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# Eco-friendly and low-cost phytodyeing for wool, cotton and polyester textile materials using *Parthenocissus Quinquefolia* L. Fruit Extracts

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**Abstract**: This study investigates the extraction of natural colorant from fresh fruits of P*arthenocissus quinquefolia* L. and the application of the extracted dye to wool yarn, cotton, and polyester fabrics in the presence and absence of various mordants. The effect of mordant type on the dyeing quality with different mordanting methods was examined. Iron sulfate, tin chloride, alum, copper sulfate, and potassium dichromate were used as mordant. The effects of these mordants on the color of the dyed samples were investigated in terms of CIELab (*L**, *a**, *b**) and K/S values. The light, washing and rubbing fastness of the dyed samples were evaluated according to ISO standards. While dyeing wool yarn without mordant produces reddish brown, and dyeing with mordant produces a wide range of colors from green to purple, blue and lilac tones are obtained in cotton fabric dyeing, and green, purple and brown tones are obtained in polyester fabric dyeing. While polyester fabrics are dyed with synthetic dyes at 130 °C, in this study they were dyed with natural dyes at 90 °C. As a result of dyeing, colors with high fastness are generally obtained.

**Keywords:** Natural dyes, *Parthenocissus quinquefolia* L., cotton fabric, wool yarn, polyester, fastness.

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## 1. INTRODUCTION

Dyes are generally used in textile, paper, cosmetic, food, pharmaceutical, and leather industries (Chiou et al., 2002; Banat et al., 1996). Water pollution due to discharge of non-biodegradable colored effluents from textile dye manufacturing and textile-dyeing sill is one of the major environmental concerns in the world today. Strong colors transferred by synthetic dyes to the receiving aquatic ecosystems poses aesthetic and serious ecological problems such as inhibition of benthic photosynthesis and carcinogenicity (Forgacs et al., 2004; Robinson et al., 2001). Textile industry uses high amounts of water, its wastewater being the main way by which dyes are discharged into the environment. Textile wastes are characterized by prominent color and high concentrations of organic and inorganic compounds caused by residual dyes that were not fixed to the fibers during the dyeing process (Cooper et al., 1995). These environmental problems of public health concern related to colored wastewaters containing synthetic dyes have diverted researchers urgently to look for eco-friendly products. For this reason, there has been a rapid return to natural dyes in the world (Tawfik et al., 2002).

The colorants of natural dyes that are obtained from animal or vegetable matter without chemical processing. Coloring agents of plants are derived from roots, leaves, barks, and trunks or fruits. Henna, madder, pomegranate, turmeric, walnut etc. are well-known examples of natural dyes. The introduction of natural dyes in textile dye houses is coupled to several requirements which have to be fulfilled, i.e., adaptation of traditional processes on modern equipment, and selection of material leading to product with acceptable fastness properties (Bechtold et al., 2003), However, natural dyes possess some limitations such as lesser availability, poor color yield, complexity of bond process and non-reproduce ability of shades. They offer much more advantages including renewable sources, minimal health hazard, no disposal problems and harmonization with nature (Adeel et al., 2009).

*Parthenocissus quinquefolia* L., is a deciduous climbing plant belonging to the Vitaceae family, native to North America and can be found in South Africa and Australia (Adel et al., 2021). This plant is a very widely known ivy and ornamental plant and its fruits are quite poisonous to humans. It can be said that there are many flavonoids such as anthocyanin groups and many other substances in the chemical structure of the plant. *Parthenocissus quinquefolia* L., is used for many different purposes today. While the plant itself is used to prevent erosion of the soil, it is known that in traditional medicine, some parts of it are used as an expectorant, its fruits are used to relieve rheumatism pain, its roots are used as a diuretic, and its bark and branches are used as cough syrup. It is also grown as an ornamental plant due to its pleasant appearance and perfect covering of fences and garden walls. (Benli, 2017).

In the literature, the dyestuff properties of extracts obtained from various parts of *Parthenocissus quinquefolia* L. have been investigated. Ticha et al. investigated a new phyto-dyeing process of natural fibers such as cotton, wool and silk using the natural aqueous extract of *Parthenocissus quinquefolia* L. (Ticha et al., 2017). In the study, anthocyanins, the main coloring components of the dye extract, were characterized by HPLC-MS analysis. Mentes Çolak et al. dyed wool yarns using the pre-mordanting method with *Parthenocissus quinquefolia* L. leaves (Çolak et al., 2020). The authors reported that matte colors were obtained from iron and copper salts, and light and bright colors were obtained from dyeings without alum and mordant. It has been reported in the literature that quinquefolia contains anthocyanin pigment as a natural dye.

In this article, it was investigated in detail whether the ripe purple fruits of *Parthenocissus quinquefolia* L. could be a source of natural dye. For this purpose, the dyeing properties of wool yarn, cotton fabric and polyester fabric types were examined. Dyeing was carried out according to non-mordanting (additive-free) and mordanting (pre-, meta-, post-mordanting) methods. The fastness of the colors, K/S values and Pantone color codes were determined and interpreted comparatively. According to literature research, the dye substance in *Parthenocissus quinquefolia* L. was identified as cyaniding (Benli, 2019) (Figure 1).

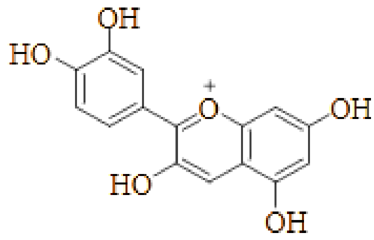


**Figure 1:** The chemical structure of cyanidine.

## 2. EXPERIMENTAL SECTION

### 2.1. Materials and chemicals

*2.1.1. Plant material*

*Parthenocissus quinquefolia* L. fruits were harvested in Tokat (Türkiye) in November 2023. The ripe purple fruits of the plant were refluxed in the soxhlet device 2 hours after collection and purple solution was obtained (w/V, 50 g/500 mL). The resulting colored solution was used in the dyeing process.

