APPLICATION OF BUTTERFLY PEA FLOWERS ON ECO NATURAL DYEING PROCESS FOR KNITTED COTTON FABRIC

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ABSTRACT

Butterfly pea flowers are widely used in life, commonly in medicine and food. In addition, the natural extracted from the butterfly pea flower is also applied to the textile and fashion industry such as the dyeing process for many types of fabrics. The paper presents the application of butterfly pea flowers in a natural dyeing process for knitted cotton fabrics. Firstly, the study used cotton knitted fabrics with five different mordants in the same experimental conditions to explore the effects. The study showed that other kinds of mordants affect the established color of dyeing fabrics. There is a wide range of colors from butterfly pea flowers which can support the fashion industry. There were five significant colors from five different mordants. Secondly, there was no difference between all the mordants for checking color fastness and color staining with level of 4-5. Finally, the measurements demonstrated the relationship between K/S, ΔE parameters, and determined mordants. The highest K/S displayed with mordant of $FeSO_4.7H_2O$ (1.537), the lowest K/S showed with no mordant (0.168). Similarly, the highest ΔE indicated with mordants of $FeSO_4.7H_2O$ (33.68), the lowest ΔE determined with mordants of Na_2CO_3 (16.99).

Keywords: Butterfly pea flower, *Clitoria ternatea*, blue pea, shibori dyeing, cotton, natural dyes.

1. INTRODUCTION

Butterfly pea flowers (*Clitoria ternatea* L.) are classified in the phylum Tracheophyta, the kingdom Plantae, the class of Magnoliopsida, and the family of Fabaceae [1-4]. Butterfly pea flowers belong to tropical flowers and are found in China, Zimbabwe, Guinea, Indonesia, and Malaysia [2-5]. Because of its appearance in many other areas and countries, it can display with many different names. For example, butterfly pea is also known as Kokkattan in Tamil, Đậu biếc in Vietnam, Kordofan pea in Sudan, Aparajita in Bengali, Lan hu die in Chinese, Dangchan in Thai, Bunga telang in Malaysia, Aparajit in Hindi, Sankhpuspi in Indian, Shankha pushpa in Konkani, Pokindong in the Philippines, blue pea or cunha in Brazil, Clitoria azul in Spanish [1-3].

Butterfly pea flowers consist of anthocyanin, betacyanin, alkaloids, carbohydrates, palmitic, resin, myristic acids, coumarin, linoleic, proteins, flavonoids, cetyl alcohol, hentriacontane, and 3-sitosterol [3]. The anthocyanin makes the blue color of butterfly pea flowers [4-6].

Butterfly pea flowers are commonly applied to food and medicine industries [7]. For instance, the application of butterfly pea was presented in local anesthetic, anti-inflammatory, blood platelet aggregation inhibiting, insecticidal, analgesic, diuretic, vascular smooth muscle relaxing properties, antimicrobial, antipyretic, and anti-diabetic [4, 7, 8]. Besides, there are many researches demonstrating the utility of flowers in the textile industry, especially in dyeing products [7-11].

The aim of the study was to assess the effects of different mordants on extracted color from butterfly pea flowers. The natural dyeing process was applied on white knitted fabrics with 100% cotton for considering effective color.

2. MATERIAL AND METHODS

2.1. Fabrics

Single Jersey is a common weft - knitted fabric. The rear and front faces are different because they are knitted by one row of needles. The characteristics can be varied based on components from wool, cotton or synthetic [12]. The study used Single Jersey fabrics with components of 100% cotton. The dimensions of the material were 20x20cm. The weight was 6,9±1 grams. The fabrics are shown in Figure 1.

The fabric samples were washed to relax and dissolve chemical additives from textile production. The knitted cotton fabrics were immersed and washed in an aqueous solution of non-ionic detergent (5 mL/L) for 40 minutes. After that, the experiments stayed at room temperature for a natural drying process.

