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Effect of Dyeing Parameters on Colour Characteristics and Fastness Properties of Silk Fabrics Dyed with Purple Corn Cob Extract

Tanawat Ruangteprat[1,a], Somchai Udon[1,b], Jaruwan Diswat[2,c], Jaratpim Wangyen[2,d], Rattanaphol Mongkholrattanasit[2,e], Hathaitip Srichompoo[2,f], Jiramet Suparat[3,g], Krailerck Visesphan[2,h*]

[1]Faculty of Textile Industries, Rajamangala University of Technology Krungthep, Bangkok, 10120, Thailand
[2]Faculty of Industrial Textiles and Fashion Design, Rajamangala University of Technology Phra Nakhon Bangkok, 10300, Thailand
[3]Textile Technology Division, Khon Kaen Industrial and Community Education College, Chonnabot Subdistrict, Chonnabot District, Khon Kaen Province, 40180, Thailand
* Corresponding author. E-mail address: krailerck.v@rmutp.ac.th
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ABSTRACT

This study investigated the dyeing behaviour of silk fabrics using a colourant extracted from purple corn cobs (*Zea mays* L.) and evaluated the effects of key dyeing parameters on colour characteristics and fastness properties. The crude dye extract was obtained by aqueous extraction followed by concentration under reduced pressure. Silk fabrics were dyed under varying conditions of temperature (30–100 °C), dyeing time (20–60 min), pH (3–9), and dye concentration (5–30% owf) at a liquor ratio of 1:100. The colour parameters (CIE L*, a*, b*) and colour strength (K/S) were measured using a spectrophotometer, and colour fastness was assessed according to ISO standards for washing, water, perspiration, rubbing, and light. Results revealed that dyeing temperature and time significantly influenced dye uptake, with the highest colour strength observed at 90 °C for 60 min. The optimum dyeing pH ranged from 3 to 5, corresponding to the stability of anthocyanin pigments in their flavylium cation form. Increasing dye concentration enhanced colour depth up to 30% owf, beyond which saturation occurred. The dyed silk exhibited good to very good washing, water, and perspiration fastness, moderate rubbing fastness, and low to fair light fastness. These findings demonstrate that purple corn cob extract provides a sustainable and effective natural dye for silk fabrics, yielding vivid reddish-purple shades with satisfactory fastness performance.

Key words: Natural dye, Purple corn cobs, Dyeing, Silk fabric, Colour fastness

INTRODUCTION

Natural dyes derived from plant, animal, or microbial sources are receiving renewed attention in textile science as society seeks to reduce the environmental burdens of synthetic dyes. The conventional dyeing and finishing stages in textile manufacturing are major contributors to resource consumption and chemical pollution. Indeed, dyeing and finishing alone account for 36% of the climate impact of the textile value chain. (Pizzicato et al., 2023). Natural dyes originated from renewables rather than petroleum feedstocks, proponents argue they offer a more sustainable alternative, especially when paired with greener extraction methods and emerging mordanting strategies that minimize toxic metal use (Das & Roy Maulik, 2024).

The benefits of natural dyes and their process tend to be more environmentally benign, which reduces the problem of wastewater pollution caused by non-biodegradable substances. In addition, natural dye studies also support circular economy goals since the dyes can be made from farm waste or leftover plant materials [1]. Advances in extraction methods have improved dye yield, reduced energy and solvent consumption, and shortened processing time. Making natural dye production more efficient and commercially sustainable (Das & Roy Maulik, 2024). In addition, Natural dyes are considered safer for human because they are biodegradable, non-toxic, and free from harmful aromatic amines and heavy metals. Many of the natural dye including those extracted from pomegranate peel, turmeric, madder root, and onion skin, contain bioactive compounds such as flavonoids and tannins that provide antimicrobial and antioxidant properties, it helps prevent skin irritation and allergic reactions (Mao & Xu, 2024).

Despite the growing interest in natural dyes, several significant disadvantages limit their wider industrial application. One of the most critical drawbacks was poor results on colour fastness washing, light, and rubbing, which remains notably short compared to synthetic dyes (Pizzicato et al., 2023). The reason was natural dye molecules often bind weaklier to fibre, making them susceptible to fading, bleeding, and colour loss when exposed to water, detergents, or ultraviolet light (Repon et al., 2024). A recent review discussed the balance between environmental safety and dye performance when using natural mordants. The review noted that bio-mordants made from plant wastehelp reducee the toxicity and environmental risks linked to heavy metals, but they often show lower colour fastness compared to traditional metallic mordants unless the dyeing process is carefully optimized (Islam et al., 2025). Another frequently reported challenge was shade reproducibility and batch variation. This was because the dye content and pigment composition in natural materials depend on factors such as plant variety, soil type, climate, harvest time, and extraction conditions, it was difficult to achieve the same hue in every dyeing batch (Yadav et al., 2025). Finally, scalability remains a major challenge. Many successful laboratory or pilot studies on natural dyes have not yet been adapted for large-scale industrial production. This is mainly due to the need for standardized processes, high investment costs, and the difficulty of fitting natural dye methods into existing factories that was designed for synthetic dyes (Yadav et al., 2023). In conclusion, natural colourants have great potential for promoting sustainability in the textile industry, and natural plant extracts are safe, skin-friendly, and suitable for sensitive applications such as medical textiles, infant wear, and eco-fashion. However, their success will depend on improving consistency, durability, affordability, and compatibility with modern manufacturing systems. These aspects remain critical focuses for future research and development in green dyeing technologies.

