniques employ a range of organic and inorganic agents to enhance dye uptake and fixation.

Conventional metallic mordants such as copper sulfate ($CuSO_4$), iron sulfate ($FeSO_4$), alum ($AlK(SO_4)_2$), and tin chloride are widely used to form coordination complexes between dyes and fibers, thereby increasing color strength and fastness properties [6]. However, concerns about the environmental persistence and toxicity of heavy metal residues have motivated research into more sustainable and bio-based mordanting systems [5]. For example, recent studies have explored the use of bio-mordants derived from organic acids, plant extracts, and other renewable sources to improve dye fixation while reducing ecological impact [7].

The use of agricultural byproducts as natural dyes has gained attention as part of circular economy strategies in textile processing. In particular, *Allium cepa* (onion) peels, an abundant waste material, contain flavonoid pigments such as pelargonidin (Fig. 1), which can serve as effective colorants when appropriately applied [8]. There is growing literature on the application of onion peel extracts for textile dyeing, demonstrating promising color yields and functional properties under various mordanting conditions [9].

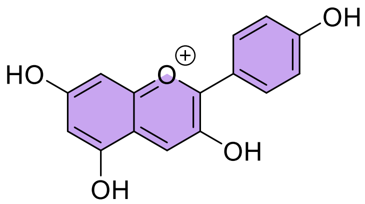

Fig. 1. The molecule of pelargonidin

The Onal-1 mordant system investigated in this study is the most important mordant developed in recent years, such that the color properties and fastness values of wool yarns or fabrics pretreated with this mordant increase considerably and give equally good results for all plant extracts [10].

2. Results and discussion

The *L**, *a**, *b**, and K/S values of wool yarns dyed with *Allium cepa* peel aqueous extract, both without pretreatment and pretreated with the Onal-1 mordant, are given in Table 1. Table 1 shows that the K/S values of wool yarns pretreated with the Onal-1 mordant are higher than those of wool fibers dyed without Onal-1 pretreatment. The highest K/S value found without Onal-1 pretreatment (K/S = 21.15) was obtained using the post–mordanting method with $CuSO_4$, followed by $FeSO_4$ (K/S = 12.14) and $AlK(SO_4)_2$ (K/S = 5.23), respectively. Among all the mordants examined, the highest K/S value (K/S = 29.27) was obtained with the post–mordanting method using $CuSO_4$ after Onal-1 pretreatment. Overall, it is noteworthy that the K/S values of wool yarns dyed after pretreatment with the Onal-1 mordant are considerably higher than those without Onal-1 pretreatment for all mordants. This increase ranges from approximately 60% to 100%.

Fastness values and color codes of wool yarns dyed without pretreatment with Onal-1 mordant are given in Table 2, and fastness values and color codes of wool yarns dyed after pretreatment with Onal-1 mordant are given in Table 3. It was determined that wool yarns dyed after pretreatment with the Onal-1 mordant exhibited higher light fastness than samples dyed without pretreatment (Tables 2 and 3).

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Table 1. L^*, a^*, b^*, c^*, h^o and K/S values of wool yarn dyed with *Allium cepa* peel extract

			Wool yarn					
	Dyeing Method	Mordant	*L**	*a**	*b**	*C**	*h^o^*	*K/S*
Unpretreated Onal-1	Pre–mordanting	$CuSO_4$	44.12	12.01	29.84	23.72	83.80	8.12
		$FeSO_4$	46.65	4.06	16.08	10.23	81.94	12.14
		$AlK(SO_4)_2$	64.51	10.76	56.90	22.26	89.78	5.23
	Meta– mordanting	$CuSO_4$	39.45	11.20	24.40	25.56	79.23	11.86
		$FeSO_4$	54.20	0.93	29.12	9.91	94.60	7.45
		$AlK(SO_4)_2$	61.82	10.02	62.74	32.23	88.91	4.82
	Post– mordanting	$CuSO_4$	42.05	11.92	30.15	24.91	81.42	21.15
		$FeSO_4$	53.57	1.28	12.57	13.40	93.10	11.92
		$AlK(SO_4)_2$	72.05	5.98	18.04	31.34	84.36	2.50
	Without mordanting	-	57.61	14.55	23.88	25.46	84.90	9.57
Pretreated Onal-1	Pre–mordanting	$CuSO_4$	29.42	5.16	16.57	25.72	81.58	20.04
		$FeSO_4$	20.25	2.97	15.29	14.50	80.25	16.20
		$AlK(SO_4)_2$	50.42	12.66	50.88	23.25	88.32	8.26
	Meta– mordanting	$CuSO_4$	30.12	5.21	16.38	11.22	80.29	21.98
		$FeSO_4$	40.32	0.98	27.12	10.33	93.22	12.01
		$AlK(SO_4)_2$	59.25	7.03	17.04	32.45	86.54	7.82
	Post– mordanting	$CuSO_4$	32.27	13.29	32.27	24.92	84.61	29.27
		$FeSO_4$	33.43	2.66	18.29	14.43	90.12	17.06
		$AlK(SO_4)_2$	49.52	2.63	19.41	32.57	84.88	5.10
	Without mordanting	–	53.57	16.42	25.24	23.91	85.90	11.43

