COLOR AND UV PROTECTION PROPERTIES OF WOOL FABRICS DYED WITH NATURAL TANNINS: VALEX, MIMOSA, AND CHESTNUT EXTRACTS

Original scientific paper
DOI: 10.5937/CT_ITI25017M

Seniha Morsümbül[1]

[1]Ege University, Faculty of Engineering, Department of Textile Engineering, İzmir, Türkiye, e-mail: seniha.elemen@ege.edu.tr, ORCID ID: 0000-0002-4929-0681

ABSTRACT: *This study investigates the dyeing behavior of wool fabrics using natural tannin-based dyes, specifically valex, mimosa, and chestnut extracts, both individually and in combination. These bio-sourced colorants are rich in polyphenolic compounds and represent sustainable alternatives to synthetic dyes, aligning with the growing demand for environmentally friendly textile processes. Wool fabrics were dyed without the use of metal mordants to evaluate the natural affinity of these tannin-rich extracts for protein-based fibers. In addition to single-component dyeings, binary and ternary combinations of the extracts were tested to explore potential synergistic or modifying effects on color performance. Color yield (K/S values), color fastness to washing and rubbing, and ultraviolet protection properties (UPF) were evaluated for all dye formulations. Results indicated that all dye sources produced distinctive shades with acceptable fastness and varying levels of UV protection. Among the single dyes, valex provided the highest UV protection, while mimosa was less effective in enhancing the UV-blocking ability of wool. The combined formulations yielded intermediate or enhanced color characteristics, suggesting interactions among the tannins. These findings highlight the potential of both individual and blended natural extracts for eco-friendly wool dyeing, with the added functional benefit of UV protection.*

Keywords: *Wool dyeing, valex, mimosa, chestnut, UV protection, color fastness.*

BOJA I UV ZAŠTITNA SVOJSTVA VUNENIH TKANINA OBOJENIH PRIRODNIM TANINIMA: EKSTRAKTI VALEKSA, MIMOZE I KESTENA

APSTRAKT: *Ova studija istražuje ponašanje bojenja vunenih tkanina korišćenjem prirodnih boja na bazi tanina, konkretno ekstrakata valeksa, mimoze i kestena – kako pojedinačno, tako i u kombinaciji. Ovi biljnog porekla koloranti bogati su polifenolnim jedinjenjima i predstavljaju održivu alternativu sintetičkim bojama, u skladu sa sve većom potražnjom za ekološki prihvatljivim tekstilnim procesima. Vunene tkanine su bojene bez upotrebe metalnih mordanata, kako bi se procenila prirodna afinitetnost ovih ekstrakata*

bogatih taninom prema proteinima u vlaknima. Pored bojenja pojedinačnim ekstraktima, ispitivane su i binarne i ternarne kombinacije, sa ciljem da se istraže mogući sinergijski ili modifikujući efekti na bojene karakteristike. Za sve formulacije boja procenjeni su intenzitet boje (K/S vrednosti), postojanost na pranje i trljanje, kao i svojstva zaštite od ultraljubičastog zračenja (UPF). Rezultati su pokazali da su svi izvori boja proizveli prepoznatljive nijanse sa prihvatljivom postojanošću i različitim nivoima UV zaštite. Među pojedinačnim bojama, valeks je obezbedio najveću UV zaštitu, dok je mimoza bila manje efikasna u poboljšanju sposobnosti vune da blokira UV zračenje. Kombinovane formulacije dale su srednje ili poboljšane bojene karakteristike, što ukazuje na moguće interakcije između različitih vrsta tanina. Ova saznanja naglašavaju potencijal i pojedinačnih i mešanih prirodnih ekstrakata za ekološko bojenje vune, sa dodatnom funkcionalnom prednošću u vidu UV zaštite.

Ključne reči: *Bojenje vune, valeks, mimoza, kesten, UV zaštita, postojanost boje.*

1. INTRODUCTION

The increasing awareness of the environmental consequences of conventional textile processing has led to a growing demand for sustainable and eco-friendly alternatives across the industry. Among these, the use of natural dyes has regained attention as a viable solution for replacing synthetic colorants, which are often associated with toxicity, non-biodegradability, and harmful effluents [1]. Historically used for centuries in traditional textile practices, natural dyes are now being reconsidered within a modern framework of circular economy and green chemistry.

