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Original article

Dyeing of Silk and Cotton Fabrics with Natural Dye Extracted from *Stevia rebaudiana* Bertoni and its Leaf Pulp

Menekşe Suzan Teker [a,*] & Kenan Turgut [b]

[a] Department of Textile and Fashion Design, Akdeniz University, Antalya, Türkiye
[b] Department of Field Crops, Akdeniz University, Antalya, Türkiye

Abstract

Stevia rebaudiana Bertoni is a herbaceous perennial plant in the Asteraceae family and is native to Northeast Paraguay. Its leaves contain steviol glycosides, a family of zero-calorie natural sweeteners that are 200-300 times sweeter than table sugar and can replace sucrose as well as other synthetic sweeteners. In addition to its use in the food sector, the plant is also considered to be a source of natural dyestuffs. Especially the utilization of the pulp after the extraction process is important in terms of providing a sustainable resource. In this study, the dyeing properties of stevia plant and its pulp were investigated. Silk and cotton fabrics were selected for this study. Alum [$KAl(SO_4)_2.12H_2O$] and iron (II) sulfate heptahydrate [$FeSO_4.7H_2O$] were used for dyeing by pre-mordanting method. Rubbing (dry and wet) and washing fastness tests and color depths were evaluated in terms of K/S and CIELAB color difference values. The data obtained in this first study in the field of dyeing with stevia plant and its pulp showed that the stevia plant can be used as an important source of natural dyestuff. The color scale obtained by using different mordants and dyeing methods can be expanded. Especially the adoption of pulp uses as an environmentally friendly approach will be a source for further studies.

Keywords: Stevia, Natural Dye, Leaf Pulp, Fastness, Color Analysis

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* **Corresponding author:**

Menekşe Suzan Teker is an associate professor in the Department Textile and Fashion Design, Akdeniz University, Antalya, Türkiye. Her research interests include the Natural Dye and Textile. She has lived, worked, and studied in Antalya, Türkiye.
Email: mesinal@hotmail.com

INTRODUCTION

In general, plant dyestuff sources have color-containing metabolites such as tannins, flavonoids, carotenoids. These metabolites are not only a source of color but also show anti-carcinogenic, anti-inflammatory and anti-bacterial properties [1,2,3]. Stevia plant is thought to be suitable for natural dye research since it shows the same effects with the steviol glycoside it contains.

Stevia rebaudiana Bertoni is herbaceous plant belonging to the Asteraceae family and is native to Northeast Paraguay [4]. The Asteraceae family, to which Stevia rebaudiana belongs, comprises 950 genera [5,6]. Stevia rebaudiana is reported to be an annual and perennial plant that typically grows in mountainous regions, open woodlands, and riversides [7].

Its leaves contain steviol glycosides, a family of zero calorie natural sweeteners that are 200-300 times sweeter than table sugar, which may substitute for sucrose as well as other synthetic sweeteners [8]. The most important features of Stevia; It is a strong natural sweetener with zero calories, does not increase blood sugar (zero glycaemic index), and does not cause tooth decay. It is used safely by diabetics as it does not increase the sugar level in the blood. It is preferred in diet products due to its zero-calorie feature.

Stevia plant, which attracts attention in the field of food, has been the subject of the study considering that it can be evaluated as a source of dyestuff. Especially recently, new searches for sustainable dye sources are quite remarkable. The assumption here is to investigate whether the plant pulps after the extraction process can also be evaluated as a source of dyestuff. In order to investigate the dyestuff properties, the same dyes procedures were made with the plant itself and its pulp and the results were given comparatively. Cellulose-based cotton fabric and animal-based silk fabric were selected to see the color and fastness change depending on the textile material.

Ahmad et al. [9] published on the health benefits, industrial applications and safety of stevia with a very extensive literature study. A literature review on the use of stevia as a source of natural coloring matter in textiles was carried out. The studies conducted with stevia were examined, it was observed that a few study was conducted on the evaluation of stevia as a dyestuff source for textile industry [10]. In this study, the use of stevia plant and its pulp as a source of dyestuff are investigated.