Purple corn was an ancient type of corn that originated in the Andean regions of Peru, where it has been grown for centuries as both a staple food and a natural colour source (Figure 1). The deep purple colour comes from a high number of anthocyanins, mainly cyanidin-3-glucoside, pelargonidin-3-glucoside, and peonidin derivatives, which are found in the outer layer and cob of the corn. These pigments are natural flavonoids known for their strong antioxidant, UV-absorbing, and pH-sensitive properties, making them promising eco-friendly colourants for textiles (Yang et al., 2009). This is because anthocyanins are water-soluble and biodegradable, purple corn dye is considered a sustainable alternative to synthetic dyes. However, their sensitivity to heat, light, and pH can cause colour fading and reduce durability. For this reason, recent studies have focused on improving extraction methods, mordanting processes, and fabric treatments to make purple corn dye more stable and suitable for long-term textile applications (Cai, Ge-Zhang & Song, 2023). Extending this research to cellulose fibres, Nakpathom et al (Nakpathom et al., 2018) investigated the dyeing of cationized cotton using natural colourant extracted from purple corn cobs Since anthocyanins are negatively charged, untreated cotton fibre show poor dye uptake. To solve this, the researcher cationized the cotton with a process that adds quaternary ammonium groups to the fibre surface, creating positive sites that attract the dye molecules. This modification significantly increased the colour strength (K/S value) and improved colour evenness compared to untreated cotton.The key finding of this study is that modifying the fibre surface plays a more significant role than altering the dye composition in achieving effective colouration with natural dyes. This approach helps achieve brighter, longer-lasting colour on cotton fabrics and brings natural dyes like purple corn closer to practical, commercial use.Other studies have also looked at how to improve the stability and extraction of anthocyanins from purple corn. Yang et al. (Yang et al., 2009) found that heating the corn at 70°C for 70 minutes with a 1:25 solid-to-liquid ratio gave the best colour strength and pigment yield. That was important factors for getting consistent dye results on fabrics. Later, Cai et al. (Cai, Ge-Zhang & Song, 2023) studied the pigment structure and discovered that when anthocyanins in purple corn were chemically bonded with small acid groups, they became more stable to light and pH changes. This made the dye more durable and suitable for long-lasting, natural textile colouration.

Silk is a natural protein fibre produced mainly by the silkworm, renowned for the lustrous sheen, smooth texture, and exceptional tensile strength. Structurally, silk is composed of fibroin and sericin,which form into the

Figure 1. Purple corn cob

cocoon filament. Fibroin is responsible for the fibre's strength and elasticity, and sericin serves as a gum-like coating that surrounds and binds the fibroin filaments (Aad, Dragojlov & Vesentini, 2024). The unique amino acid composition of silk, especially it highly contents glycine, alanine, and serine, promotes strong hydrogen bonding and molecular affinity with natural dyes and mordants, making it an excellent substrate for eco-friendly dyeing processes (Biswal et al., 2022). The investigation of the dyeing of silk fabric using pomegranate peel extract with metal mordants such as alum and iron sulfate. The result revealed that silk dyed produced deeper, richer shades. Overall, the dyed fabrics showed good to very good wash and rubbing fastness (ratings 4.5) and moderate light fastness (3.5) (Yang et al., 2023). The silk retained reasonable colour strength due to the natural interaction between silk fibroin and tannins. The dyeing of silk fabric using onion outer skin extract, which contains natural flavonoids such as quercetin. The study examined how different metal mordants affected colour shade and fastness. Results showed that aluminum and iron sulfate produced richer, brighter colours with higher colour strength (K/S values) compared to unmordanted silk, while copper sulfate gave darker tones. Fastness tests confirmed that mordanted samples had better resistance to washing and light, demonstrating that onion skin extract is an effective and eco-friendly natural dye for silk when used with appropriate mordants (Uddin, 2014). Mongkholrattanasit et al. (Mongkholrattanasit et al., 2014a) studied how purple corn cob extract can be used as

a natural dye for silk fabric. The research focused on how different metal mordants,aluminum potassium sulfate, ferrous sulfate and copper sulfate affected the fabric's colour and colour fastness. The dyeing was done using a post-mordanting method, where the fabric was dyed first and then treated with the mordant at various concentrations. The results showed that the type and amount of mordant changed both the shade and colour strength (K/S value) of the silk. Fabrics dyed without mordant appeared light violet-pink, while aluminum mordant produced a similar but slightly stronger shade. The use of copper sulfate resulted in a gray tone with the highest colour strength, and ferrous sulfate produced a violet-gray colour. Tests following ISO standards revealed that the dyed silk had very good washing and water fastness (ratings 4.5), fair to good light fastness (3.5), and good rubbing fastness (4.5). Overall, the study confirmed that using metal mordants can significantly improve the depth and durability of colour from purple corn dye on silk fabric.