Figure 1. Knitted cotton fabric

2.2. Extract preparation

Research material was contained in dried dark blue flowers of the butterfly pea (*Clitoria ternatea* L.,) which originated and planted in Vietnam. Dye and dried flowers achieved from the butterfly pea flower plant are shown in Figure 2.

The dried butterfly pea flowers were weighed and poured into the water at a ratio of 1:50 (gram: mL) at room temperature. The mixture solution was kept for 60 minutes to allow the release of the flower color into the water. Then, the mixture was put in a gauze fabric to collect the clean extracted solution.

Figure 2. Solution

2.3. Mordants

There were five kinds of mordants, including Ferrous Sulfate Heptahydrate 100%; Cupric Sulfate Pentahydrate ≥ 99% ($CuSO_4.5H_2O$, AR, Xilong, Cas 7758-99-8); Aluminium Potassium Sulfate dodecahydrate (AR, Xilong, Cas 7784-24-9); Sodium Carbonate (Na_2CO_3, AR, 500G, Xilong, Cas 497-19-8); Citric Acid monohydrate 99.5% (AR, 500G, Xilong, Cas 5949-29-1). The chemicals were from Xilong Ltd, China. The chosen technique was simultaneous mordanting methodology. Molecular weight is shown in Table 1.

Table 1. Molecular weight of mordants

Name	Chemical formula	Molecular weight (g/mol)
Ferrous Sulfate Heptahydrate 100%	$FeSO_4.7H_2O$	278.02
Cupric Sulfate Pentahydrate ≥ 99%	$CuSO_4.5H_2O$	249.69
Aluminium Potassium Sulfate dodecahydrate 100%	$KAl(SO_4)2.12H_2O$	474.39
Sodium Carbonate 100%	Na_2CO_3	105.99
Citric Acid monohydrate 99.5%	$C_6H_8O_7.H_2O$	210.14

2.4. Experiment

During this research, an eco-friendly natural dye extracted from butterfly pea flowers was applied. The experiment used beakers of 500 mL for the dyeing process. A total of six dye beakers were chosen for this examination. The 200 mL water extraction of the butterfly pea flowers was poured into each beaker. After that, knitted cotton fabrics were placed into each cup for 30 minutes at a humidity at (56±1)%, room temperature (29±1)°C, and stirred continuously during the experiments. Each beaker added 2 grams of mordants with the below conditions as Table 2.

Table 2. Beaker conditions

Beakers	Mordant (2 g)	Solution (mL)	Fabric (g)
1	No mordants	200	6.9
2	$FeSO_4.7H_2O$	200	6.9
3	$CuSO_4.5H_2O$	200	6.9
4	$KAl(SO_4)^2.12H_2O$	200	6.9
5	Na_2CO_3	200	6.8
6	$C_6H_8O_7.H_2O$	200	6.9

2.5. Color determination and characterization

The colors after the dyeing process matched the standards of the color identification system developed by Pantone, according to the sampler – Pantone FHI Cotton TCX 2801 from the Fashion, Home + Interiors (FHI) System. The Pantone classification is an effective appliance for quick color specification and detection which consists of 2801 textile colors, followed by Figure 3.

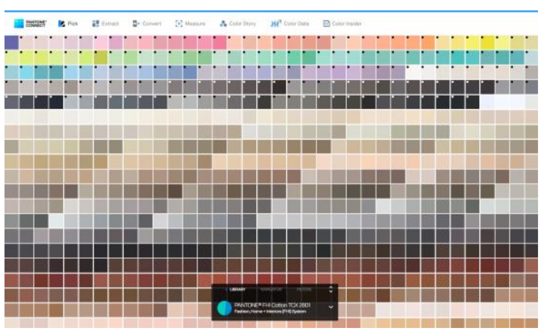

Figure 3. Pantone FHI Cotton TCX 2801

2.6. Color fastness and color staining

Samples were washed with a ratio of 4 grams of ECE detergent, 1 liter of water, and 10 steel balls. Color fastness was identified with temperature wash at 30 °C according to ISO 105-C06 A1S:2010 using a MESDAN LAB machine. The color staining was checked with a gray ruler following the AATCC standard with 5 levels, followed by Figure 4.