MATERIALS and METHODS

Materials

Stevia leaves and pulp were used as the material for this study. Dried leaves and leaf pulp of *Stevia rebaudiana* were obtained from Güney Agripark R&D Centre in Antalya. The company produces natural sweeteners from stevia leaves using extraction technology.

Pure silk(satin) fabric weighing 64 g/m^2 and pure cotton (voile) fabric weighing 72 g/m^2 bought from Erol Kumaşçılık, Antalya, were used. Three different laboratory grade (ZAG) mordants were used, aluminum potassium sulfate [$KAl(SO_4)_2.12H_2O$] and ferrous (II) sulphate [$FeSO_4.7H_2O$]. Also, ascorbic acid was used as an auxiliary material while using iron mordant.

1-liter glass jars were used for dyeing and mordanting processes. Vestel household washing machine was used to wash the fabrics. Color strength and colorimetric values were measured by 3nh NS800 (D65, specular inclusion, 10°) spectrophotometer. For measurements Kern PFB 1200-2, weighing capacity 1200 g, accuracy: 0.01 g was used.

Method

Scouring of cotton fabric was done ZAG brand sodium carbonate [Na_2CO_3] (soda ash) before dyeing process[11]. The silk fabrics were scoured with Pureal natural silk laundry detergent at washing machine [12,13].

Fabric dimensions for dyeing were determined by considering the fastness tests to be applied afterwards. They were calculated as 10x20 cm for rubbing fastness tests and 20x20 cm for washing fastness tests. Each piece of cotton fabric weighs 6 g and silk fabric weighs 7,4 g. Since the dyestuff properties of the plant and its leaf pulp were examined for the first time, it was thought that the dyeing and mordanting methods and mordants to be performed should be basic (Table 1).

Table 1. Dyeing processes for stevia plant and for its leaf pulp.

Plant/Pulp	Cotton	Unmordanted	
		Pre-mordanted	alum
			ferrous (II) sulphate
	Silk	Unmordanted	
		Pre-mordanted	alum
			ferrous (II) sulphate

For dyeing experiments were followed according to Sukemi *et.al* 2019, plants were extracted by aqueous extraction technique at boil for 30 min [14]. 5 L tap water was added onto plant and its leaf pulp by separately. In each process of extraction, the mixture was cooled down and were filtered accurately [15,16]. This filtered solution was used as a dyeing liquor, containing a 1:1 ratio of fabric (g) to plant pulp (g) [17,18]. The dyebath liquor solution was arranged 1:80.

Whole cotton fabric (107 g) scouring was carried out with the 1:50 (fabric to water) ratio and 5 g/L sodium carbonate at boiling temperature for 60 min [19,20]. After boiling, fabric was washed at washing machine without any materials at 60℃ - 60 min program. Also, whole silk fabric (97 g) scouring was performed with Pureal natural silk laundry detergent in a delicate, hand wash mode at

30℃ by an Vestel washer machine. The instructions for use stated on the product were followed and 15 mL (1 part) of detergent was added for 97 g of silk. Fabrics were air-dried (indoors) at room temperature.

Pre-mordanting methods were applied with %20 aluminum potassium sulfate (alum) [$KAl(SO_4)_2.12H_2O$] and %1 ferrous (II) sulfate [$FeSO_4.7H_2O$] [21, 22].

Cotton fabrics got wet before mordanting for 30 min. Pre-mordanting method applied to cotton fabric with %20 alum and %1 ferrous sulfate at 1:80 fabric to liquor ratio. % 1 Ascorbic acid was added into the iron mordant. Ferrous sulfate ($FeSO_4·7H_2O$) is used in mordanting, a process in which Fe^{2+}ions can transform into Fe^{3+} ions in a water solution. Ascorbic acid acts as a reducing agent to prevent this transformation [23]. Ascorbic acid effectively reduces Fe^{3+} back to Fe^{2+}, maintaining the iron in its active mordant form and preventing the formation of Fe^{3+} complexes that impair dye uptake. Mordanting bath was headed up to 80°C, let it to be cold and fabrics were left this bath for 24 hours. Then mordant bath was let to be cold down to room temperature. The mordanted fabrics washed with tap water and were air-dried (indoors) at room temperature. As the same ratios and time durations, mordanting method was applied to silk fabrics. However, mordanting bath temperature was headed up to 55°C.