*2.1.2. Textile materials*

Prescoured wool yarn (2 nM) were obtained commercially from Tokat (Türkiye). Before use, it was bleached with a solution containing 200 mL of hydrogen peroxide and 50 mL of ammonia (30%) at 50 °C for 60 minutes at a liquor ratio of 100:6. Then, the obtained material was neutralized with formic acid solution, washed thoroughly with distilled water and dried at room temperature for 48 hours.

The bleached cotton (235 g/m$^2$) was commercially obtained from Toga Tekstil company, Tokat-Türkiye. The recommended process consists of preparing the fabric in a pre-bath containing a certain amount of cationizing agent at 50 °C for 30 minutes. Then the cotton was dried at room temperature.
The polyester fabric (185 g/m$^2$) was purchased from Toga textile company, Tokat-Türkiye.

*2.1.3. Precationizing of cotton fabric*

The recommended process consists of preparing the fabric in a pre-bath containing a certain amount of cationizing agent at 50 °C for 30 minutes. Then the cotton was dried at room temperature and the bleached cotton was commercially obtained from Tokat Toga Tekstil company.

*2.1.4. Chemicals and instrument*

Mordants (Iron sulfate, tin chloride, alum, copper sulfate, and potassium dichromate) were obtained from Merck. Extraction was performed using Soxhlet apparatus. The color properties of the dyed samples were evaluated by Premier Colorscan SS 6200A Spectrophotometer in terms of CIELab values ($L*$, $a*$, $b*$, $C*$) and color strength (K/S) values. Color codes were determined using Color Index numbers. Light fastness (Atlas weather–ometer), washing fastness (Launder–meter) and rubbing fastness (255 model crock–meter) of all dyed samples, determined according to ISO 105–C06 and CIS, were tested.

*2.1.5. Extraction of dyestuff solution from P.quinquefolia L. fruit*

50 g of fresh *Parthenocissus quinquefolia* L. fruit was refluxed using distilled water (500 mL) and became colorless in the Soxhlet apparatus. This process was continued until a total of 4 liters of colored extract was obtained, and finally, the extracts were collected when a stable color tone was obtained.

*2.1.6. Plant dyeing method without mordant*

Woolen yarns, cotton fabrics and polyester fabrics were dyed at a ratio of 50:1. The dyeing bath was kept at medium pH (6.55). The dyeing temperature was maintained at 85 °C for 45 min. The dyed samples were then rinsed with water. Finally, the fabrics were washed thoroughly with cold water, pressed and dried at room temperature.

*2.1.7. Mondanting methods*
Mordanting methods (Iron sulfate, tin chloride, alum, copper sulfate, and potassium dichromate) were performed as we have previously reported in the literature (Önal et al., 2021; Önal et al., 2023).

*Pre–mordanting method*
The textile products (5 g) were heated in 0.1 M mordant solution (100 mL) for 1 h at 90 ℃. It was heated in 0.1 M mordant solution (100 mL) for 1 h at 90 ℃. After cooling it was rinsed with distilled water and put into dye–bath solution (100 mL). It was heated at 90 ℃ for 1 h. The dyed samples were rinsed with distilled water and dried.

*Meta–mordanting method*
0.1 M mordant solution, dyestuff solution and textile materyals were heated in the flask and heated at 90 °C for 1 h. After cooling, it was rinsed and dried.

*Post–mordanting method*
The textile products (5 g) were firstly treated with the dyestuff solution at 90 °C for 1 h. After cooling, it was rinsed with distilled water and put into 0.1 M mordant solution (100 mL) and heated for 1h at 90 °C. The dyed samples were rinsed with distilled water and dried.

The dyeing diagram for all samples is given in Figure 2. In meta-mordanting, solid mordant corresponding to 0.1 M 100 mL concentration value was added to the dyestuff solution extracted from *P. Quinquefolia* L fruits, and a Flotte ratio of 1:100 was applied. The dyeing process was carried out for 60 minutes at 90 °C with a temperature increase of 1.5–2 ℃ per minute. At the end of the dyeing period, after it was left to cool to room temperature and filtered, washed with distilled water, rinsed and dried.

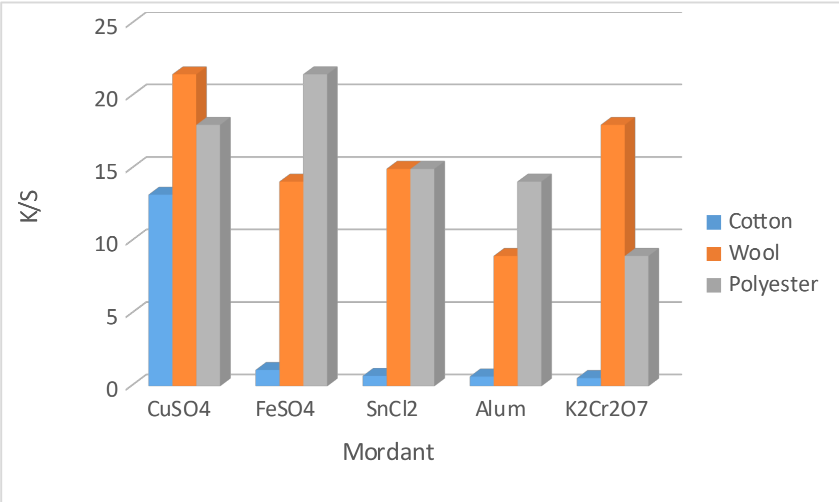


**Figure 2:** Dyeing temperature.

## 3. RESULTS AND DISCUSSION

Fastness values and color codes of dyed wool yarns, cotton fabrics, and polyester fabrics are presented in Table 1, Table 2 and Table 3, respectively.