Figure 4. Gray ruler

2.7. Color strength and color difference

The color strength (K/S) and color difference (ΔE) were calculated following the CIE. All the results were checked according to ISO 105 J01:1997. The color strength or K/S ratio of dye fabrics was calculated by the Kubelka-Munk equation based on the relative color strength. According to Premier Colorscan, the value of the reflectance was conducted:

$$K/S = (1-R)^2 / 2R, \text{ with: } R = \frac{\textbf{Light flux reflected by the sample}}{\textbf{Light flux reflected by a reference white similarly illuminated}} \quad (1)$$

CIE Lab values were measured for fabrics that were dyed under controlled conditions, modified treatments, and with various mordants. R represents the reflectance of the dyed fabric as a decimal fraction, and K/S was determined.

The numeric distance between the standard and the batch is identical, but their visual differences vary. The issue lies in the fact that the X, Y, Z tristimulus color space lacks visual uniformity. This flaw is also present in the x, y chromaticity diagram, where equal variations in chromaticity coordinates fail to result in uniform differences in perceived color. The most significant progress in the creation of color-difference formulas was the introduction of the CIELAB formula, endorsed by the CIE in 1976:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad (2)$$

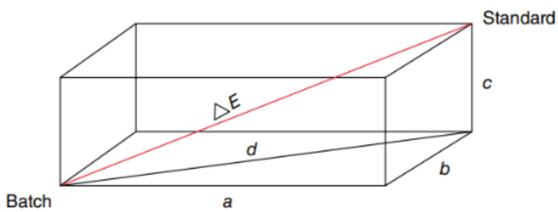

Figure 5. Color difference (ΔE) between a batch and a standard, ΔE2 = c2 + a2 +b2,
ΔE2 = c2 + d2 (3), with d2 = a2 + b2 (4).

L*, a*, and b* represent the three axes of a color space derived from the X, Y, Z space, designed to be significantly more visually uniform. The * symbols signify that the L*, a*, b* values are derived using a cuberoot approximation of a more intricate set of originally developed equations.

3. RESULTS

3.1. Pantone color measurement

Scan images of knitted cotton fabric with butterfly pea flowers without and with mordants such as $FeSO_4.7H_2O$, $CuSO_4.5H_2O$, $KAl(SO_4)^2.12H_2O$, Na_2CO_3, $C_6H_8O_7.H_2O$ are presented in Figure 6. Pantone color measurement results are presented in Table 3.

The color palettes obtained on cotton fibers with different mordants are totally different. The color of samples was compared with Pantone color measurements to decide the color name for each dyeing experiment. Based on the Pantone, without mordant showed a baby lavender color after the dyeing process. Bark color was obtained after using Ferrous Sulfate Heptahydrate. In addition, the application of Cupric Sulfate Pentahydrate ≥99% received an orchid color. Besides, the begonia - pink color was obtained by adding Aluminium Potassium Sulfate dodecahydrate. Significantly, the appearance of subtle green is based on the use of Sodium Carbonate. Finally, the mixture of Citric Acid monohydrate 99.5% led to lilac sachet color.

Figure 6. Cotton knitted fabric after the dyeing process

Samples: S1 – raw knitted cotton fabric; S2 – raw knitted cotton fabric + $FeSO_4.7H_2O$; S3 – raw knitted cotton fabric + $CuSO_4.5H_2O$; S4 – raw knitted cotton fabric + $KAl(SO_4)^2.12H_2O$; S5 – raw knitted cotton fabric + Na_2CO_3; S6 – raw knitted cotton fabric + $C_6H_8O_7.H_2O$.

