RESEARCH ARTICLE AGROBIOLOGICAL RECORDS
ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
Open Access Journal

PHYTOCHEMICAL SCREENING AND FASTNESS EVALUATION OF NATURAL TEXTILES DYED WITH *RADERMACHERA IGNEA* EXTRACTS

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ABSTRACT

This study investigated the phytochemical composition of different parts of *Radermachera ignea* and evaluated its potential as a natural colorant source for cotton and silk. Phytochemical screening of bark, leaves, and flowers was conducted using standard qualitative assays, while dye extraction from fresh and withered flowers was performed using aqueous and ethanol solvents at concentrations of 25–95%. Dyeing experiments incorporated natural and metal mordants, with Cu^{2+}, Fe^{2+}, and Al^{3+} treatments standardized to 0.0001 mol of central metal ion per gram of fiber, followed by colorimetric evaluation using the L*, a*, and b* system. Wash fastness was assessed using simulated ultrasonic washing with sodium lauryl sulfate, and light fastness was evaluated under UVC irradiation as an accelerated comparative photodegradation stress test. Results showed significant differences ($P<0.05$) in L*, a*, and b* values among extraction methods and mordant treatments. Withered flower extracts obtained using 75% ethanol generally produced stronger coloration and higher redness (a*) in cotton and silk, whereas Cu^{2+} and Fe^{2+} mordants enhanced yellowness (b*) and relative color retention after washing and UVC exposure. Natural mordants, particularly tea leaves and banana sap, improved red-tone development, while copper-based mordanting was more effective in maintaining yellow tones under accelerated light exposure. The key methodological contribution of this study is the standardization of metal mordant comparisons based on equivalent central metal-ion concentrations rather than total metal-salt weight, enabling a more comparable assessment of Cu^{2+}, Fe^{2+}, and Al^{3+} mordant effects. These findings provide practical guidance for selecting plant-based extracts and mordanting strategies for sustainable textile coloration. However, RI flower pigments, likely dominated by carotenoid-type compounds such as zeaxanthin, showed limited fixation and stability on textile fibers, suggesting that further stabilization strategies are required before practical textile application.

***Keywords*:** *Radermachera ignea,* Phytochemical screening, Natural dye, Wash fastness, Light fastness.

Article History (ABR-26-151) || Received: 17-Apr-2026 || Revised: 20-May-2026 || Accepted: 30-May-2026 || Published Online: 06-Jun-2026

1. INTRODUCTION

Natural dyes and pigments are becoming more significant as a sustainable substitute to synthetic dyes. Derived from renewable resources, these materials are recognized for their biodegradability and safety, offering a variety of color options and uses across sectors such as textiles, cosmetics, food, and pharmaceuticals. Ongoing research and technological advancements show that natural dyes offer a viable alternative to synthetic dyes, fostering a more sustainable and eco-friendly future (Negi, 2025a; 2025b). The pigments, as colored secondary metabolites, provide the world with a vibrant array of hues. They mainly come from plants are essential for their survival and adaptation mechanisms, such as flavonoids, carotenoids, pyrroles, quinones, azaphilones, melanins, betalains, flavins, and additional categories (Tang et al., 2024).

Radermachera ignea (RI) (Kurz) Steenis (synonym: *Mayodendron igneum* (Kurz) Kurz), the emblem tree of Suranaree University of Technology, Nakhon Ratchasima, Thailand. It is naturally distributed in dry evergreen and mixed deciduous forests in southern China, Vietnam, Laos, Thailand, and Myanmar, and is recognized for its bright orange flowers (Ngernsaengsaruay et al., 2026). Previous phytochemical studies have reported several compounds from different parts of this species. Guo et al. (2007) identified 19 compounds from RI bark, including phenolic compounds, chromones, monoterpenes, diterpenes, triterpenes, amides, and anthraquinones. Hashem et al. (2007), Hashem et al. (2012) and Shabana et al. (2013) reported sterols, diterpenes, triterpenes, flavonoids, and coumarins

Citation: Wathakit K, Sombatpraiwan S and Phasinam K, 2026. Phytochemical screening and fastness evaluation of natural textiles dyed with *Radermachera ignea* extracts. Agrobiological Records 24: 152-164. https://doi.org/10.47278/journal.abr/2026.033

ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
Open Access Journal

from RI leaves. Sompong & Trakanrungroj (2010) identified zeaxanthin as the major pigment in RI flowers, along with steroid compounds. These reports indicate that RI contains several phytochemical groups that are potentially relevant to natural coloration.