When Table 1 is examined, the highest score in washing fastness in the final mordanting with iron sulfate was found to be 5, wet fastness as 4, dry fastness as 4–5, and light fastness as 4. Washing, wet, dry rubbing and light fastness values obtained with copper sulfate are close to 5. Dry rubbing fastness in all three mordanting methods is 5. Light fastness is on average 4-5 and is higher than iron sulfate. In pre-mordanting with alum, the washing fastness is 4-5, and the dry and wet rubbing fastness for the three mordanting methods is 5. Light fastness is 4 in pre- and meta-mordanting and 3-4 in post-mordanting. The washing, dry and wet rubbing fastnesses obtained with alum are higher than copper sulfate and iron sulfate, but are slightly lower in terms of light fastness. In dyeing with $K_2Cr_2O_7$, the fastness to washing, wet and dry rubbing is 5 for all three mordanting methods, and the fastness to light is 3-4.

**Table 1:** Fastness values and color codes of dyed cotton fabrics.

| Method | Mordant | Wash fastness[a] | Rubbing fastness[b] (wet-dry) | Light fastness[c] | Color code (Pantone) |
|---|---|---|---|---|---|
| Pre– | $FeSO_4$ | 4 – 5 | 4 – 4/5 | 3 – 4 | 7529CS |
| Meta– | $FeSO_4$ | 4 – 5 | 4 – 4/5 | 4 | 401 CS |
| Post– | $FeSO_4$ | 5 | 4/5 – 5 | 4 | 4675CS |
| Pre– | $CuSO_4$ | 5 | 5 – 4/5 | 4 – 5 | 7530 CS |
| Meta– | $CuSO_4$ | 4 – 5 | 5 – 5 | 4 – 5 | 413 CS |
| Post– | $CuSO_4$ | 4 – 5 | 5 – 5 | 4 – 5 | 726 CS |
| Pre– | $KAl(SO_4)_2$ | 4 – 5 | 5 – 5 | 4 | 406 CS |
| Meta– | $KAl(SO_4)_2$ | 5 | 5 – 5 | 4 | 454 CS |
| Post– | $KAl(SO_4)_2$ | 5 | 5 – 5 | 3/4 | 5527 CS |
| Pre– | $K_2Cr_2O_7$ | 5 | 5 – 5 | 4 | 155 CS |
| Meta– | $K_2Cr_2O_7$ | 5 | 5 – 5 | 3/4 | 474 CS |
| Post– | $K_2Cr_2O_7$ | 5 | 5 – 5 | 3/4 | 473 CS |
| Pre– | $SnCl_2$ | 5 | 5 – 5 | 4 | 7437 CS |
| Meta– | $SnCl_2$ | 5 | 5 – 5 | 4 | 7436 CS |
| Post– | $SnCl_2$ | 5 | 5 – 5 | 3/4 | 434 CS |
| | unmordant | 3 – 4 | 5 – 5 | 2 – 3 | 686 CS |

[a]Wash and [b]rubbing 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.

In dyeing with $SnCl_2$, the washing, wet and dry rubbing fastnesses for all three mordanting methods are 5, and the light fastness value is approximately the same as the $K_2Cr_2O_7$ mordant.

In dyeing without mordant, washing fastness was determined as 3/4, dry and wet rubbing fastness was determined as 5, and light fastness was determined as 2–3. Ranking according to the fastness values of mordants:

$CuSO_4$> $Kal(SO_4)_2$>$SnCl_2$>$K_2Cr_2O_7$>$FeSO_4$.

Ranking mordanting methods according to their effectiveness:

Pre-mordanting>Meta-mordanting>Post mordanting>No mordanting

In dyeing cotton fabrics without mordant, washing fastness was determined as 3–4 (medium), dry and wet rubbing fastness was determined as 5 (very good), and light fastness was determined as 1–2 (poor). Higher values were found in mordant dyeings. This result proves that the use of mordant increases fastness.

In the dyeing of cotton fabric; green, light brown color tones with copper sulfate; gray, lilac light brown color tones with iron sulfate; light lilac, beige color tones with alum, cream tones with potassium dichromate; dark lilac and light lilac color tones were obtained with stannous chloride, while a matte gray color tone were obtained in dyeing without mordant.

**Table 2:** Fastness values and color codes of dyed wool yarn.

| Method | Mordant | Wash fastness[a] | Rubbing fastness[b] (wet-dry) | Light fastness[c] | Color code (Pantone) |
|---|---|---|---|---|---|
| Pre– | $FeSO_4$ | 4/5 | 3/4 – 3 | 2/3 | 444 CS |
| Meta– | $FeSO_4$ | 4 | 3/4 – 4 | 3 | 425 CS |
| Post– | $FeSO_4$ | 4 | 4/5 – 4/5 | 3 | 404 CS |
| Pre– | $CuSO_4$ | 5 | 4/5 – 4/5 | 3/4 | 416 CS |
| Meta– | $CuSO_4$ | 5 | 3/4 – 4 | 2/3 | 446 CS |
| Post– | $CuSO_4$ | 4/5 | 4/5 – 4/5 | 2/3 | 3995 CS |
| Pre– | $KAl(SO_4)_2$ | 4/5 | 5 – 5 | 3 | WmGy 4CS |
| Meta– | $KAl(SO_4)_2$ | 4/5 | 5 – 5 | 3 | 402 CS |
| Post– | $KAl(SO_4)_2$ | 4/5 | 5 – 5 | 2/3 | WmGy 5CS |
| Pre– | $K_2Cr_2O_7$ | 5 | 4 – 5 | 3 – 4 | 7502 CS |
| Meta– | $K_2Cr_2O_7$ | 5 | 4 – 5 | 3 – 4 | 7509 CS |
| Post– | $K_2Cr_2O_7$ | 5 | 4 – 4/5 | 3 – 4 | 7511 CS |
| Pre– | $SnCl_2$ | 2/3 | 3 – 4 | 3 | 431 CS |
| Meta– | $SnCl_2$ | 3 | 3 – 3 | 3 – 4 | 451 CS |
| Post– | $SnCl_2$ | 5 | 5 – 5 | 3 | 4495 CS |
| | unmordant | 2/3 | 4/5 – 5 | 1/2 | WmGy 2CS |

[a]Wash and [b]rubbing 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.

Table 2 reveals that, the washing fastnesses for wool yarn dyeing with iron sulfate are 4-4/5 for pre- and post- mordanting methods, while it is 4 points for meta-mordanting. However, wet rubbing fastness is lower than dry rubbing fastness (3/4).