Table 3. Results of Pantone color measurement of knitted cotton fabric

Sample	Color	Name	Pantone TCX
S1		Baby Lavender	16-3923 TCX
S2		Bark	16-1506 TCX
S3		Orchid	15-3214 TCX
S4		Begonia Pink	15-2214 TCX
S5		Subtle Green	14-6008 TCX
S6		Lilac Sachet	14-2710 TCX

3.2. Effect of mordants on color fastness

The color fastness showed no different results when using different kinds of mordants. The experiment had the same liquor ratio of solution and the same weight of mordants. The samples showed color fastness with level-1 and 4-5 on the gray ruler. The results are shown in Table 4.

Table 4. Color fastness and color staining

Parameters		S1	S2	S3	S4	S5	S6
Fastness		1	1	1	1	1	1
Stain	Acetate	4-5	4-5	4-5	4-5	4-5	4-5
	Cotton	4-5	4-5	4-5	4-5	4-5	4-5
	Nylon	4-5	4-5	4-5	4-5	4-5	4-5
	Polyester	4-5	4-5	4-5	4-5	4-5	4-5
	Acrylic	4-5	4-5	4-5	4-5	4-5	4-5
	Wool	4-5	4-5	4-5	4-5	4-5	4-5

Samples: S1 – raw knitted cotton fabric; S2 – raw knitted cotton fabric + $FeSO_4.7H_2O$; S3 – raw knitted cotton fabric + $CuSO_4.5H_2O$; S4 – raw knitted cotton fabric + $KAl(SO_4)^2.12H_2O$; S5 – raw knitted cotton fabric + Na_2CO_3; S6 – raw knitted cotton fabric + $C_6H_8O_7.H_2O$.

3.3. Effect of mordants on K/S and ΔE

The findings showed that K/S has a significant distinction when using different kinds of mordants. K/S value has been indicated with 0.0206 at the beginning. Without mordants, the parameters have been calculated with K/S mean = 0,168. With Ferrous Sulfate Heptahydrate, the K/S value was 1.537 for the average value. Continuously, using mordant of Cupric Sulfate Pentahydrate ≥ 99% led to K/S mean =0.751. Similarly, the application of Aluminium Potassium Sulfate dodecahydrate indicated 0.771 for K/S mean. Continuously, the result of Sodium Carbonate also showed with 0.561. After all, the K/S mean reached only 0.246 when using Citric Acid monohydrate for the mordant method. The findings are shown in Table 5 and Figure 7.

Table 5. K/S value

	S1	**S2**	**S3**	**S4**	**S5**	**S6**
K/S Begin	0.0206	0.0206	0.0206	0.0206	0.0206	0.0206
1	0.1568	1.6368	0.8176	0.8862	0.5791	0.2455
2	0.1659	1.5585	0.8373	0.8158	0.5758	0.2511
3	0.1804	1.5273	0.7338	0.7042	0.5700	0.2458
4	0.1811	1.6470	0.7642	0.7471	0.5368	0.2513
5	0.1551	1.3136	0.6015	0.7014	0.5409	0.2372
K/S Mean	**0.168**	**1.537**	**0.751**	**0.771**	**0.561**	**0.246**

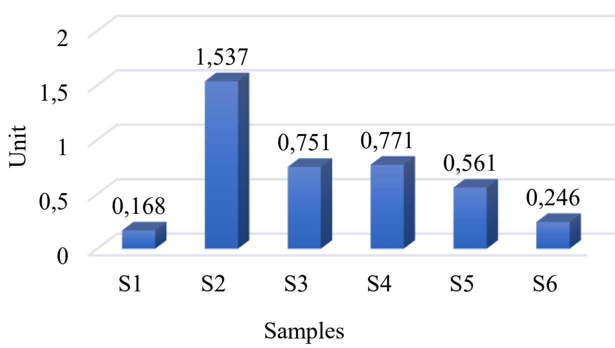

Figure 7. K/S value

Similarly, the ΔE value indicated the difference between a range of mordants. The finding illustrates the value of 22.42 without mordants. When using Ferrous Sulfate Heptahydrate, ΔE got 33.68 for the average result. In addition, the application of Cupric Sulfate Pentahydrate ≥99% showed a value of 31.32. Similarly, there was nearly the same outcome by the utility of Aluminium Potassium Sulfate dodecahydrate with 30.93. Substantially, the ΔE value only indicated 16.99 when calculating for Sodium Carbonate. Finally, with a mordant of Citric Acid monohydrate, the reaction pointed out a ΔE value of 30.10. The results are shown in Table 6 and Figure 8.