The dyeing experiments were basically divided into two, plant and its leaf pulp, and then applied to cotton and silk fabrics without mordant and with three different mordants. After plant extraction, dye bath was set to 500 mL and added into glass jars. The dyeing process was applied as the same as mordanting process.

Colorimetric measurement of the samples was carried out using 3nh NS800 and measurement settings are as follows: Illuminant: D65, Observer Angle: 10°, Color Space: CIE LAB, LCh, Color Formula: CIE 1976. Untreated fabrics for cotton and silk were measured as standard. L* represents the difference between light (where L*=100) and dark (where L*=0). a* represents the difference between green (-a*) and red (+a*), and b* represents the difference between yellow (+b*) and blue (-b*), and the next term is the Chroma (C) is about measure of how dull or vivid a color is from the neutral gray/black range to highly pure chromatic value [24]. The colorimetric values for dyed fabrics are listed in Table 2.

The color difference ΔE was calculated by the Equation (1):

$$\Delta E=\sqrt{(\Delta L)2 +(\Delta a)2+(\Delta b)2 }$$

The K/S (color strength) value was calculated by Equation (2):

$$K/S= (1-R)2 / 2R$$

where R is the observed reflectance.

Dry and wet rubbing fastness values determined according to TS EN ISO 105-X12 and wash fastness values were determined according to TS EN ISO 105-C06/A1S. According to Grey Scale, 1-2-3-4-5 are rating classes also half rating values can be used as 4-5 (1- very poor, 2-poor, 3-fair, 4-good and 5-excellent). Fastness test results are listed below according to dyestuff in Table 3.

RESULTS and DISCUSSION

Color Measurements

The colorimetric values for dyed fabrics are listed in Table 2. Comparisons and evaluations in color analysis were made between plant and its leaf pulp dyeing and in some cases cotton and silk were also evaluated. When the brightness value L was analyzed, it was observed that generally higher values were obtained from the dyeing with pulp of stevia (lighter shades). The brightness of the plant and leaf pulp dyed cotton fabrics with iron mordant is higher. In silk fabrics, it was observed that unmordanted and iron mordanted fabrics had higher L values. It is seen that more greenish color values are obtained in cotton and silk fabrics dyed with the plant. In the dyeing with pulp, the fabrics showed more reddish shades. It is also seen that silk fabrics have more reddish values than cotton fabrics. b* values showed that all fabric samples have more yellowish color shades. It is seen that the highest b* value is obtained especially in alum mordanted cotton and silk fabrics. When C* values are examined, it is seen that more vivid colors are observed in alum mordanted fabrics in relation to b* (+) coordinates. When we look at the ΔE values, it is observed that they increase significantly in alum mordanted fabrics. ΔE values are analyzed according to fabric types; it is seen that the dyes made with plants have higher color difference values. Color strength is increased especially in silk fabrics dyed with plants. When the silk fabrics are analyzed within themselves, the highest color strength value is obtained in plant dyed fabrics with alum mordant. In cotton fabrics, higher color strength values were obtained in dyeing with the plant. Similarly, higher values were obtained in alum mordanted cotton fabrics.

Table 2. Colorimetric data of cotton and silk fabrics dyed with plant and pulp.