However, the reports found focus on detailed identification of pure compounds in depth; no reports on the overall composition of different parts of the RI tree have been found. It is well known that people are increasingly prioritizing health and the environment. Therefore, natural products and dyes are becoming more popular. However, natural dyes have limitations; some are difficult to adhere to fibers, light colors, or are easily washed out or fade when exposed to light (Alegbe & Uthman, 2024). Therefore, in addition to selecting a mordant that ensures good color adhesion to the fibers, it is also necessary to test for wash resistance and fading from light.

Dyeing involves mordants, which may be metal salts or natural substances, acting as bridges between dye molecules and fibers to improve adhesion. Conventional mordant dosing is commonly expressed as concentration in solution or percent on weight of fiber (owf.). Because different metal salts contain different molecular weights, counterions, and waters of crystallization, equal mass-based dosing does not deliver equivalent amounts of active central metal ions.

Natural dyeing commonly requires mordants to improve the interaction between dye molecules and textile fibers. Mordants may be metal salts or natural substances and can act as bridges that promote complex formation and improve dye adhesion (Wang et al., 2025). In many textile studies, metal mordants are applied based on concentration in solution, such as g/L or g/100 mL, or based on percentage on weight of fiber (Mongkholrattanasit et al., 2013; Repon et al., 2017; Sarker et al., 2020; Triwiswara & Indrayani, 2020; Hosen et al., 2021; Paramasivam et al., 2022; Mai et al., 2024; Sepahi et al., 2025).

However, mass-based comparison may not provide an equivalent amount of active central metal ions because different salts contain different molecular weights, counterions and waters of crystallization. For example, $CuSO_4$ $5H_2O$, $FeSO_4$ $7H_2O$ and $KAl(SO_4)_2$ $12H_2O$ contain different proportions of Cu2+, Fe2+, and Al3+, respectively, as well as sulfate ions and crystalline water that do not directly function as central ions in dye–fiber complexation. Therefore, applying different metal salts with the same total mass does not necessarily yield comparable availability of the central metal ion. To address this issue, the present study standardized Cu^{2+}, Fe^{2+}, and Al^{3+} mordants based on equivalent central metal ion concentration, specifically 0.0001 mol central metal ion per gram of fiber.

The limited reports have discussed mordant comparison using an ion-equivalent basis; therefore, this approach may provide a more comparable framework for evaluating metal mordant effects in natural dyeing. Natural mordants are also important in sustainable textile coloration because they may reduce reliance on synthetic or heavy metal mordants. However, unlike purified metal salts, natural mordants contain complex mixtures of tannins, polyphenols, minerals, sugars, and other plant constituents, making exact quantification of active mordanting components difficult. For this reason, natural mordants are commonly prepared using traditional extraction methods based on plant material mass, extraction temperature, and extraction time. In this study, tea leaves, licorice root, pomegranate peel, and banana sap were selected as natural mordant sources and compared with metal mordants to assess their effects on the performance of RI flower dyeing.

In addition to initial color development, wash and light fastness are key limitations of many natural dyes. Wash fastness is affected by detergent chemistry, water, temperature and mechanical action. Sodium lauryl sulfate (SLS) was used in this study as a representative detergent, while ultrasonic washing was applied to generate mechanical stress through cavitation. Using ultrasonic waves, mechanical force is generated through vibrations in a medium. This creates rapidly collapsing and expanding air cavities, or ultrasonic cavitation, which generates physical forces that can be used to simulate washing conditions in a test tube.