OBJECTIVES

This study investigated the dyeing behaviour of silk fabrics using a colourant extracted from purple corn cobs (Zea mays L.) and evaluated the effects of key dyeing parameters on colour characteristics and fastness properties.

EXPERIMENTAL

Materials

A commercially manufactured plain-weave silk fabric was pretreated by scouring in an aqueous solution containing a nonionic surfactant at 50 °C for 30 minutes, followed by thorough rinsing and air-drying under ambient conditions. The purple corn cobs used as the natural dye source were obtained from Ratchaburi Province, Thailand. A nonionic soaping agent supplied by Star Tech Chemical Industrial Co., Ltd. (Thailand) was employed during the dyeing process.

Equipment

Dyeing was performed using a checker dyeing machine (Newav Lab Equipments Co., Ltd., Thailand). Absorbance spectra were recorded with a UV–Vis double-beam spectrophotometer (Halo DB-20, Australia) using 1 cm quartz cuvettes. The colour values (L*, a*, b*) and colour strength (K/S) values of the dyed silk fabrics were evaluated with a spectrophotometer (Color Quest XE, HunterLab, USA).

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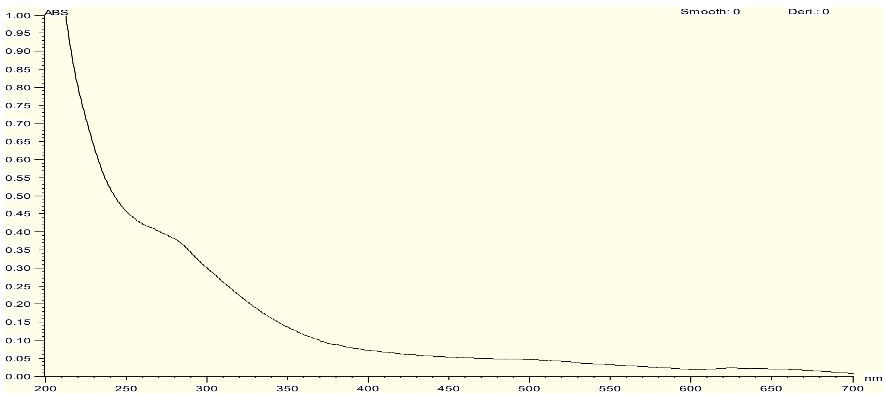

Figure 2. UV–Vis absorption spectrum of the crude dye extract from purple corn cob in distilled water.

Extraction of natural colourant from purple corn cob

Fresh purple corn cobs were extracted by boiling in distilled water at a material-to-liquor ratio of 1:40 for 1 h. The extract was cooled, filtered, and concentrated under reduced pressure to obtain the crude dye. For calibration, the crude extract was dissolved in distilled water to prepare standard solutions. A linear relationship between absorbance and concentration was observed at the maximum absorption wavelength (λ_{max} = 280 nm) (Figure 2), and the initial dye concentration was determined to be 5.4 g/L from the calibration curve (Mongkholrattanasit et al., 2014a), (Mongkholrattanasit et al., 2014b), (Mongkholrattanasit et al., 2014c).

Optimization of dyeing conditions

To establish the optimal dyeing conditions, silk fabrics were dyed with purple corn cob extract (30% owf; liquor ratio 1:100) through a series of experiments evaluating four dyeing parameters: temperature, time, pH, and dye concentration. The effect of temperature was studied by dyeing at 30–100 °C for 60 min at pH 6.4. Dyed samples were subsequently soaped and washed as described earlier. To investigate dyeing time, samples were dyed at 90 °C and pH 6.4 for 20–60 min. The influence of pH was evaluated by adjusting the dyebath to values between 3 and 9 with acetic acid or sodium carbonate, followed by dyeing at 90 °C for 60 min. Finally, the effect of dye concentration was assessed by dyeing at 90 °C and pH 6.4 for 60 min using 5, 10, 20, and 30% owf of the dye extract.

Colour measurement

The colour parameters (CIE L* a* *b***) and colour strength (K/S) of the dyed silk fabrics were measured using a spectrophotometer under illuminant D65 with a 10° standard observer. In the CIE colour system, L* denotes lightness (0 = black, 100 = white), a* represents the red–green axis (+a* = red, −a* = green), and b* corresponds to the yellow–blue axis (+b* = yellow, −b* = blue) [18–20]. The K/S values, expressing colour strength, were derived from the Kubelka–Munk equation (Mongkholrattanasit, Klaichoi & Rungruangkitkrai, 2022),(Mongkholrattanasit, Klaichoi & Rungruangkitkrai, 2021).