Table 6. ΔE value

	S1	S2	S3	S4	S5	S6
1	22.52	34.24	31.49	31.67	17.42	30.18
2	22.61	33.65	32.34	31.35	17.30	30.35
3	23.21	33.81	31.39	30.46	17.12	30.11
4	22.91	34.74	31.50	30.62	16.60	30.25
5	20.87	31.95	29.90	30.54	16.53	29.63
ΔE Mean	**22.42**	**33.68**	**31.32**	**30.93**	**16.99**	**30.10**

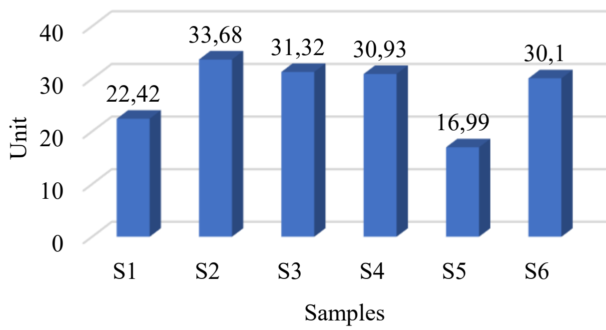

Figure 8. ΔE value

The aim of the study was to assess the effects of different mordants on the extracted color from butterfly pea flowers. The natural dyeing process was applied on white knitted fabrics with 100% cotton for considering effective color.

4. DISCUSSION

There was a range of colors when using different mordants during the dyeing process. Without any mordants, the color displayed in baby lavender is the characteristic hue resulting from anthocyanin pigments of butterfly pea flowers. However, the dyeing colors were changed significantly by the application of many types of mordants. There was bark, orchid, begonia pink, subtle green, and lilac sachet for Ferrous Sulfate Heptahydrate, Cupric Sulfate Pentahydrate, Aluminium Potassium Sulfate dodecahydrate, Sodium Carbonate and Citric Acid monohydrate, respectively. The variation in color observed when butterfly pea flowers are combined with different mordants is attributed to the presence of anthocyanins in the flower extract. These pigments are highly sensitive to pH changes, and the mordants alter the pH environment, resulting in a diverse range of colors. Specifically, anthocyanin extracts from butterfly pea flowers appear red under strongly acidic conditions (pH 1–3), purple at mildly acidic levels (pH 4–6), blue at neutral pH (pH 7), green in mildly alkaline environments (pH 8–10) and yellow under strongly alkaline conditions (pH 11–14) [12]. The results are entirely consistent with previous studies on the color change of anthocyanins under different pH conditions. $CuSO_4{\cdot}5H_2O$, $KAl(SO_4)^2{\cdot}12H_2O$, and $C_6H_8O_7{\cdot}H_2O$ create a mildly acidic environment (pH 4–6), resulting in a purple color, while Na_2CO_3 creates a mildly alkaline environment (pH 8–10), producing a green color. Similarly, butterfly pea extract without any mordant creates a neutral environment (pH = 7), resulting in a blue color. In contrast, the bark color observed with $FeSO_4{\cdot}7H_2O$ is due to a mildly acidic environment combined with the natural color contribution of iron ions, producing a characteristic dark shade.