Photodegradation is a process in which a material breaks down by absorbing energy from light. Generally, UV light is the primary source of photodegradation (Singh & Sharma, 2008; Wang et al., 2020; Ding et al., 2022). UVC irradiation has higher photon energy than UVA and visible light; for example, a 253.7 nm UVC photon provides approximately 4.89 eV, while a 365 nm UVA photon provides approximately 3.40 eV based on the Planck–Einstein relation (Da Silva & Faria, 2003). Although UVC does not directly represent natural sunlight exposure at the earth's surface, it can serve as an accelerated comparative photodegradation stress test under controlled conditions. Therefore, in this study, UVC irradiation was used as a screening tool to compare relative color stability among treatments rather than as a direct simulation of natural service conditions.

The present study was designed to address four main research gaps: (i) the lack of comparative phytochemical screening among different RI plant parts; (ii) the limited evaluation of RI flower extract as a natural textile colorant; (iii) the need for a more comparable basis for metal mordant dosage using equivalent central metal ion concentration; and (iv) the need to evaluate RI-dyed fibers under accelerated washing and light exposure conditions. The hypotheses were that RI flowers could provide measurable coloration on cotton and silk, that natural and metal mordants would significantly affect L*, a*, and b* color values and fastness behavior, and that standardizing metal mordants by equivalent central ion concentration would allow clearer comparison among Cu^{2+}, Fe^{2+}, and Al^{3+} treatments. Therefore, this research comprised two components: (A) preliminary phytochemical screening of RI

ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
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bark, leaves, and flowers; and (B) evaluation of cotton and silk dyeing performance using RI flower extracts with natural and metal mordants, followed by simulated ultrasonic washing and UVC irradiation exposure.

2. MATERIALS AND METHODS

The RI Tree is the official tree of Suranaree University of Technology (SUT). Its species has been verified and certified by the university's botany experts for several decades. These plant samples were collected from SUT campus, Nakhon Ratchasima, Thailand, in February 2025. Bark samples, defined as the outer layer extending to the cambium, middle-aged leaves, and fresh blooming flowers were collected for phytochemical screening. The samples were washed with reverse osmosis (RO) water, dried at 40°C for 24 h, ground, and sieved through a 0.250 mm screen.

For dyeing experiments, RI flowers were divided into two groups: fresh flowers, including flowers blooming on the tree or newly fallen flowers that remained fresh, and withered flowers, which had turned dark orange or brown but were not completely dry. Cotton threads were raw twisted cotton obtained from Chiang Mai Province, Thailand, and silk threads were degummed silk obtained from Chul Thai Silk Co., Ltd., Phetchabun Province, Thailand. Natural mordant materials included commercial dried tea leaves, dried licorice root, dried pomegranate peel, and banana sap obtained from banana floral inflorescences within the university farm.

2.1. Phytochemical Screening

2.1.1. Preparation of plant extracts: Each plant powder was immersed in a solvent at a ratio of 5 g/100 mL and stirred at room temperature for 6 h using a magnetic stirrer. The solvents were selected according to the target phytochemical groups. Water was used for tannins and phlobatannins; 65% ethanol was used for saponins, flavonoids, and anthraquinones; 75% ethanol was used for coumarins and triterpenoids; and 85% ethanol was used for steroids and deoxy sugars. The samples were then treated in an ultrasonic bath at 40 kHz and 300 W for 30 min at 30°C, filtered through Whatman No. 1 filter paper, and concentrated using a vacuum evaporator. The crude extracts were collected for qualitative phytochemical assays.

***2.1.2. Qualitative phytochemical assays*:** The qualitative phytochemical screening methods were modified from Evans (2009), Ben et al. (2013), Quraishi (2016), Gul et al. (2017), Narakornwit et al (2018), Shaikh and Patil (2020), Dubale et al. (2023) and Taesotikul et al. (2023). The assays included tests for tannins, phlobatannins, saponins, flavonoids, anthraquinones, coumarins, triterpenoids, steroids, deoxy sugars, and reducing sugars.

For tannin detection, ferric chloride, lead acetate, and gelatin tests were performed. In the ferric chloride test, 0.2 g of crude extract obtained from water extraction was mixed with 5.0 mL of distilled water and heated in a water bath for 5 min. The solution was filtered, and five drops of 1% ferric chloride solution were added. A greenish-black or bluish-black color indicated the presence of tannins. In the lead acetate test, 1 mL of extract was mixed with 10 mL of water and five drops of 1% lead acetate solution. A white precipitate indicated the presence of tannins. In the gelatin test, 1% gelatin solution containing sodium chloride was added to approximately 1 g of extract. Formation of a white precipitate indicated the presence of tannins.