The washing fastness values (5) of wool yarn samples dyed using $CuSO_4$ mordant are slightly higher than the washing fastness values of $FeSO_4$. In dyeing with $CuSO_4$ mordant, the wet and dry rubbing fastnesses are 4 in meta- mordanting and 4/5 in pre- and post-mordanting methods. Light fastness is 2/3 for all three mordants.

The washing, wet and dry rubbing fastnesses obtained in all three mordanting methods with alum mordant are on average 4-4/5 and are higher than other mordants. The light fastness was found to be approximately 3.

The washing fastness (5), wet rubbing fastness (4), dry rubbing fastness (4/5), and light fastness (3-3/4) were found.of wool yarns mordanted with $K_2Cr_2O_7$ mordant. In wool yarn dyeing using $SnCl_2$ mordant, fastness values were found to be 2/3 in pre-mordanting, 3 in meta-mordanting and 5 in post-mordanting method. Light fastness is very close to other mordants in all three mordanting methods.

According to the no mordanting dyeing method, the washing fastness of wool yarn dyeing was found to be 2/3, while the dry rubbing fastness was found to be 5 and the wet rubbing fastness was found to be 2/3.

In dyeing with wool yarn without mordant, washing fastness was determined as 2-3 (moderate), dry and wet rubbing fastness was determined as 4-5 (very good), light fastness was determined as 1-2 (poor). Higher values were found in mordanted dyeings. This result shows that the use of mordant increases the fastness.

If we were to rank them in terms of fastness values; we can write it as:
$CuSO_4$> $K_2Cr_2O_7$> $KAl(SO_4)_2$>$FeSO_4$ >$SnCl_2$

If we were to rank the mordanting method in terms of its effectiveness; we can write it as:

Pre-mordanting > Meta-mordanting > Post mordanting > No mordanting

In wool yarn dyeing with *P. Quinquefolia* extract, green and purplish green; bluish green with iron sulfate; gray and light green with alum; brown with potassium dichromate; Bluish green, dark green and light brown color tones were obtained with stannous chloride.

**Table 3:** Fastness values and color codes of dyed polyester fabric.

| Method | Mordant | Wash fastness[a] | Rubbing fastness[b] (wet-dry) | Light fastness[c] | Color code (Pantone) |
|---|---|---|---|---|---|
| Pre– | $FeSO_4$ | 3/4 | 5 – 5 | 2/3 | 719 CS |
| Meta– | $FeSO_4$ | 4/5 | 4/5 – 4/5 | 4 | Cl Gy 5 CS |
| Post– | $FeSO_4$ | 4/5 | 5 – 5 | 4 | 406 CS |
| Pre– | $CuSO_4$ | 3/4 | 5 – 5 | 3/4 | Wm Gy5CS |
| Meta– | $CuSO_4$ | 3/4 | 5 – 5 | 4/5 | Wm Gy3CS |
| Post– | $CuSO_4$ | 5 | 5 – 5 | 4/5 | Wm Gy1CS |
| Pre– | $KAl(SO_4)_2$ | 4/5 | 5 – 5 | 4 | Cl Gy 1CS |
| Meta– | $KAl(SO_4)_2$ | 4/5 | 5 – 5 | 4 | Wm Gy4CS |
| Post– | $KAl(SO_4)_2$ | 4/5 | 5 – 5 | 4/5 | 664 CS |
| Pre– | $K_2Cr_2O_7$ | 4/5 | 4/5 – 5 | 3 – 4 | 4685 CS |
| Meta– | $K_2Cr_2O_7$ | 4/5 | 4/5 – 5 | 3 – 4 | 489 CS |
| Post– | $K_2Cr_2O_7$ | 4/5 | 4/5 – 5 | 3 – 4 | 474 CS |
| Pre– | $SnCl_2$ | 4 | 5 – 5 | 3 – 4 | 503 CS |
| Meta– | $SnCl_2$ | 4/5 | 5 – 5 | 3 – 4 | 4755 CS |
| Post– | $SnCl_2$ | 4/5 | 5 – 5 | 3 | 482 CS |
| | unmordant | 1/2 | 3/4 – 4 | 1/2 | 727 CS |

[a]Wash and [b]rubbing 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.

Based on Table 3, while the washing fastness with iron sulfate mordant in polyester fabric dyeing with *P.Quinquefolia* fruit extract was found to be 4/5 for all three mordanting methods, wet and dry rubbing fastnesses were determined to be close to each other (4/5-5). Light fastness was determined in pre-mordanting (2/3), meta-and in the post- mordanting (4).

The fastness values found with copper sulfate are very close to those of iron sulfate.

Washing fastnesses obtained with alum for all three mordanting methods are (4/5), wet and dry rubbing fastnesses are (5), and light fastnesses are approximately (4). As a result of dyeing with $K_2Cr_2O_7$, washing fastness (4/5), wet and dry fastness (4/5) and light fastness (3/4) were measured.

If we were to rank them in terms of fastness values, we can write it as:

$CuSO_4$ > $KAl(SO_4)_2$ > $K_2Cr_2O_7$ > $SnCl_2$ > $FeSO_4$

If we were to rank the mordanting method in terms of its effectiveness we can write as:

Pre-mordanting > Meta-mordanting > Post mordanting > No mordanting

In dyeing of polyester fabric without mordant, washing fastness was determined as 1-2 (poor), dry and wet rubbing fastness was determined as 3-4 (moderate), and light fastness was determined as 1-2 (poor). Higher values were found in mordant dyeings. This result evidences that the use of mordant increase the fastness.

As a result, according to Tables 1, 2 and 3, it can be deduced also that mordanting improved wash, rubbing, and light fastness properties of dyed cotton, polyester fabric and wool yarn.

Colors obtained from polyester fabric dyeings; metallic light green- metallic light brown with copper sulfate; metallic light brown – coffee with iron sulfate; metallic light lilac with alum; bright light brown with potassium dichoromate; the color tones ranging from dark lilac to light lilac were obtained with stannous choloride.