One group of natural dyes that holds particular promise is tannin-based plant extracts, which are not only capable of producing color but also possess mordanting properties due to their strong affinity for protein-based fibers. Tannins, being polyphenolic in nature, can form stable complexes with wool keratin without requiring the use of metal salts, making them especially attractive in the context of metal-free dyeing [2]. Among the various plant-derived tannins, valex, mimosa, and chestnut stand out for their high tannin content and commercial availability. These extracts are traditionally used as mordants or auxiliaries in natural dyeing; however, they also impart their own distinct shades and can be considered natural dyes in their own right [2-4].

Despite the known dyeing potential of these tannin sources, studies that systematically compare their behavior under controlled conditions are limited. Even less explored is the effect of combining different tannin extracts in various proportions, which may influence not only color strength and tone but also the overall fastness properties of the dyed fabric. Furthermore, tannins are known to absorb ultraviolet radiation due to their aromatic and phenolic structure [5-7], yet their contribution to UV protection in dyed wool fabrics has received relatively little attention in the literature. Understanding the extent to which these natural dyes enhance ultraviolet protection could add a valuable functional dimension to their use.

This study aims to investigate the dyeing properties of wool fabrics using valex, mimosa, and chestnut extracts—both individually and in binary and ternary mixtures—under identical dyeing conditions. In addition to evaluating color yield (K/S values), washing and

rubbing fastness, and visual appearance, the ultraviolet protection factor (UPF) of each dyed fabric was assessed to determine the functional benefits offered by these plant-derived dyes. Wool, being a naturally proteinaceous and renewable fiber, serves as an ideal substrate to examine the behavior of tannin-based dyes. The fabrics were dyed without metal mordants to assess the natural binding capacity of each extract and their mixtures. By exploring the color and functional properties imparted by both individual and blended tannin extracts, this study contributes to the development of sustainable, metal-free dyeing strategies for wool and highlights the added value of natural dyes in eco-friendly textile coloration.

2. MATERIALS AND METHODS

2.1. Materials

The scoured and bleached 100% wool fabric, woven at a weight of 145 g/m^2, was supplied by Yünsa Inc. (Tekirdağ, Türkiye) and used as received (without any further treatment prior to the experimental part). Commercial tannin extracts (valex, mimosa, and chestnut) used in this study were obtained from AR-TU Kimya (Manisa, Türkiye) and was used without any purification. Acetic acid was purchased from Merck.

2.2. Dyeing Process

The wool fabrics were dyed using an exhaust dyeing method with natural tannin-based extracts. Three different plant-derived dyes – valex, mimosa, and chestnut – were used individually and in binary and ternary combinations. All dyeings were performed at a constant concentration of 3% o.w.f. (on the weight of fabric), either as single extracts or in equal-ratio mixtures (e.g., 1.5% + 1.5% or 1% + 1% + 1%).

The dyeing process was carried out in a laboratory dyeing machine at a liquor-to-goods ratio of 20:1. The pH of the dye bath was adjusted to 4.5–5.0 using acetic acid. Dyeing was performed at 90°C for 60 minutes. After dyeing, the samples were rinsed thoroughly with warm distilled water for 15 minutes, followed by another rinse and air drying at room temperature.

2.3. Color Measurements

Colorimetric evaluations of the dyed wool fabrics were performed using a Hunterlab Ultra Scan PRO spectrophotometer. Measurements were conducted based on the CIELAB color space system, utilizing D65 standard illuminant and a 10° standard observer angle. In this color system, L* indicates the brightness of the fabric, a* describes the red-green axis, and b* corresponds to the yellow-blue axis. From these values, chroma (C*) and hue angle (h°) were also calculated to characterize color saturation and hue.

The color strength (K/S value) of each sample was determined through reflectance measurements at the wavelength of maximum absorption (400 nm), applying the Kubelka–Munk function. This equation is expressed as:

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

where *R* refers to the reflectance of the dyed fabric.