Table 2**.** Fastness values and color codes of wool yarns dyed without using Onal-1 mordant.

Method	Mordant	Wash fastness[a]	Rubbing fastness[b] (wet–dry)	Light fastness[c]	Color code (Pantone)
Pre–	$FeSO_4$	3–4	3/4 – 4/5	3–4	15-1234
Meta–	$FeSO_4$	3	3/4 – 4/5	3–4	14-1041
Post–	$FeSO_4$	3–4	4 – 5	3	18-1430
Pre–	$CuSO_4$	4–5	4/5 – 4/5	4–5	18-0939
Meta–	$CuSO_4$	4–5	4/5 – 5	4–5	18-0840
Post–	$CuSO_4$	4–5	4/5 – 5	4	18-0435
Pre–	$AlK(SO_4)_2$	4–5	4/5 – 5	3–4	15-6904
Meta–	$AlK(SO_4)_2$	4	4/5 – 5	3–4	14-0927
Post–	$AlK(SO_4)_2$	4–5	4/5 – 5	3–4	12-0714
Without mordanting	-	3–4	3/4 – 4	2–3	17-1036

[a]Wash and [b]rub fastness 1 = poor, 2 = moderate, 3 = fairly good, 4 = good, 5 = very good, [c]Light fastness 1 = very poor, 2 = poor, 3 = moderate, 4 = fairly good, 5 = good, 6 = very good, 7 = excellent, 8 = outstanding

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Table 3. Fastness tests and color codes of wool yarns pretreated with Onal-1 mordant

Method	Mordant	Wash fastness[a]	Rubbing fastness[b] (wet–dry)	Light fastness[c]	Color code (Pantone)
Pre–	$FeSO_4$	4–5	4 – 4/5	6–7	18-1031
Meta–	$FeSO_4$	4–5	3/4 – 4/5	5–6	17-1432
Post–	$FeSO_4$	4	4/5 – 5	5–6	17-1340
Pre–	$CuSO_4$	4–5	4/5 – 4/5	6–7	18-0550
Meta–	$CuSO_4$	4–5	4/5 – 5	6–7	17-1147
Post–	$CuSO_4$	4–5	5 – 5	6	160518
Pre–	$AlK(SO_4)_2$	4–5	4/5 – 5	6–7	15-0318
Meta–	$AlK(SO_4)_2$	4–5	4/5 – 5	5–6	14-0327
Post–	$AlK(SO_4)_2$	4–5	4/5 – 5	5–6	13-0840

[a]Wash and [b]rub fastness 1 = poor, 2 = moderate, 3 = fairly good, 4 = good, 5 = very good, [c]Light fastness 1 = very poor, 2 = poor, 3 = moderate, 4 = fairly good, 5 = good, 6 = very good, 7 = excellent, 8 = outstanding

Wool yarns dyed unpretreated and pretreated with the Onal-1 mordant are shown in Figures 2 and 3.

Fig 2. Dyed wool yarns unpretreated with Onal-1 mordant

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Fig. 3. Dyed wool yarns pretreated with Onal-1 mordant

2.1. Dyeing mechanism

The wool molecule consists of amino acid units. Proteins are formed from amino acids that contain free amino and carboxyl groups. Therefore, wool can be considered an amphoteric compound. During wool dyeing, hydrogen bonds form between the dyestuff and the amino (–NH_2) groups of the wool.