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

where *R* is the reflectance, *K* the absorption coefficient, and *S* the scattering coefficient. All dyed samples exhibited a characteristic absorption peak at 400 nm.

Colour fastness properties

Colour fastness to washing, light, rubbing, water, and perspiration was assessed following ISO 105-C06 A1S:2010, ISO 105-B02:2014, ISO 105-X12:2016, ISO 105-E01:2013, and ISO 105-E04:2013, respectively (The International Organization for Standardization, 2010. ISO 105-C06, The International Organization for Standardization, 2013a. ISO 105-E01, The International Organization for Standardization, 2013b. ISO 105-E04, The International Organization for Standardization, 2014. ISO 105-B02, The International Organization for Standardization, 2016. ISO 105-X12).

RESULTS AND DISCUSSION

Effect of dyeing temperature on colour properties

Table 1 shows the colour values (L*, a*, b*) and colour strength (K/S) of silk fabrics dyed with purple corn cob dye solution at temperatures between 30 °C and 100 °C, under a dyeing time of 60 min, pH 6.4, and a liquor ratio of 1:100. The results demonstrate that temperature had a pronounced influence on the colour strength, brightness, and hue of the dyed silk fabrics.

As shown in Table 1, the colour strength (K/S) increased continuously from 0.79 at 30 °C to 1.15 at 100 °C, indicating that higher dyeing temperatures enhanced the uptake of anthocyanin colourants by the silk fibre. This behavior reflects the typical thermally activated diffusion mechanism, where increasing temperature accelerates

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the molecular mobility of dye molecules and enlarges the amorphous regions of the silk fibroin structure. The elevated temperature thus improves the penetration of anthocyanins into the fibre matrix and facilitates stronger dye–fibre interactions, likely through hydrogen bonding and van der Waals forces [10].

Table 1 Colour values and colour strength of silk fabrics dyed with purple corn cob dye solution at different temperatures.

Temperature (^{o}C)	Colour strength (K/S)	Colour value			Colour obtained
		L*	a*	b*	
30	0.79	69.90	11.27	6.35	
50	1.02	68.30	11.08	7.29	
70	1.09	66.96	12.27	8.08	
90	1.14	64.70	12.15	8.77	
100	1.15	64.62	11.79	8.76	

The nearly constant K/S value between 90 °C (1.14) and 100 °C (1.15) suggests that the dyeing equilibrium was reached around 90 °C. Beyond this temperature, further increases produced only marginal improvement in colour depth, implying that the dye–fibre binding sites were almost saturated and additional thermal energy mainly caused minor structural rearrangements rather than higher dye uptake. This trend aligns with the findings of Nakpathom et al. (2018), who reported optimal colour yield for purple corn cob dye on cationized cotton at approximately 100 °C, and Mongkholrattanasit et al. (2014a) , who observed maximum colour depth in silk dyed with purple corn cob extract at 90 °C under similar dyeing conditions.

The L* values decreased progressively from 69.90 at 30 °C to 64.62 at 100 °C, indicating that the fabric colour became darker with increasing temperature. This darkening effect corresponds to the higher dye concentration within the silk fibres and greater light absorption at elevated dyeing temperatures. Simultaneously, the a* values (representing redness) increased slightly from 11.27 to 11.79, while b* values (yellowness) rose from 6.35 to 8.76, suggesting a gradual shift in hue toward reddish-yellow tones. Visually, the silk fabrics dyed at 30–50 °C appeared light violetish-pink, at 70–90 °C they developed a reddish-purple hue, and at 100 °C they showed a deeper reddish-brownish purple. These shade variations are characteristic of the temperature-dependent stability of anthocyanins, which are sensitive to thermal transformation and pH changes. At higher temperatures, partial degradation of glycosidic bonds and formation of chalcone intermediates contribute to the darkening and hue shift.

Anthocyanins, the primary pigments in purple corn cob extract, exhibit complex stability behavior under heat. As temperature increases, the equilibrium between the flavylium cation (red form) and its hydrated or chalcone forms (colourless or yellowish) shifts toward the less stable products. However, when bound to silk fibroin, anthocyanins gain partial thermal protection due to hydrogen bonding between hydroxyl groups of anthocyanins and amide groups of fibroin. This explains the maintenance of colour intensity up to 90 °C before noticeable pigment degradation occurs at higher temperatures.

The results indicate that dyeing at 70–90 °C yields the most desirable colour characteristics—high colour strength, good brightness, and a stable reddish-purple hue—without significant pigment degradation. Dyeing below this range results in lighter, less saturated colours due to limited dye diffusion, while dyeing above 90 °C risks pigment oxidation and dark, dull shades. Therefore, for practical silk dyeing applications using purple corn cob extract, maintaining the temperature near 90 °C is recommended to achieve optimal colour performance and reproducibility.