2.4. Fastness Testing

The washing fastness of the dyed wool fabrics was evaluated using a Gyrowash machine operated at 40 °C for 30 minutes. The procedure followed the ISO 105-C06 (A1S) standard, and the washing process was performed in the presence of ECE reference detergent. After washing, the samples were rinsed with water and dried at room temperature. Changes in shade and staining on adjacent fabrics were assessed using the standard grayscale method. For rubbing fastness, the ISO 105-X12 protocol was applied using a Crockmeter device. Both dry and wet rubbing tests were conducted to determine the extent of color transfer from the dyed fabric onto a white test cloth. The staining intensity was again rated by comparison to a grayscale, providing a visual scale for assessing color fastness to mechanical friction.

2.5. Ultraviolet Protection Factor Analysis

The ultraviolet protection factor (UPF) and UVR transmission (T%) properties of the dyed wool fabrics were measured using a Labsphere UV 2000F analyzer, following the AS/NZS 4399:2017 standard. Measurements were taken from four different areas on each fabric sample, and the average UPF value was calculated to ensure reliable representation of the material's UV-blocking performance.

According to the AS/NZS 4399:2017 classification, fabrics with a UPF rating of 50 or higher are considered to provide excellent protection against ultraviolet radiation. Depending on the instrument's capacity, UPF values can theoretically reach up to 2000. The categorization of UPF values based on this standard is summarized in Table 1.

Table 1: UPF rating categories and corresponding UV protection levels

Classification	UV Radiation Blocking (%)	UPF Rating
Minimum	93.3	15
Good	96.7	30
Excellent	98.0	50, 50+

3. RESULTS AND DISCUSSION

3.1. Color Properties

The colorimetric results of wool fabrics dyed with different tannin-based extracts are presented in Table 2 and visually illustrated in Figure 1. As expected, all dyed samples exhibited significant color differences compared to the undyed control, as reflected by substantial changes in L*, a*, and b* values. The fabric dyed with 3% valex showed the lowest L* value (61.43), indicating the darkest appearance among all samples, consistent with its highest K/S value (4.06). In contrast, the mimosa-dyed fabric exhibited the highest a* value (8.00), suggesting a stronger red hue component, while chestnut extract yielded the highest b* value (20.11), reflecting a more pronounced yellow tone.

Table 2: Colorimetric values of wool fabrics dyed with tannin extracts

Sample ID	L*	a*	b*	C*	h°	K/S
Undyed	86.6	-0.30	13.50	13.5	91.26	0.46
3% Valex	61.43	5.16	19.30	19.97	75.03	4.06
3% Mimosa	65.73	8.00	12.14	14.54	56.6	1.41
3% Chestnut	63.34	7.06	20.11	21.31	70.66	3.38
1.5% Valex + 1.5% Mimosa	62.40	6.55	16.26	17.53	68.07	2.82
1.5% Valex + 1.5% Chestnut	63.03	6.04	20.40	21.28	73.51	3.72
1.5% Mimosa + 1.5% Chestnut	64.54	7.64	17.16	18.78	66.01	2.42
1% Valex + 1% Mimosa + 1% Chestnut	63.02	4.33	17.39	17.92	76.01	2.91

Chroma (C*) and hue angle (h°) values further clarified the differences in color saturation and shade direction. Chestnut extract resulted in the highest C* (21.31), indicating strong color vividness. In general, binary and ternary mixtures produced intermediate color characteristics between their individual counterparts. For instance, the 1.5% Valex + 1.5% Chestnut sample showed relatively high color strength (K/S: 3.72) and saturation (C*: 21.28), demonstrating potential synergy between the two extracts. The ternary mixture (1% Valex + 1% Mimosa + 1% Chestnut) displayed a more balanced shade (h°: 76.01) and moderate K/S value (2.91), making it visually appealing despite not reaching the maximum color depth.