The dyeing results demonstrated that different chosen mordants have effects on the K/S and ΔE. The K/S value showed the lowest value without any mordants. Significantly, there was no change in color fastness or color staining when using different kinds of mordants. For instance, the application of Ferrous Sulfate Heptahydrate got the highest results. Cupric Sulfate Pentahydrate and Aluminium Potassium Sulfate Dodecahydrate presented nearly the same K/S value. The application of Sodium Carbonate showed the lowest value of K/S when compared with other mordants. Additionally, the ΔE value showed the lowest result in Aluminium Potassium Sulfate dodecahydrate rather than without mordants. The highest finding was indicated by the use of Cupric Sulfate Pentahydrate.

The findings concluded that the color of natural dyeing was not stable. These results are consistent with previous research results [13, 14]. The color belongs to many other factors, such as applied mordants. The research indicated the significant effect of different kinds of mordants on the natural dyeing process of butterfly pea flowers. The considerable difference of the displayed color is based on chemical bonds between anthocyanin of butterfly pea flowers and the applied mordants.

5. CONCLUSION

This paper explores the use of butterfly pea flowers as a natural dye for knitted cotton fabrics. The study applied five different mordants under identical experimental conditions to assess their impact on dyeing outcomes. Results showed that the choice of mordant significantly influenced the resulting fabric colors, with a diverse range of hues achieved - highlighting the potential of butterfly pea flowers for the fashion industry. Each mordant produced a distinct color, totaling five notable shades. In terms of color fastness and staining, no significant differences were observed among the mordants, with all achieving ratings of 4-5. Additionally, measurements of color strength (K/S) and color difference (ΔE) revealed clear correlations with the mordants used. The highest K/S value (1.537) was obtained using $FeSO_4 \cdot 7H_2O$, while the lowest (0.168) occurred without a mordant. Similarly, the highest ΔE (33.68) was also recorded with $FeSO_4 \cdot 7H_2O$, and the lowest (16.99) with Na_2CO_3. Future research should be more concentrated on the characteristics of chemical bonds for creating color.

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TÓM TẮT

ỨNG DỤNG HOA ĐẬU BIẾC VÀO QUY TRÌNH NHUỘM SINH THÁI CHO VẢI DỆT KIM COTTON

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Hoa đậu biếc được sử dụng rộng rãi trong cuộc sống, thông thường được dùng trong y học và thực phẩm. Ngoài ra, màu tự nhiên chiết xuất từ hoa đậu biếc còn được ứng dụng trong thời trang cụ thể trong ngành dệt may và thời trang như quy trình nhuộm cho nhiều loại vải. Bài báo này trình bày ứng dụng của hoa đậu biếc trong quy trình nhuộm tự nhiên cho vải dệt kim chất liệu cotton. Đầu tiên, nghiên cứu sử dụng vải cotton dệt kim kết hợp với năm loại chất cầm màu nhuộm khác nhau trong cùng điều kiện thử nghiệm để tìm hiểu các hiệu ứng. Nghiên cứu cho thấy các loại chất cầm màu nhuộm khác nhau ảnh hưởng đến màu nhuộm của vải. Kết quả cũng tạo ra nhiều màu sắc từ hoa đậu biếc có thể ứng dụng tốt cho ngành thời trang. Có năm loại màu sắc khác nhau được tạo ra từ năm loại chất cầm màu khác nhau. Thứ hai, nghiên cứu nhận thấy không có sự khác biệt giữa tất cả các loại chất cầm màu nhuộm khi kiểm tra độ bền màu giặt. Cuối cùng, các phép đo chứng minh mối quan hệ giữa các thông số K/S, ΔE và sự kết hợp khác nhau của các loại chất cầm nhuộm đã chỉ định. K/S cao nhất hiển thị với chất nhuộm $FeSO_4.7H_2O$ (1,537), K/S thấp nhất hiển thị khi không có chất cầm màu nhuộm (0,168). Tương tự như vậy, ΔE cao nhất được hiển thị với chất cầm màu $FeSO_4.7H_2O$ (33,68), ΔE thấp nhất được xác định với chất cầm màu Na_2CO_3 (16,99).

Từ khóa: Hoa đậu biếc, *Clitoria ternatea*, Blue Pea, nhuộm shibori, cotton, nhuộm tự nhiên.