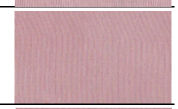
Effect of dyeing time on colour properties

Table 2 presents the colour values (L*, a*, b*) and colour strength (K/S) of silk fabrics dyed with purple corn cob dye solution for different dyeing durations ranging from 20 to 60 minutes under fixed conditions: temperature 90 °C, dye concentration 30% owf, pH 6.4, and a liquor ratio of 1:100. The results demonstrate that dyeing time had a distinct influence on the colour intensity, shade uniformity, and chromatic coordinates of the dyed silk fabrics.

The colour strength (K/S) values increased markedly from 0.86 at 20 minutes to 1.14 at 60 minutes, reflecting a progressive enhancement in dye uptake as the dyeing time increased. The most significant increase occurred between 20 and 30 minutes, where K/S rose from 0.86 to 1.06, indicating rapid diffusion of dye molecules during the initial phase of dyeing.

After 40 minutes, the rate of increase in K/S values slowed, suggesting that the dye–fibre system was approaching equilibrium. At 50–60 minutes, the K/S values plateaued (1.13–1.14), indicating that dye adsorption had reached near saturation, and further prolongation of time produced minimal improvement in colour strength. This trend corresponds to the diffusion–adsorption equilibrium model observed in natural dyeing systems, where dye uptake initially increases rapidly due to a high concentration gradient but eventually stabilizes as the internal diffusion resistance and dye–fibre binding balance each other (Kamel et al., 2007).

Table 2 Colour values and colour strength of silk fabrics dyed with purple corn cob dye solution at different time.

Time (min)	Colour strength (K/S)	Colour value			Colour obtained
		L*	a*	b*	
20	0.86	68.56	10.07	7.20	
30	1.06	65.95	11.35	8.02	
40	1.08	65.45	11.38	8.37	
50	1.13	64.90	11.36	8.36	
60	1.14	64.70	12.15	8.77	

The overall improvement in colour strength with longer dyeing time can also be attributed to enhanced molecular interaction between anthocyanin pigments and the fibroin chains of silk. At prolonged exposure, dye molecules can better penetrate the amorphous regions of the silk structure, establishing hydrogen bonding and van der Waals interactions with amino and hydroxyl groups on the fibre surface (Nakpathom et al., 2018).

The L* values decreased consistently from 68.56 at 20 minutes to 64.70 at 60 minutes, demonstrating a gradual darkening of the dyed fabric with increasing dyeing time. This reduction in lightness corresponds with greater dye uptake and increased surface coverage of the fibre by anthocyanins. The a* (redness) and b* (yellowness) values also rose gradually from 10.07 to 12.15 and 7.20 to 8.77, respectively, reflecting a shift toward deeper reddish and yellowish tones.

The visible colour transformation progressed from a light violetish-pink at 20 minutes to a reddish-purple hue at 40–50 minutes, and finally to a deep reddish-purple at 60 minutes. This shade evolution aligns with the increasing concentration of anthocyanins absorbed by the silk fibre, as well as possible aggregation of pigment molecules on the fibre surface at longer dyeing times. A similar trend was reported by Mongkholrattanasit et al.

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(Mongkholrattanasit et al., 2014b), who found that longer dyeing durations intensified the hue of silk fabrics dyed with purple corn cob extract, producing more saturated and darker shades.

The dye uptake kinetics of natural colourants, particularly anthocyanins, are strongly influenced by time and temperature. During the early stages of dyeing, the adsorption process dominates, controlled by the concentration gradient between the fibre and the dye bath. As time progresses, diffusion into the fibre's amorphous regions becomes the rate-limiting step. The steady-state equilibrium observed after 50 minutes in this study indicates that most available dye-binding sites on the silk fibroin had been occupied (Nakpathom et al., 2018), (Nakpathom et al., 2018). Moreover, anthocyanins are relatively stable at 90 °C for limited time periods, but prolonged exposure beyond one hour may promote pigment hydrolysis or oxidation, leading to a decrease in colour intensity and shade dullness. Thus, maintaining a dyeing time within 50–60 minutes ensures sufficient dye–fibre interaction without significant pigment degradation.

Based on these results, a dyeing time of 50–60 minutes can be considered optimal for achieving maximum colour strength and a deep, uniform reddish-purple hue on silk fabrics dyed with purple corn cob extract. Shorter dyeing times yield lighter and less intense shades, while excessively long durations do not significantly enhance colour strength and may risk pigment instability. This optimal range aligns closely with previous findings on the dyeing of natural pigments on silk and cotton substrates.