### 3.1. Determination of color performance

The pre–, meta– and post– mordanting dyed samples were investigated for fastness properties. The spectral reflectance measurements of the naturally dyed samples were determined using a spectrophotometer (Konica Minolta 3600d). Color strength was determined as K/S values of the dyed samples using the Kubelka–Munk equation (Džimbeg-Malčić et al., 2011) . K/S and *L**, *a**, *b** values of cotton fabrics, wool yarn, and polyester fabrics are given in Tables 4, 5, and 6, respectively.

**Table 4:** K/S and *L** *a** *b** values of cotton fabrics.

| Fabric | Mordant/Method | L* | a* | b* | K/S |
|---|---|---|---|---|---|
| Cotton | $FeSO_4$ (pre-) | 61.88 | –1.22 | 3.96 | 1.10 |
| | $FeSO_4$ (meta-) | 60.86 | -1.86 | 3.61 | 1.11 |
| | $FeSO_4$ (post) | 68.64 | 0.16 | 12.44 | 1.05 |
| | $CuSO_4$ (pre-) | 63.11 | -3.17 | 9.38 | 13.20 |
| | $CuSO_4$ (meta-) | 64.79 | -3.97 | 8.16 | 1.15 |
| | $CuSO_4$ (post-) | 67.85 | -0.71 | 15.29 | 1.27 |
| | $KAl(SO_4)_2$ (pre-) | 72.63 | -1.75 | 2.62 | 0.50 |
| | $KAl(SO_4)_2$ (meta-) | 72.98 | -3.10 | 8.47 | 0.66 |
| | $KAl(SO_4)_2$ (post-) | 78.63 | 0.51 | 6.88 | 0.40 |
| | $K2Cr_2O_7$ (pre-) | 77.47 | -0.13 | 11.84 | 0.52 |
| | $K2Cr_2O_7$ (post-) | 79.09 | -1.47 | 13.19 | 0.55 |
| | $K2Cr_2O_7$ (pre-) | 79.34 | 0.15 | 12.50 | 0.48 |
| | $SnCl_2$ (pre-) | 66.78 | 0.54 | -4.93 | 0.70 |
| | $SnCl_2$ (meta-) | 70.55 | -0.34 | -2.65 | 0.50 |
| | $SnCl_2$ (post-) | 76.60 | -1.43 | -2.94 | 0.34 |
| | Non – mordant | 71.68 | -2.59 | 8.26 | 0.74 |

**Table 5:** K/S and *L* a* b** values of wool yarn.

| Fabric | Mordant/Method | L* | a* | b* | K/S |
|---|---|---|---|---|---|
| Wool | $FeSO_4$ (pre-) | 38.02 | -2.56 | 6.64 | 7.02 |
| | $FeSO_4$ (meta-) | 27.52 | -1.89 | 5.51 | 14.10 |
| | $FeSO_4$ (post) | 35.15 | -2.24 | 6.54 | 8.33 |
| | $CuSO_4$ (pre-) | 41.27 | -3.12 | 17.62 | 10.00 |
| | $CuSO_4$ (meta-) | 29.89 | -4.14 | 7.54 | 13.01 |
| | $CuSO_4$ (post-) | 31.34 | 1.43 | 17.74 | 21.50 |
| | $KAl(SO_4)_2$ (pre-) | 38.65 | -1.61 | 9.39 | 8.97 |
| | $KAl(SO_4)_2$ (meta-) | 42.18 | -0.15 | 9.33 | 6.95 |
| | $KAl(SO_4)_2$ (post-) | 43.04 | -2.85 | 7.55 | 5.25 |
| | $K_2Cr_2O_7$ (pre-) | 56.88 | 1.77 | 23.04 | 4.20 |
| | $K_2Cr_2O_7$ (post-) | 52.78 | 1.39 | 26.00 | 7.00 |
| | $K_2Cr_2O_7$ (pre-) | 42.37 | 8.10 | 32.01 | 18.02 |
| | $SnCl_2$ (pre-) | 33.05 | -3.75 | 3.93 | 13.15 |
| | $SnCl_2$ (meta-) | 36.43 | -2.08 | 16.78 | 14.98 |
| | $SnCl_2$ (post-) | 45.42 | 0.37 | 22.56 | 7.95 |
| | Non – mordant | 51.06 | 5.76 | 12.49 | 4.00 |

**Table 6:** K/S and *L* a* b** values of polyester fabrics.

| Fabric | Mordant/Method | L* | a* | b* | K/S |
|---|---|---|---|---|---|
| Polyester | $FeSO_4$ (pre-) | 72.23 | 1.68 | 8.72 | 0.70 |
| | $FeSO_4$ (meta-) | 59.95 | –1.08 | 0.99 | 1.11 |
| | $FeSO_4$ (post) | 69.20 | -0.19 | 7.61 | 0.77 |
| | $CuSO_4$ (pre-) | 73.81 | -2.63 | 3.73 | 0.50 |
| | $CuSO_4$ (meta-) | 67.47 | -0.48 | 6.64 | 0.86 |
| | $CuSO_4$ (post-) | 70.41 | –0.66 | 7.11 | 0.75 |
| | $KAl(SO_4)_2$ (pre-) | 73.39 | -0.94 | 1.98 | 0.61 |
| | $KAl(SO_4)_2$ (meta-) | 68.90 | -1.28 | 2.10 | 0.60 |
| | $KAl(SO_4)_2$ (post-) | 70.47 | -0.58 | 2.43 | 0.52 |
| | $K2Cr_2O_7$ (pre-) | 73.85 | -0.13 | 4.35 | 0.57 |
| | $K2Cr_2O_7$ (post-) | 59.95 | -1.08 | 0.99 | 0.42 |
| | $K2Cr_2O_7$ (pre-) | 78.49 | -0.10 | 8.43 | 0.51 |
| | $SnCl_2$ (pre-) | 73.19 | -0.55 | 0.15 | 0.42 |
| | $SnCl_2$ (meta-) | 68.86 | -2.08 | 0.38 | 0.65 |
| | $SnCl_2$ (post-) | 72.15 | -1.02 | 0.35 | 0.55 |
| | Non – mordant | 75.66 | -3.13 | 8.83 | 0.55 |

Table 4 reveals that mordanting for cotton fabrics relatively increases color strength, especially in the case of $CuSO_4$ mordanted fabrics.

