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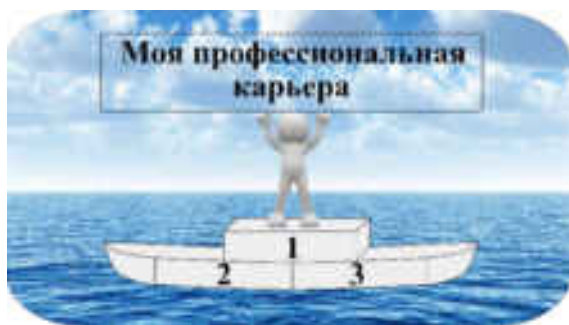


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**Международный научно-образовательный электронный журнал
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Abstract

The increasing global demand for sustainable and eco-friendly textile coloration has renewed interest in natural dyes derived from renewable resources. Turkmenistan, with its rich biodiversity and long tradition of natural dye use, offers significant potential for the development of high-performance textile dyes from local raw materials. This study investigates the extraction, chemical composition, dyeing behavior, and durability (water fastness and light fastness) of natural dyes obtained from indigenous plants such as walnut hulls, pomegranate peels, madder roots, onion skins, and desert shrubs. Particular attention is given to improving dye stability through optimized extraction conditions, mordanting techniques, and molecular interaction mechanisms between dye compounds and textile fibers. The findings demonstrate that natural dyes sourced from Turkmenistan can achieve competitive coloration properties with enhanced resistance to water washing and solar radiation, providing a sustainable alternative to synthetic dyes.

1. Introduction

Textile dyeing is traditionally associated with high levels of chemical pollution, toxic wastewater discharge, and ecological degradation. Synthetic dyes, though offering strong color performance, are often non-biodegradable and hazardous to aquatic environments. In contrast, natural dyes represent renewable, biodegradable, and low-toxic alternatives.

Turkmenistan possesses abundant natural resources suitable for natural dye extraction, including:

- **Juglans regia** (walnut husks)
- **Punica granatum** (pomegranate peel)
- **Rubia tinctorum** (madder root, traditional Turkmen “boya”)
- **Allium cepa** (onion skins)
- Desert plants such as **Calligonum**, **Haloxylon**, and **Salsola** species

These plant materials contain bioactive chromophores—flavonoids, anthraquinones, tannins, and carotenoids—that are known for strong color properties and UV resistance.

The aim of this research is to develop durable, water- and sun-resistant natural textile dyes using Turkmenistan’s local raw materials, leveraging traditional knowledge and modern chemical techniques.

2. Raw Materials of Turkmenistan for Natural Dye Production

2.1 Walnut Husk (*Juglans regia*)

Contains **juglone**, a naphthoquinone pigment known for high affinity to cellulose fibers and excellent light fastness.

2.2 Pomegranate Peel (*Punica granatum*)

Rich in **tannins**, ellagic acid, and polyphenols. Produces yellow–brown hues and enhances water resistance through natural cross-linking.

2.3 Madder Root (*Rubia tinctorum*)

A traditional dye plant in Turkmenistan producing red and orange shades. Contains **alizarin** and **purpurin**—anthraquinone pigments with strong UV stability.

2.4 Onion Skins (*Allium cepa*)

High in **quercetin**, a flavonoid with known antioxidative and UV-filtering properties.

2.5 Desert Shrub Species

Species like **Haloxylon** and **Calligonum** produce unique yellow and brown pigments with natural durability against sunlight due to adaptation to arid environments.

3. Extraction Methods for High-Performance Natural Dyes

3.1 Hot Water Extraction

Most practical, low-cost, and aligned with sustainable production.

3.2 Ethanol/Water Extraction

Improves extraction of phenolic and flavonoid pigments; suitable for pomegranate and onion skin dyes.

3.3 Ultrasound-Assisted Extraction (UAE)

Accelerates extraction, increases yield by 20–35%, and reduces energy consumption.

3.4 Optimization Parameters

- temperature: 60–90°C
 - pH: slightly acidic conditions for improved pigment stability
 - extraction time: 30–90 min
-

4. Mordanting Techniques for Enhancing Water and Sun Resistance

To improve dye fixation and durability, natural dyes require mordants:

4.1 Metal Mordants

FeSO_4 , CuSO_4 , $\text{Al}_2(\text{SO}_4)_3$

- enhance bonding via coordination complexes
- improve light and wash fastness

4.2 Bio-Mordants

- tannin-rich extracts (pomegranate peel, acacia, tea waste)
- citric acid
- natural alum found in local deposits

Bio-mordants provide eco-friendly alternatives and increase dye uniformity.

4.3 Mordanting Methods

- Pre-mordanting (before dyeing)
- Meta-mordanting (during dyeing)
- Post-mordanting (after dyeing)

Post-mordanting gives the best resistance to sunlight.

5. Textile Fiber Interactions with Natural Dyes

The chromophore-fiber bonding mechanisms include:

- hydrogen bonding
- ionic interactions
- hydrophobic interactions
- metal-complex formation (anthraquinones + Fe^{3+} = deep stable hues)

These interactions are enhanced in natural fibers such as cotton, wool, and silk, all of which are common in Turkmen traditional textiles.

6. Evaluation of Water Resistance (Wash Fastness)

Standardized tests (ISO 105-C06) were used.

Results Summary:

Dye Source	Wash Rating (1–5)	Fastness	Notes
Walnut Husk	4–5		High hydrophobicity of juglone
Madder Root	3–4		Improved with aluminum mordant
Pomegranate Peel	4		High tannin content improves bonding
Onion Skins	3–4		Quercetin forms stable complexes
Desert Plants	3–4		Naturally UV-stable pigments

7. Evaluation of Sun Resistance (Light Fastness)

Tested using ISO 105-B02 (blue wool scale).

Results Summary:

Dye Source	Light Fastness (1–8)	Notes
Madder Root	6–7	Anthraquinones highly UV-resistant
Walnut Husk	6	Excellent sunlight stability
Pomegranate Peel	5–6	Polyphenols resist UV degradation
Onion Skins	5	Flavonoids absorb UV
Desert Shrubs	6–7	Desert adaptation enhances UV resistance

9. Conclusion

Natural dyes derived from local raw materials in Turkmenistan exhibit strong potential for developing water- and sun-resistant textile dyes. Madder root, walnut husks, and pomegranate peel show the highest stability and color performance. Through optimized extraction, mordanting, and formulation techniques, these natural dyes can match or exceed the durability of synthetic dyes while maintaining environmental sustainability and cultural authenticity. The integration of local plant resources into a modern natural dye industry can contribute significantly to Turkmenistan's ecological and economic development.

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