Effect of pH on the colour properties of dyed silk

Table 3 presents the colour values (L*, a*, b*) and colour strength (K/S) of silk fabrics dyed with purple corn cob dye solution at different pH levels, ranging from 3.0 to 9.0, under controlled dyeing conditions of 90 °C for 60 min, dye concentration of 30% owf, and a liquor ratio of 1:100. The results reveal that the pH of the dyebath has a profound influence on both dye uptake and colour appearance of the silk fabrics.

The colour strength (K/S) reached its maximum value of 1.21 at pH 3.0, gradually decreased to 1.07 at pH 5.0, and dropped sharply to 0.73 at pH 7.0 and 0.15 at pH 9.0. This trend clearly indicates that acidic conditions favored the highest dye uptake, whereas neutral and alkaline conditions significantly reduced colour strength. This behavior can be attributed to the ionic nature and structural stability of anthocyanins, the major pigments in purple corn cob extract. Anthocyanins exist predominantly as the flavylium cation (red form) under acidic conditions (pH < 4), which enhances their affinity toward the slightly negatively charged silk fibroin surface through electrostatic attraction and hydrogen bonding.

Table 3 Colour values and colour strength of silk fabrics dyed with purple corn cob dye solution at different pH

pH	Colour strength (K/S)	Colour value			Colour obtained
		L*	a*	b*	
3.0	1.21	60.73	12.77	9.99	
5.0	1.07	65.83	10.60	8.50	
7.0	0.73	70.04	11.2	7.94	
9.0	0.15	86.16	0.76	11.41	

The strong colour yield at pH 3.0 thus corresponds to a high concentration of stable flavylium ions capable of forming ionic and hydrogen bonds with amino groups (-NH_2) of silk fibroin [29]. In contrast, at pH 9.0, the highly alkaline medium leads to deprotonation of both the dye and the silk surface, creating electrostatic repulsion that inhibits dye adsorption (Nakpathom et al., 2018), (Rungruangkitkrai et al., 2025).

The colour coordinates further support these findings. The L* value increased from 60.73 at pH 3.0 to 86.16 at pH 9.0, indicating a transition from dark to very light colour tones as the solution became more alkaline. This increase in lightness is consistent with the loss of chromophoric integrity of anthocyanins at higher pH levels due to ring-opening reactions and pigment degradation (Rungruangkitkrai et al., 2025).

Meanwhile, the a* (redness) value decreased drastically from 12.77 at pH 3.0 to 0.76 at pH 9.0, demonstrating that the red colouration intensity sharply declined with increasing pH. Conversely, the b* (yellowness) value increased slightly from 9.99 to 11.41, indicating a shift from reddish-purple to dull yellowish tones under alkaline conditions. This hue shift corresponds to the conversion of red flavylium ions into bluish or yellowish chalcone forms as the pH increased beyond neutrality.

Visually, silk fabrics dyed at pH 3.0 appeared deep reddish-purple, at pH 5.0 they were pinkish-purple, at pH 7.0 they became light violet-pink, and at pH 9.0 they turned pale yellow-brown (De Nisi et al., 2021). These chromatic variations confirm the strong dependence of anthocyanin colour on pH and align well with the visible spectral behavior described in prior work by Nakpathom et al.(2018) and De Nisi et al. (2011), where silk fabrics exhibited vivid hues only in acidic dye baths.

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The dyeing behavior observed across the pH range is governed by the structural equilibrium of anthocyanins in aqueous solutions. In acidic environments (pH 1–4), the flavylium cation dominates, giving rise to red to purple colours with high tinctorial strength. At intermediate pH (5–7), the equilibrium shifts toward the quinoidal base and hemiketal forms, resulting in lower colour intensity. Under alkaline conditions (pH > 8), irreversible ring opening to chalcone structures leads to pigment bleaching and colour loss (Rungruangkitkrai et al., 2025). Moreover, the stability of silk fibroin under acidic conditions contributes to better dye affinity compared to cellulose fibres, which are more sensitive to low pH. The proteinaceous nature of silk allows anthocyanins to interact through hydrogen bonds and π–π stacking, enhancing dye fixation and resistance to colour fading (Nakpathom et al., 2018). However, in alkaline conditions, partial hydrolysis of silk fibroin may occur, further reducing dye uptake efficiency.

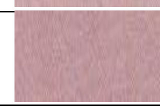
Overall, the results indicate that an acidic dye bath (pH 3–5) is optimal for dyeing silk fabrics with purple corn cob extract. This range ensures maximum colour strength, vivid reddish-purple hues, and structural stability of the anthocyanins. Neutral and alkaline conditions should be avoided as they drastically diminish dye affinity and colour intensity due to pigment deprotonation and degradation.

Influence of dye concentration on colour properties

Table 4 presents the coluor values (L*, a*, b*) and colour strength (K/S) of silk fabrics dyed with purple corn cob dye solution at different dye concentrations ranging from 5% to 30% owf under fixed dyeing conditions of 90 °C for 60 minutes, pH 6.4, and a liquor ratio of 1:100. The results clearly demonstrate that the concentration of dye in the bath significantly affects both the colour intensity and the visual appearance of the dyed silk fabrics.