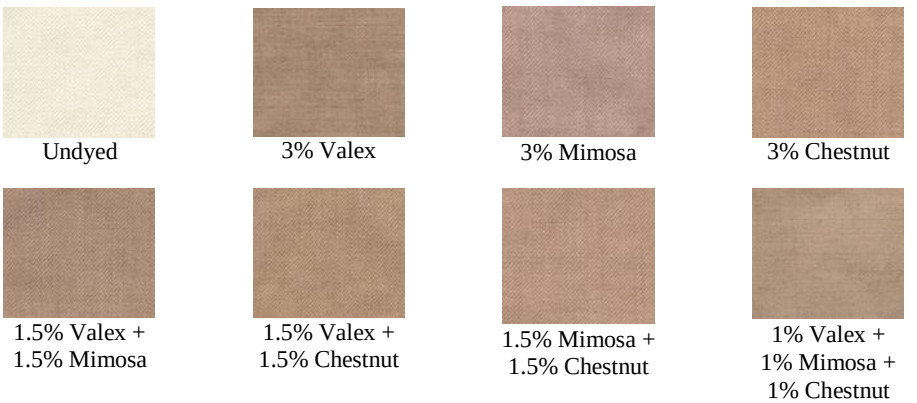

Figure 1: Visual appearance of undyed and dyed wool samples

These results confirm that not only the type of tannin extract but also the blending ratio significantly influences the color strength and tone, allowing for tunable dyeing outcomes in natural coloration of wool fabrics.

3.2. Ultraviolet Protection Properties

UPF values and UV transmittance data of the dyed wool fabrics are summarized in Table 3 and visualized in Figure 2. All dyed samples demonstrated superior UV-blocking capabilities compared to the undyed control, confirming the functional benefit of tannin-based extracts. The undyed fabric showed a UPF of 63.22, offering moderate UV protection. In contrast, fabrics dyed with valex achieved remarkably high UPF values, peaking at 1587.87, indicating nearly complete blocking of UVA and UVB rays (0.17% and 0.06% transmission, respectively).

Mimosa- and chestnut-dyed samples also exhibited significant UV protection, with UPF values of 267.54 and 783.28, respectively. Binary mixtures, such as Valex + Chestnut and Valex + Mimosa, achieved UPF ratings of 985.27 and 490.84, which fall within the "excellent protection" category as defined by the AS/NZS 4399 standard. Interestingly, the ternary mixture provided a UPF of 1116.26, suggesting a possible synergistic effect among the three extracts. This implies that combinations of tannin sources can be tailored not only for color aesthetics but also for functional UV shielding.

The reduction in UV transmission values for both UVA and UVB regions supports the hypothesis that polyphenolic compounds present in tannins contribute significantly to UV absorption. These findings reinforce the dual role of natural tannin-based dyes: providing coloration and enhancing UV protection.

Table 3: Ultraviolet Protection Factor (UPF) and transmittance of UV radiation (T%) for wool samples

Sample ID	UPF	T (UVA%)	T (UVB%)
Undyed	63.22	6.26	0.90
3% Valex	1587.87	0.17	0.06
3% Mimosa	267.54	1.66	0.20
3% Chestnut	783.28	0.44	0.10
1.5% Valex + 1.5% Mimosa	490.84	0.58	0.15
1.5% Valex + 1.5% Chestnut	985.27	0.32	0.09
1.5% Mimosa + 1.5% Chestnut	669.79	0.63	0.11
1% Valex + 1% Mimosa + 1% Chestnut	1116.26	0.47	0.06