No.	Fabric	Plant/ Pulp	Mordant	L*	a*	b*	C*	h°	λ	ΔE	K/S
Standard	Cotton			92.863	3.037	-3.516	4.646	310.825	400		0,32454174
	Silk			92.770	1.394	0,477	1.473	18.883	400		0,059759095
1	Cotton	Plant	unmordanted	65.578	-4.800	12.703	13.579	110.699	400	32.695	0,322591904
2			alum	55.606	-4.655	24.984	25.414	100.555	400	47.534	2,896667625
3			ferrous (II) sulphate	69.201	-4.083	12.432	13.085	108.180	400	29.410	0,172857143
4	Cotton	Pulp	unmordanted	75.992	1.661	14.607	14.702	83.511	400	24.799	0,019561793
5			alum	66.650	2.209	25.327	25.423	85.015	400	38.983	0,718132399
6			ferrous (II) sulphate	76.654	2.298	15.569	15.737	81.605	400	25.050	0,020495104
7	Silk	Plant	unmordanted	65.452	-8.039	13.249	15.498	121.247	400	31.597	1,997906
8			alum	62.346	-7.513	36.152	36.924	101.740	400	47.725	6,930544
9			ferrous (II) sulphate	63.986	-7.966	13.288	15.493	120.942	400	32.867	2,245511
10	Silk	Pulp	unmordanted	76.276	0,919	15.728	15.755	86.658	400	22.469	0,727781
11			alum	75.549	0,578	25.800	25.806	88.716	400	30.634	1,482706
12			ferrous (II) sulphate	76.344	1.058	15.953	15.988	86.204	400	22.571	0,740729

Fastness Tests

Washing and rubbing fastness results are listed in Table 3. The dry rubbing fastness values of the dyed samples varied between 4 and 4/5. The wet rubbing fastness of the dyed samples generally ranged between 3 and 4, but a slight decrease was observed in alum mordanted fabrics dyed with plant. Staining values of adjacent fibers, varied between 4 and 4/5, but mostly 4/5. This means that the adjacent fibers were not stained by the washing bath and good values were obtained. However, for all the samples, the colour change values for wash fastness were very poor, ranging from 1 to 2/3. It is thought that post-dyeing fixation/finishing processes should be applied for higher and acceptable washing fastness values.

Table 3. Fastness properties of cotton and silk fabrics dyed with plant and pulp

No.	Fabric	Plant/ Pulp	Mordant	Washing Fastness (Staining on)							Rubbing Fastness	
				CA*	Co*	PA*	PES*	PAN*	Wo*	Color change	Dry	Wet
1			unmordanted	4/5	4/5	4/5	4/5	4/5	4/5	1	4/5	4
2	Cotton	Plant	alum	4/5	4	4/5	4/5	4/5	4/5	1	4	3
3			ferrous (II) sulphate	4/5	4/5	4/5	4/5	4/5	4/5	1	4/5	4
4			unmordanted	4/5	4/5	4/5	4/5	4/5	4	1	4/5	4
5	Cotton	Pulp	alum	4/5	4/5	4/5	4/5	4/5	4/5	1/2	4/5	4
6			ferrous (II) sulphate	4/5	4/5	4/5	4/5	4/5	4/5	1	4/5	4
7			unmordanted	4/5	4/5	4/5	4/5	4/5	4	1/2	4/5	4
8	Silk	Plant	alum	4/5	4/5	4/5	4/5	4/5	4/5	1	4/5	3/4
9			ferrous (II) sulphate	4/5	4	4/5	4/5	4/5	4/5	1/2	4	3/4
10			unmordanted	4/5	4/5	4/5	4/5	4/5	4	2/3	4/5	4
11	Silk	Pulp	alum	4/5	4/5	4/5	4/5	4/5	4/5	2	4/5	4
12			ferrous (II) sulphate	4/5	4/5	4/5	4/5	4/5	4/5	2/3	4/5	4

*CA: acetate, Co: cotton, PA: polyamide, PES: polyester, PAN: acrylic, Wo: wool

The experimental results reveal that both Stevia rebaudiana Bertoni leaves, and their residual pulp can effectively serve as natural dye sources for cotton and silk fabrics. When comparing fabric types, silk consistently exhibited higher color strength (K/S), particularly when dyed with the plant extract and mordanted with alum, reaching a peak K/S value of 6,93 (Table 4-5). Cotton fabrics, by contrast, demonstrated more muted, earthy shades with generally lower K/S values, although vividness improved notably with alum mordant. In the source comparison, samples dyed with plant extract yielded darker and more greenish tones (lower L* and negative a* values), while those dyed with leaf pulp displayed lighter, warmer shades with reddish undertones (positive a*). Across both fabrics, pulp-derived colors showed higher b* values, especially when paired with alum, indicating a stronger yellow component. Chroma (C*) was maximized with alum mordant for both dye sources, demonstrating its effectiveness in enhancing saturation. Color difference (ΔE) values were higher in plant-dyed fabrics, suggesting more distinguishable coloration. However, leaf pulp samples still provided adequate contrast and uniform tone, making them a valuable sustainable alternative. Fastness results indicated satisfactory performance in rubbing (4–4/5), though wash fastness was generally poor due to elevated washing temperatures. Future laundering under 40 °C may yield improved durability. Also, it is thought that washing fastness values can be improved with the application of fixation and finishing processes applied after the dyeing process in textiles.