These interactions result in stable complex compounds known as inner complexes. As previously stated, a new mordant mixture, Onal-1 (H_2NCONH_2 + NH_3 + CaC_2O_4), was applied to enhance color properties.

The colors obtained using this system are darker and brighter. This can be explained as follows: the ammonia (NH_3) in the mordant mixture opens the wool fibers and facilitates dyestuff penetration into the fiber, while urea (H_2N–CO–NH_2) increases the dye's solubility. Fiber swelling reduces the degree of aggregation of ions in the medium and facilitates the diffusion of the dyestuff into the fiber. The high diffusion rate allows rapid establishment of equilibrium and the quick elimination of irregularities in dye adsorption. The oxalate ion ($C_2O_4^{2-}$) in calcium oxalate (CaC_2O_4) increases the stability of the complex formed, thereby contributing to higher fastness and K/S values.

Proposed dyeing mechanism between wool and dyestuff can be seen in Figure 4.

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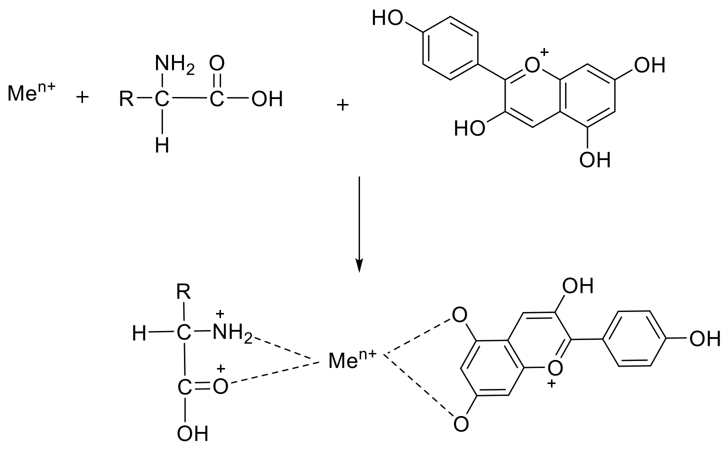

Fig. 4. Proposed dyeing mechanism between wool and dyestuff (Me^{n+}: Metal salt cation, Cu^{2+}, Fe^{2+}, Al^{3+})

The Onal-1 dyeing mechanism is shown schematically below in two steps:

Step 1. [Wool yarn + Onal-1 mordant (H_2NCONH_2+ NH_3+ CaC_2O_4)]
Leave at room temperature for 24 hours.

Step 2. Wool yarns pretreated with Onal-1 mordant are dyed according to the mordanting methods.

To summarize our previous studies demonstrating the effectiveness of the Onal-1 mordant: in wool yarn dyeing with the roots of *Alkanna tinctoria*, the light fastness values measured for $FeSO_4$, $CuSO_4$ and $AlK(SO_4)_2$ mordants were higher in dyeings performed with the Onal-1 mordant [10]. In a study conducted using pomegranate fruit extract, light fastness values obtained for viscose, linen fabric, and wool at pH 4 and pH 7 were higher (5–6) when the Onal-1 mordant was applied [11]. In a comprehensive study using red cabbage, the dyeing capacities of wool, cotton fabric, and wood samples were investigated. It was determined that the positive contribution of the Onal-1 mordant to K/S values was approximately 50% for cotton fabrics, 20% for wool fabrics, and 70–75% for wood samples [12]. In another study using white mulberry leaves [13], cotton fabric, wool yarn, polyester fabric, leather, and pine wood samples were dyed. Dyeing was performed using pre–, meta– and post–mordanting methods with the aforementioned mordants ($FeSO_4$, $CuSO_4$, $AlK(SO_4)_2$). The fastness and K/S values of samples pretreated with the Onal-1 mordant were higher than those of samples dyed without pretreatment. Therefore, the unique properties of the Onal-1 mordant were confirmed in this study.

3. Materials and methods

All chemicals and mordants ($CuSO_4.5H_2O$, $FeSO_4.7H_2O$ and $AlK(SO_4)_2.12H_2O$) were obtained from Sigma Aldrich. All chemicals were analytical grade. The *Allium cepa* peels used in the study were prepared using *Allium cepa* obtained from a local market.