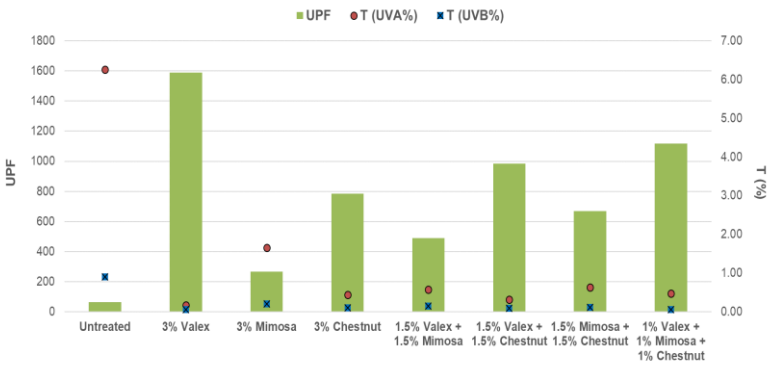

Figure 2: UPF and UV transmittance (T%) of wool samples

3.3. Fastness Properties

Fastness results presented in Table 4 indicate generally good performance for all dyed samples. Washing fastness showed no staining (grade 5) and minimal color change (4 to 5) across all formulations, confirming good fixation of tannin-based colorants to wool fibers. Rubbing fastness was also favorable, with both dry and wet tests yielding grades between 4/5 and 5.

Table 4: Fastness values of wool samples

Sample ID	Washing fastness		Rubbing fastness	
	Staining	Color change	Dry	Wet
3% Valex	5	4/5	5	4/5
3% Mimosa	5	4/5	5	5
3% Chestnut	5	3/4	5	4/5
1.5% Valex + 1.5% Mimosa	5	4/5	5	4/5
1.5% Valex + 1.5% Chestnut	5	4	5	4/5
1.5% Mimosa + 1.5% Chestnut	5	3/4	5	5
1% Valex + 1% Mimosa + 1% Chestnut	5	4/5	5	4/5

Among the individual dyes, mimosa and valex performed slightly better in rubbing fastness than chestnut. However, chestnut-containing combinations still achieved acceptable ratings. The ternary mixture displayed consistent fastness across all parameters, supporting its potential as a balanced natural dye formulation.

These results validate the application of tannin extracts as natural dyes that not only provide acceptable color fastness but also eliminate the need for metal mordants, contributing to safer and more sustainable textile processing.

4. CONCLUSION

This study demonstrated the potential of valex, mimosa, and chestnut extracts as sustainable dye sources for wool fabrics. All three extracts, both individually and in combination, produced distinct and aesthetically appealing colors with acceptable fastness properties. Valex stood out as the most effective dye in terms of color strength and UV protection, while mimosa imparted brighter tones with superior rubbing fastness.

Blending of extracts enabled intermediate and harmonious color outcomes, along with enhanced functional performance such as UV shielding. Notably, the ternary blend achieved high UPF values and good color characteristics, confirming the value of extract combinations in optimizing both appearance and function.

Overall, the findings highlight the versatility of tannin-based natural dyes in producing eco-friendly wool textiles that combine aesthetic richness with added protective features. The results provide a scientific basis for further development of multifunctional natural dyeing strategies in sustainable textile applications.

REFERENCES

[1] Pizzicato, B., Pacifico, S., Cayuela, D., Mijas, G., Riba-Moliner, M. (2023). Advancements in Sustainable Natural Dyes for Textile Applications: A Review. *Molecules*, 28(16), 5954.

[2] Benli, H. (2024). Bio-mordants: a review. *Environmental Science and Pollution Research* 31(14), 20714-20771.

[3] Che, J., Yang, X. (2022). A recent (2009–2021) perspective on sustainable color and textile coloration using natural plant resources. *Heliyon*, 8(10), e1097.

[4] Erkan, G., Şengül, K., Kaya, S. (2014). Dyeing of white and indigo dyed cotton fabrics with Mimosa tenuiflora extract. *Journal of Saudi Chemical Society*, 18(2), 139-148.

[5] Islam, M. T., Repon, M. R., Liman, M. L. R., Hossain, M. M., Al Mamun, M. A. (2021). Plant tannin and chitosan-templated cellulose for improved absorption of UV protective natural chromophores. *Sustainable Chemistry and Pharmacy*, 21, 100452.

[6] Oliviero, M., Stanzione, M., D'Auria, M., Sorrentino, L., Iannace, S., Verdolotti, L. (2019). Vegetable tannin as a sustainable UV stabilizer for polyurethane foams. *Polymers*, 11(3), 480.

[7] Grifoni, D., Bacci, L., Di Lonardo, S., Pinelli, P., Scardigli, A., Camilli, F., Romani, A. (2014). UV protective properties of cotton and flax fabrics dyed with multifunctional plant extracts. *Dyes and pigme*