As the dye concentration increased from 5% to 30% owf, the colour strength (K/S) increased steadily from 0.38 to 1.07, indicating greater dye uptake and colour saturation at higher concentrations. The rise in K/S values suggests that a higher concentration of anthocyanin pigments in the dyebath enhances the diffusion gradient between the dye solution and the silk fibre, thereby promoting more effective dye adsorption and penetration. This phenomenon agrees with diffusion-controlled adsorption models, where dye molecules migrate from a concentrated bath toward the less saturated fibre interior until equilibrium is achieved (Nakpathom et al., 2018), (Rungruangkitkrai et al., 2025).

Table 4 Colour values and colour strength of silk fabrics dyed with purple corn cob dye solution at different dye concentration

Dye conc. (% owf.)	Colour strength (K/S)	Colour value			Colour obtained
		L*	a*	b*	
5	0.38	79.55	4.56	8.20	
10	0.48	76.26	6.59	7.86	
20	0.78	69.86	8.98	8.57	
30	1.07	65.83	10.60	8.50	

At low concentrations (5–10% owf), the limited number of dye molecules results in partial surface coverage of the fibre, producing pale shades. As the dye concentration increases (20–30% owf), the available pigment molecules increase the probability of interaction with active sites on the silk fibroin, resulting in higher colour yield and deeper shades. However, the rate of increase in K/S values begins to level off beyond 20% owf, suggesting that the adsorption sites on the silk fibre approach saturation.

The L* value decreased progressively from 79.55 at 5% owf to 65.83 at 30% owf, reflecting a darkening of the dyed silk as the dye concentration increased. This decrease in lightness correlates directly with the higher colour strength observed, as greater pigment deposition on the fibre surface reduces reflectance. The a* (redness) value increased from 4.56 at 5% owf to 10.60 at 30% owf, while the b* (yellowness) values remained nearly constant around 8.0–8.5, suggesting a shift toward more reddish-purple hues with minimal changes in yellow tone. The overall colour tone transitioned visually from pale pinkish-violet at low concentration to deep reddish-purple at 30% owf.

The improvement in colour strength with increasing dye concentration can be attributed to the enhanced availability of anthocyanins capable of interacting with the functional groups of silk fibroin. The amino ($-NH_2$) and hydroxyl (-OH) groups on silk form hydrogen bonds with the hydroxyl groups of anthocyanin molecules, stabilizing the adsorbed pigments. At higher dye concentrations, multilayer adsorption or co-pigmentation may occur on the fibre surface, leading to greater optical density (Nakpathom et al., 2018),(Rungruangkitkrai et al., 2025).

Nevertheless, excessive dye concentration may lead to pigment aggregation, uneven adsorption, or surface saturation, which can cause dullness or lower gloss in the resulting shade. Similar behavior was observed in studies using other natural dyes, such as lac and cochineal, where dye–dye interactions reduced light scattering efficiency at high concentration (Kamel et al., 2007).

The results indicate that increasing the dye concentration enhances the colour strength and richness of hue up to about 20–30% owf, beyond which the improvement becomes less pronounced. Therefore, dyeing with 30% owf purple corn cob extract at 90 °C and pH 6.4 can be considered optimal for producing vivid, uniform reddish-purple silk fabrics with balanced brightness and colour saturation.

Evaluation of fastness properties of silk fabrics dyed with purple corn cob

Table 5 summarizes the colour fastness properties of silk fabrics dyed with purple corn cob dye solution at 90 °C for 60 min, pH 6.4, dye concentration 30% owf, and a liquor ratio of 1:100. The fastness tests included washing, water, perspiration (acid and alkaline), crocking (dry and wet), and light. The overall fastness ratings ranged from good to very good, confirming that purple corn extract imparts stable dyeing performance on silk under standard conditions.

Table 5 Colour fastness test of silk fabrics dyed with purple corn cob dye solution.

Colour fastness to	Washing	Water	Perspiration		Crocking		Light
			Acid	Alkaline	Dry	Wet	
Colour change	4.0	4.5	4.0	3.5	-	-	3.5
Colour staining					4.0	4.0	-
-Acetate	4.5	4.5	4.5	4.0	-	-	-
-Cotton	4.5	4.5	4.5	3.5	-	-	-
-Nylon	4.5	4.5	4.5	4.0	-	-	-
-Polyester	4.5	4.5	4.5	4.0	-	-	-
-Acrylic	4.5	4.5	4.5	4.0	-	-	-
-Wool	4.5	4.5	4.5	4.0	-	-	-