3.1. Instruments

Dyeing of wool yarns or fabrics were performed with a Termal HT 610NHT model dyeing machine. A 255 model crock-meter was used for crocking fastness. Color characteristics of dyed samples were determined with a Primer Colorscan SS6200A spectrophotometer using illuminant D65 and 10^0 standard observer in terms of CIELab values (*L*, *a**, *b**, *c**) and color strength (K/S). Color strength in visible region of the spectrum (400–700 nm) was calculated based on Kubelka-Munk equation:

$$\frac{K}{S}=\frac{(1-R)^2}{2R} \quad (1)$$

Where K is the coefficient of absorption, S is the coefficient of scattering, and R is the reflectance at maximum absorbance wavelength.

In CIE Lab color space, *L*, *a*, *b* axes correspond to X, Y and Z axes respectively. CIE Lab color space system is shown in Figure 5 [14].

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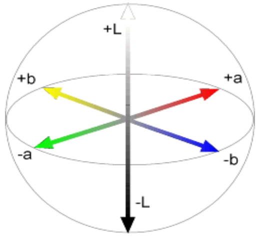

Fig. 5. CIELab color space

In the CIE Lab* color space, *L** represents lightness, *a** indicates the red–green axis, and *b** indicates the yellow–blue axis. *L** ranges from 0 (black) to 100 (white). Negative *a** values indicate greenness, while positive values indicate redness–the further from zero, the stronger the green or red component. Similarly, negative *b** values indicate blueness, and positive values indicate yellowness, with the magnitude reflecting the intensity of the color [14].

3.2. Methods

A plane-weave wool yarn (2.30 g/1 m) was scoured at 60–65 °C for 30 min using commercial ECE–2 reference detergent and then dried. Wool yarns or other materials were pretreated with 1800 mL of the Onal-1 mordant system [600 mL of urea 3% (v/v H_2O) + 600 mL of ammonia 3% (v/v H_2O) + 600 mL of calcium oxalate 3% (g/v H_2O)] at room temperature for 24 h.

Extraction of *Allium cepa* peel
20 grams of *Allium cepa* peel were extracted with distilled water using a Soxhlet-type apparatus at its boiling point until the solution became colorless (maintaining a material-to-liquor ratio of M/L = 1/100). The solution obtained from the extraction process was used in the dyeing experiments.

Dyeing Process
Without–mordanting method

Wool yarns were dyed at a liquor ratio of 1:100. The dyeing bath was maintained at a neutral pH (6.55). The dyeing temperature was held at 85 °C for 45 min. The dyed samples were then rinsed with water, thoroughly washed with cold water, pressed, and dried at room temperature.

Mordanting methods

Mordanting methods were performed as previously reported in the literature [15–17].

Pre–mordanting method

Wool yarns (1 g) were heated in 0.1 M mordant solution (100 mL) at 85 °C for 45 min. After cooling, the yarns were rinsed with distilled water and then placed into the dye bath (100 mL). The mixture was heated at 85 °C for 1 h. The dyed samples were rinsed with distilled water and dried.

Meta–mordanting method

Solid mordant salts equivalent to 0.1 M were added to the dyestuff solution along with the wool yarns, and the mixture was heated in a flask at 85 °C for 1 h. After cooling, the samples were rinsed with distilled water and dried.

Post–mordanting method

The textile samples (1 g) were first treated with the dyestuff solution at 85 °C for 1 h. After cooling, they were rinsed with distilled water and then placed into 0.1 M mordant solution (100 mL) and heated at 85 °C for 1 h. The dyed samples were finally rinsed with distilled water and dried.

4. Conclusion

The effects of Onal-1 mordant pretreatment on both mordanted and unmordanted wool yarns were investigated in terms of color strength and fastness properties. The wool yarns pretreated with the Onal-1 mordant showed enhanced dyeability. Findings from the present study suggest that wool yarns can be dyed with onion (*Allium cepa*) peels using Onal-1 pretreatment in the presence of $CuSO_4$, $FeSO_4$, and $AlK(SO_4)_2$

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mordants, achieving satisfactory wash, rubbing, and light fastness, as well as high K/S values. Further studies are needed to fully evaluate the long-term performance and environmental impacts of this mordant system.

In conclusion, this study demonstrates that sustainability, value-added utilization of waste materials, and improved color performance can be addressed simultaneously within the field of natural dyeing. The findings provide a solid scientific basis for future academic and applied research aimed at developing environmentally friendly textile dyeing processes.

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