The color strength (K/S) of cotton samples decreased in the following order: $CuSO_4$ > $FeSO_4$ > $SnCl_2$ > $K_2Cr_2O_7$ > alum

Table 5 reveals that mordanting for wool yarn relatively increases color strength, especially in fabrics mordanted with $CuSO_4$. Dyeing performances of wool fabrics increase especially depending on color strength (K/S) values as follows: $CuSO_4$ > $FeSO_4$ > $K_2Cr_2O_7$ > $SnCl_2$ > alum

According to Table 6, mordanting relatively increased the color strength, especially in the case of polyester fabrics mordanted with $FeSO_4$ mordanting.

Dyeing performances of polyester fabrics increase especially depending on color strength (K/S) values as follows: $CuSO_4$ > $FeSO_4$ > $K_2Cr_2O_7$ > alum > $SnCl_2$

The highest K/S values for cotton, wool and polyester fabrics are given in Figure 3.

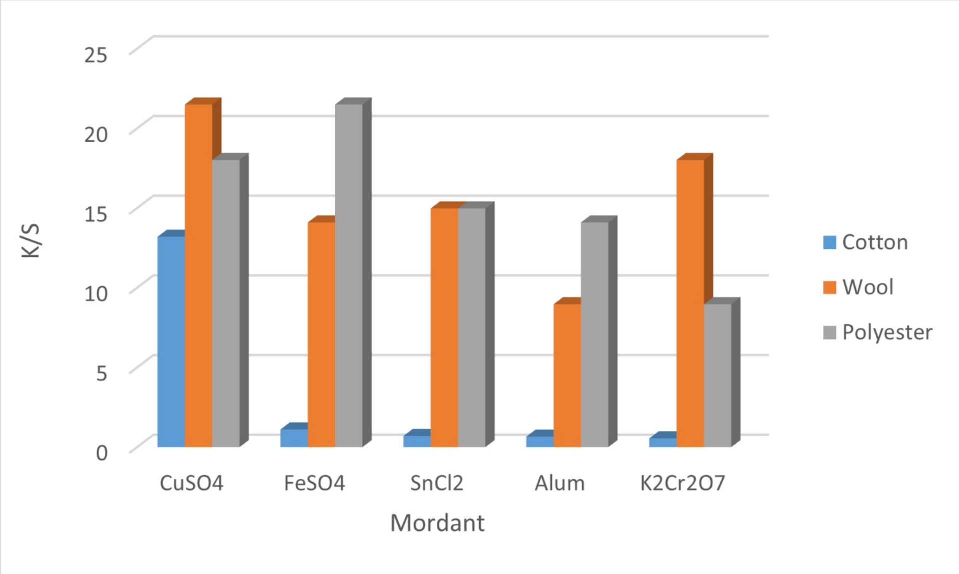


**Figure 3:** The highest K/S values for cotton, wool and polyester fabrics.

Figure 3 shows the highest K/S values for dyed cotton fabrics. While the highest value in the chart is 13.20, obtained in pre-mordanting with $CuSO_4$ mordant, these values are 1.11 in meta-mordanting with $FeSO_4$, 0.70 in pre-mordanting with $SnCl_2$, 0.66 for alum, 0.66 for $K_2Cr_2O_7$. Figure 3 shows the highest K/S value for dyed wool yarns. While the highest value of 21.50 was obtained in pre-mordanting with $CuSO_4$ mordant, these values were 18.02 in pre-mordanting with $K_2Cr_2O_7$, 14.98 in co-mordanting with $SnCl_2$, 14.10 in meta-mordanting for $FeSO_4$, and 8.97 in pre-mordanting for alum. Figure 3 shows the highest K/S value for dyed polyester fabrics. While the highest value of 1.11 was obtained in mordanting with $FeSO_4$ mordant, these values were 0.86 in pre-mordanting for $CuSO_4$, 0.65 in pre-mordanting with $SnCl_2$, 0.61 in pre-mordanting for alum, and 0.51 in pre-mordanting for $K_2Cr_2O_7$.

When the K/S values of cotton fabric, wool yarn and polyester fabrics are compared, the following order is given:

wool yarn>cotton fabric>polyester fabric

When compared in terms of K/S values, it is understood that the meta mordanting method is more effective than the pre- and post-mordanting method.

Samples of cotton fabrics, wool yarn, and polyester fabrics dyed with P*arthenocissus quinquefolia* L. fruit extract are shown in Figure 4.

### 3.2. Proposed Dyeing Mechanism

Mordant means fixative. It ensures better binding of the dye to the fiber or fabric and also increases the fastness of the dyed fiber. As mentioned before, copper sulfate, iron sulfate, alum, tin chloride, and potassium dichromate were used as mordant in this study. According to the results, it is clear that the best colorations are achieved by meta- and post-mordanting with $FeSO_4$, which can be explained by its good binding ability with anthocyanins and functional groups of fibers. Additionally, ferrous sulfate has the capacity to form coordination complexes and easily chelate with the dye molecule. From a mechanistic perspective and considering the length of the bonds, only Cyanidin, which has hydroxyl groups in the ortho position on the ring, is capable of chelating with the iron atom. As a result, the structure of the dye-mordant complex with Cyanidin and $FeSO_4$ is proposed in Figure 5. Since ferrous sulfate coordination numbers are equal to 6, some coordination sites will remain vacant during their interaction. Functional groups of the fibers can then occupy these regions. In this way, the metal can form a ternary complex in which one region binds to the fiber and the other region binds to the dye. The wool yarn dyeing mechanism is given in

Figure 3, the cotton fabric dyeing mechanism is given in Figure 6, and the polyester fabric dyeing mechanism is given in Figure 7. Mordant means fixative. It provides better bonding of the dyestuff to the fiber or fabric, and also increases the fastness of dyed fiber. As mentioned before, in this study, copper sulfate, ferrous sulfate, alum, stannous choloride and potassium dichromate were used as mordant.