The dyed silk exhibited good to very good washing fastness, with a colour change rating of 4.0 and staining ratings between 4.0–4.5 for all fibre types. Similarly, water fastness showed a colour change rating of 4.5, with negligible staining on adjacent fibres. These results suggest that anthocyanins from purple corn extract form relatively strong physical and chemical interactions with the silk fibroin structure. The silk's amino ($-NH_2$) and hydroxyl (-OH) groups provide hydrogen bonding and van der Waals interactions with the hydroxyl groups of anthocyanin molecules, which enhances dye fixation and resistance to desorption during laundering (Nakpathom et al., 2018),(Mongkholrattanasit et al., 2014a). The perspiration fastness ratings under acidic and alkaline conditions were 4.0 and 3.5, respectively, indicating slightly lower resistance in the alkaline medium. Anthocyanins are known to be pH-sensitive pigments whose chromophore stability decreases under basic environments due to structural conversion from the red flavylium cation to the colourless chalcone form. Under acidic perspiration, the dye–fibre complex remains more stable because the silk surface is protonated, enhancing ionic attraction with the negatively charged anthocyanin groups. In contrast, at alkaline pH, the silk surface becomes deprotonated, weakening these interactions and leading to partial desorption or oxidation of the pigment (Mongkholrattanasit et al., 2014a), (Mongkholrattanasit et al., 2014b).

The dry crocking fastness rating was 3.0, while wet crocking was slightly lower (2.5–3.0), indicating moderate resistance to rubbing. This reduction in wet crocking resistance can be attributed to surface pigment particles that remain loosely bound or aggregated during high dye loading at 30% owf. In wet conditions, water acts as a plasticizer, weakening the physical adhesion between dye molecules and the fibre surface (Kamel et al., 2007).

The light fastness of the dyed silk was grade 3.5, corresponding to low-fair resistance to photofading. This result aligns with the known photochemical instability of anthocyanins, which are prone to degradation under ultraviolet (UV) exposure due to cleavage of the flavylium structure and oxidation of phenolic groups (Rungruangkitkrai et al., 2025). However, the relatively compact structure of silk and possible co-pigmentation effects between anthocyanins and fibre-bound proteins may retard the rate of fading.

In general, the purple corn–dyed silk demonstrated good to very good resistance to washing, water, and perspiration, moderate rubbing fastness, and fair light fastness. These results confirm that natural anthocyanin colourants from purple corn can produce durable shades on silk without the need for heavy-metal mordants, offering a sustainable alternative to synthetic dyes. While the limited light stability remains a known limitation of anthocyanin dyes, several studies suggest improvement via mordanting with iron or aluminum salts, co-pigmentation with tannins, or the incorporation of UV-absorbing biopolymers (Mongkholrattanasit et al., 2014b), (Mongkholrattanasit et al., 2014c), (Rungruangkitkrai et al., 2025). Figure 3. Silk shawl dyed with purple corn cob extract using the tie-dye technique, showing a deep reddish-purple colour. The variation in tone and pattern reflects the characteristic uneven dye penetration of tie-dyeing, resulting in an aesthetically unique and naturally patterned appearance.

Figure 3 Tie-dyeing of silk shawl using natural dye extracted from purple corn cobs

CONCLUSION

The findings of this study confirm that purple corn cobs, an agricultural by-product rich in anthocyanins, can serve as an effective and sustainable natural dye source for silk fabrics. The variation of dyeing parameters-temperature, time, pH, and dye concentration-significantly influenced colour intensity and tone. Optimum dyeing performance was achieved at 90 °C for 60 minutes, with a pH range of 3 - 5 and a dye concentration of 30% owf, yielding a deep reddish-purple shade with high colour strength. The dyed silk exhibited good overall colour fastness, particularly to washing, water, and perspiration, while maintaining moderate rubbing and low to fair light resistance. These results demonstrate that silk has high affinity for anthocyanin-based dyes under mildly acidic conditions. Beyond the technical outcomes, this research also emphasizes the environmental and economic potential of utilizing purple corn cobs as a renewable resource for natural textile dyes. Their application in silk dyeing aligns with global trends in sustainable and health-conscious textile production, highlighting the feasibility of producing biodegradable, non-toxic, and aesthetically appealing fabrics through natural dyeing methods.

Future work

Future research on the application of purple corn cob extracts as natural dyes for silk fabrics can be expanded in several meaningful directions. Although the present study establishes optimal dyeing conditions and demonstrates satisfactory fastness properties, further investigations are needed to improve dye stability and broaden practical applications. One important area for future work is the enhancement of light fastness, as anthocyanin-based dyes are inherently sensitive to photodegradation. Exploring natural or bio-based fixatives, encapsulation technologies. Additionally, extending the study to other textile fibres such as cotton, wool, and regenerated fibre could provide insight into fibre dye interactions and support wider industrial use. Experimental work should also examine the scalability of dye extraction and application processes, including energy-efficient heating methods, optimized solvent systems, and potential for continuous dyeing operations. Life-cycle assessment (LCA) and cost–benefit analysis would further clarify the environmental and economic viability of large-scale adoption.

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