Overall, the findings demonstrate that both the primary plant and its byproduct can produce viable and diverse colorations, with silk offering greater vibrancy and pulp contributing to sustainable dyeing practices without compromising on visual appeal.

Table 4. Fabric-Based Comparison

Feature	Cotton Fabric	Silk Fabric
Color Strength (K/S)	Highest with alum mordants when dyed with the plant	Highest overall with plant extract + alum mordant (K/S = 6,93)
Lightness (L*)	Brighter when dyed with pulp; plant extract gives deeper tones	Pulp yields brighter tones; plant extract gives darker shades
a* (Red-Green)	Plant-dyed samples → negative a* (greenish); pulp → positive a* (reddish)	a* values more positive overall in pulp → reddish hues
b* (Yellow-Blue)	High b* values in pulp + alum mordant → strong yellow tones	High b* with pulp + alum → vivid yellow tones
Chroma (C*)	Alum > Ferrous in color vividness	Most vivid: plant extract + alum mordant
ΔE (Color Difference)	More visible shifts with plant dyeing (higher ΔE)	Strongest visible color difference: plant + alum mordant
Fastness	Good rubbing (4–4/5), but low wash fastness	Similar trends

Table 5. Source-Based Comparison

Characteristic	Stevia Leaf (Raw)	Leaf Pulp (Post-Extraction)
Color Tone	Darker, more greenish-olive tones	Brighter, more reddish-yellow hues
a* (Red-Green)	Negative a* → cooler greens	Positive a* → warmer reds (especially on silk)
b* (Yellow-Blue)	Generally positive → warm hues, but lower than pulp	Strong b* boost, especially in alum mordant combinations
ΔE (Color Difference)	Higher ΔE in most plant-dyed samples → more distinctive colors	Lower but still perceivable ΔE shifts
K/S Values	Higher overall color depth, especially with alum mordant on silk	More subtle depth, but sustainable and uniform color possibilities
Sustainability	Fresh material usage	Utilization of a waste product → strong contribution to circular dyeing
Fastness	Rubbing good; wash fastness weak	Comparable fastness; may improve with finishing processes

Conclusion

The experimental results reveal that both Stevia rebaudiana Bertoni leaves, and their residual pulp can effectively serve as natural dye sources for cotton and silk fabrics. While the plant extract provided deeper, greenish tones with greater color strength—especially on silk substrates—the leaf pulp offered lighter, warmer hues, making it a valuable sustainable alternative. Rubbing fastness results were consistently good, while washing fastness was affected by washing temperatures, suggesting that cooler washing conditions can improve durability. It is also predicted that washing fastness can be improved by post-dyeing fixation treatments/finishing processes. The successful reuse of post-extraction stevia pulp highlights its potential role in supporting circular and eco-friendly dyeing practices. These findings not only broaden the application of stevia beyond the food industry but also contribute meaningfully to the development of sustainable coloration systems in textile production.

Additional Declaration

Author Contributions

All authors contributed to the study conception and design. The stevia plant and its pulp were provided by Kenan Turgut and the taxonomy and information on the structure of the plant belongs to him. Dyeing experiments, color analysis and interpretation of the data were carried out by Menekşe Suzan Teker. All authors read and approved of the final manuscript.

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Responsible Artificial Intelligence Statement

In this study, artificial intelligence tool Microsoft 365 Copilot was used in only Table 4 and 5.

Conflicts of Interest

The authors declare that there are no conflicts of interest related to the publication of this study.

Ethics Approval

In all processes of this study, the principles of Pen Academic Publishing Research Ethics Policy were followed.

This study does not require ethics committee approval as it does not involve any direct application on human or animal subjects.

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