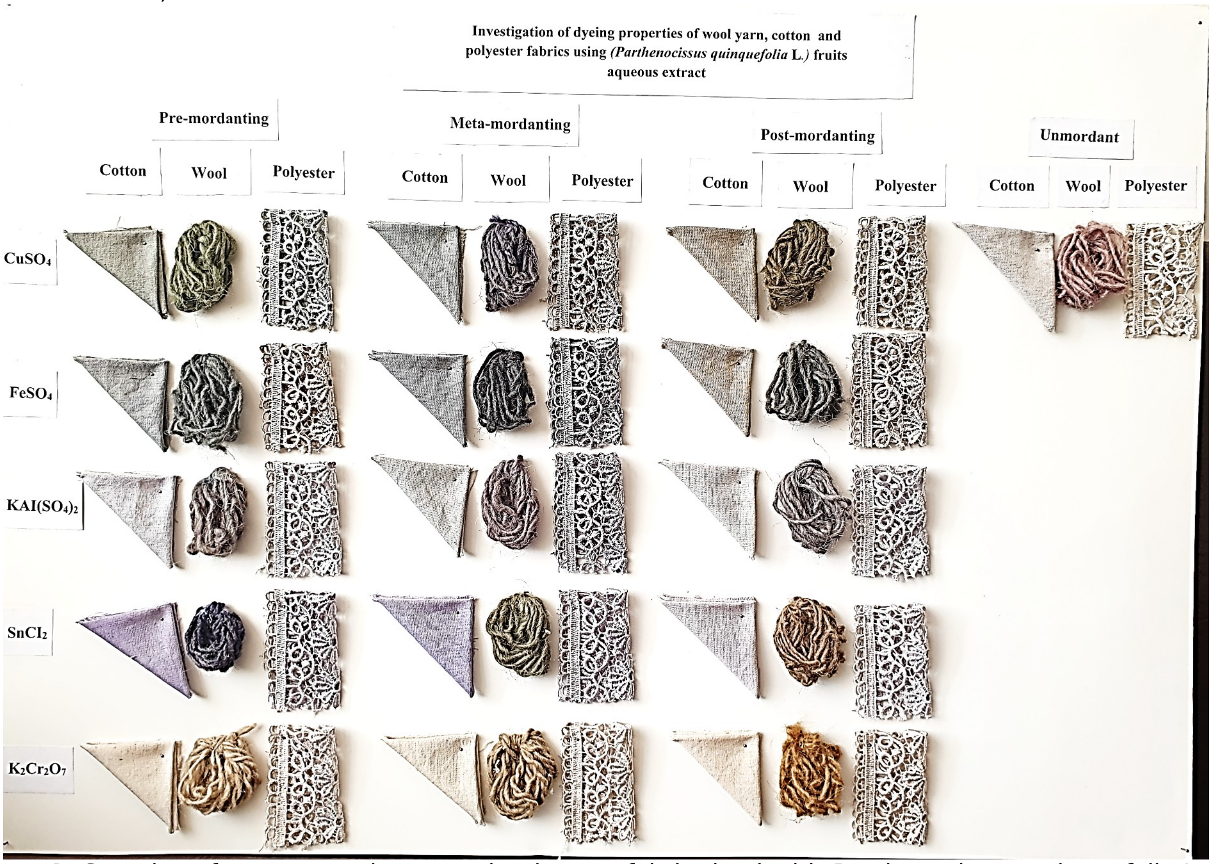


**Figure 4:** Samples of cotton, wool yarn and polyester fabric dyed with P*arthenocissus quinquefolia* L. fruit extract.

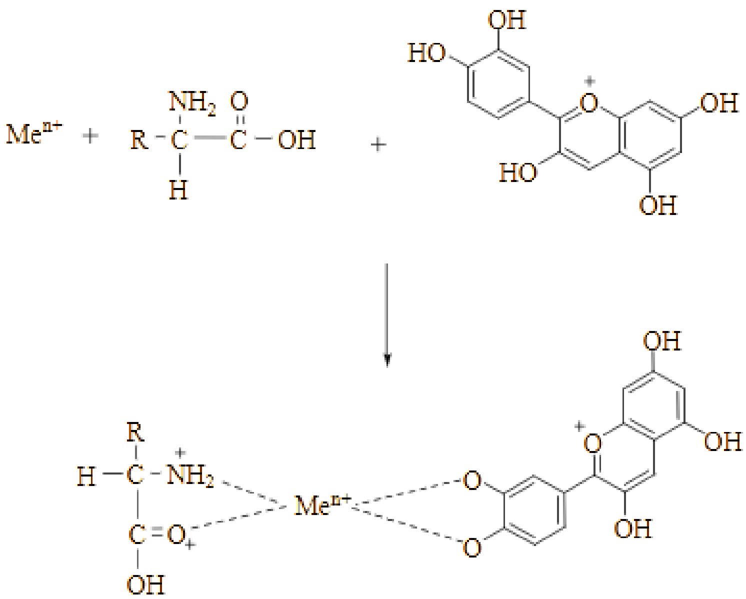


**Figure 5:** The proposed dyeing mechanism of wool yarn with cyanidine ($Me^{n+}$ : mordant cation).

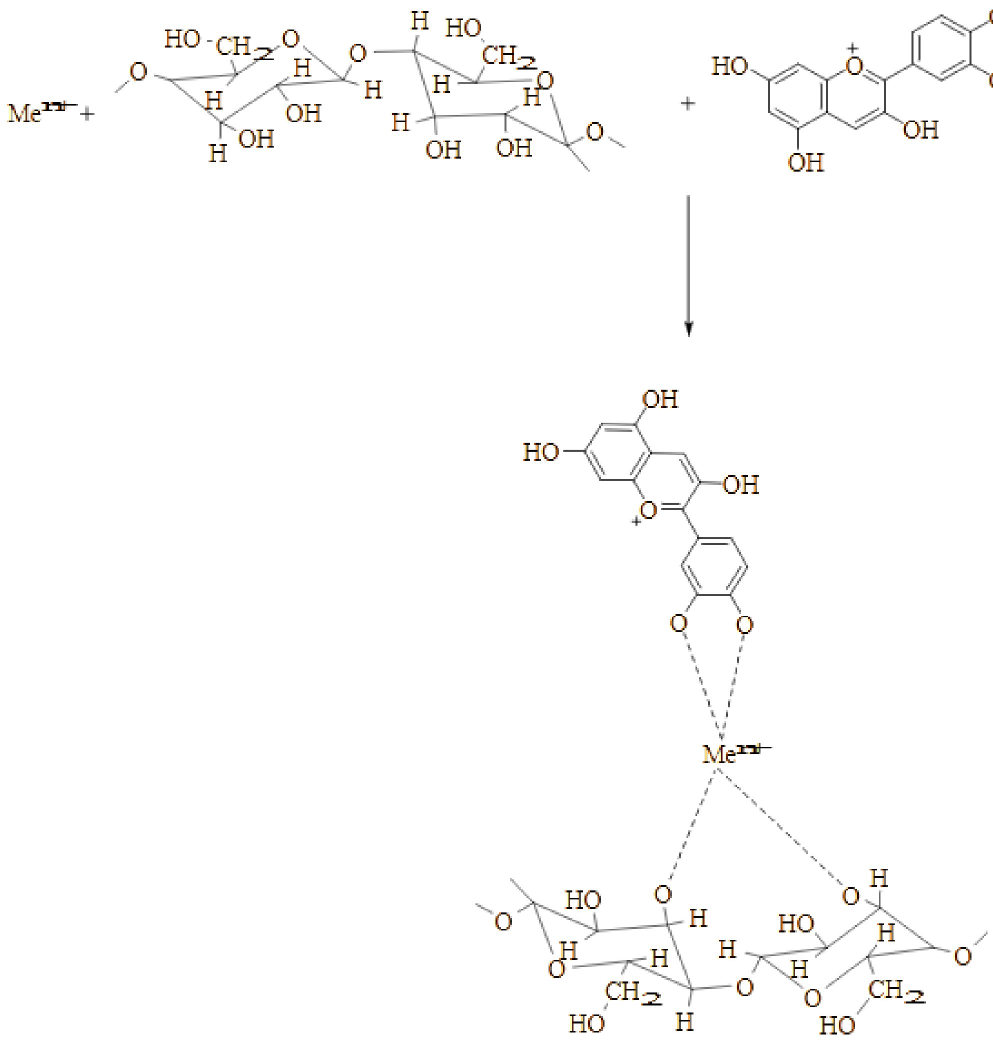

**Figure 6:** The proposed dyeing mechanism of cotton fabric with cyanidine ($Me^{n+}$: mordant cation).

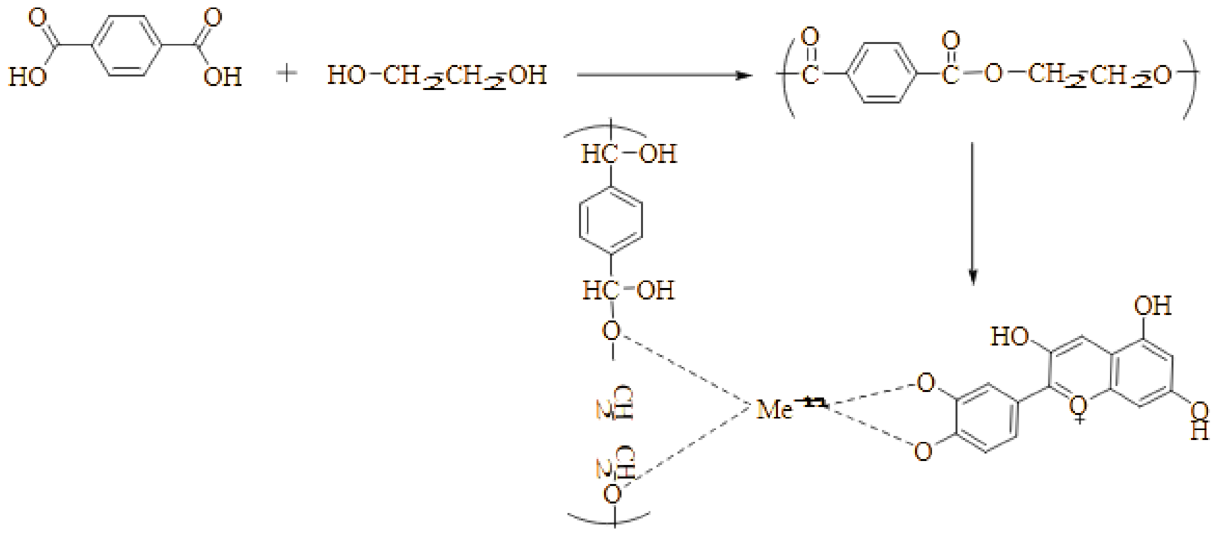

**Figure 7:** The proposed dyeing mechanism of cotton fabric with cyanidine ($Me^{n+}$ : mordant cation).

## 4. CONCLUSION

In this study, the extract of fresh fruits of P*arthenocissus quinquefolia* L. was used in dyeing cotton fabric, wool yarn, and polyester fabric. The washing, dry and wet rubbing fastness of the dyed samples gave good results. Light fastness is medium to below average. With the use of mordant, the fastness properties of cotton, wool, and polyester fabrics are improved. Considering that natural dyes generally have poor fastness, it can be stated that the solidity properties of various dyed samples in this study can be considered good. However, although polyester fabrics are dyed at 130 ℃ in the industrial process, they can also be dyed below 100 ℃. This result will also save energy and provide a significant advantage in dyeing synthetic materials. When all the results obtained are evaluated, it is clearly seen that P*arthenocissus quinquefolia* L. fresh fruits can be used in biomelecular wool yarn, cotton fabric and polyester fabric dyeing.

## 5. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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