For phlobatannin detection, 0.2 g of crude water extract was mixed with 5.0 mL of distilled water, heated in a steam bath for 5 min, and filtered. A 10% hydrochloric acid solution was added to the filtrate, followed by heating in a water bath for 5 min. Development of a red color indicated the presence of phlobatannins.

For saponin detection, 0.2 g of crude extract obtained from 65% ethanol extraction was mixed with 5.0 mL of distilled water, heated in a water bath for 5 min, and shaken vigorously. Persistent foam lasting longer than 15 min indicated the presence of saponins.

For flavonoid detection, 0.2 g of crude extract obtained from 65% ethanol extraction was dissolved in 5.0 mL of 65% ethanol, shaken, and filtered. Shinoda's test was performed by adding a piece of magnesium and a few drops of concentrated hydrochloric acid to the filtrate. Pew's test was performed by adding a small piece of zinc metal and concentrated hydrochloric acid, followed by heating in a water bath for 5 min. A pink-red color indicated the presence of flavonoids. Additional tests included sodium hydroxide, concentrated sulfuric acid, Rao and Sheshadri's nitric acid test, and boric acid-acetic acid fluorescence observation. The sodium hydroxide solution test yields a positive result when it turns yellow-brown or red. The concentrated sulfuric acid test yields a positive result when it turns pink-red. The Rao and Sheshadri test with concentrated nitric acid produces a blue color, and the final method involves testing with boric acid and adding 2–3 drops of acetic acid, resulting in a yellow color and green fluorescence.

For anthraquinone detection, 0.2 g of crude extract obtained from 65% ethanol extraction was mixed with 5 mL of 10% sulfuric acid, shaken, heated in a water bath for 5 min, filtered, cooled to room temperature, and extracted with 5 mL of chloroform. Then, 3 mL of 10% ammonia solution was added. A pinkish-red color indicated the presence of anthraquinones.

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ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
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For coumarin detection, 0.2 g of crude extract obtained from 75% ethanol extraction was dissolved in 5.0 mL of 75% ethanol, shaken, and filtered. A 6 M sodium hydroxide solution was added to the filtrate. A dark yellow color, confirmed by fluorescence under UV light at 365 nm, indicated the presence of coumarins.

For triterpenoid detection, 0.2 g of crude extract obtained from 75% ethanol extraction was dissolved in 5 mL of chloroform, shaken, and filtered. Concentrated sulfuric acid was added slowly to the filtrate. Formation of a brown ring at the interface indicated the presence of triterpenoids

For steroid detection, the Liebermann-Burchard test was performed. Crude extract obtained from 85% ethanol extraction was dissolved in 5 mL of chloroform and filtered. Glacial acetic acid was added to the filtrate, followed by concentrated sulfuric acid. A blue or bluish-green color indicated the presence of steroids, whereas a red, orange, or purple color suggested triterpenoids.

For deoxy sugar detection, the Keller-Kiliani (KK) test was performed. Crude extract obtained from 85% ethanol extraction was dissolved in 5 mL of chloroform and filtered. A 1% ferric chloride solution and glacial acetic acid were added, followed by gradual addition of concentrated sulfuric acid. Formation of a brown ring at the interface indicated the presence of deoxy sugars.

For reducing sugar detection, Benedict's test was performed. Benedict's solution was prepared from 4.325 g of copper sulfate pentahydrate, 43.25 g of sodium citrate, and 25 g of sodium carbonate dissolved in distilled water to a final volume of 500 mL. The aqueous extract was mixed with Benedict's solution at a ratio of 1:2 (v/v) and heated for 3–5 min. Formation of a brick-red precipitate indicated the presence of reducing sugars.

2.2. Dyeing and Fastness Evaluation

2.2.1. Dye extraction from RI flowers: Fresh and withered RI flowers were dried at 45°C for 12 h and ground through a 1 mm sieve. Dye extraction was performed using water and ethanol solvents at concentrations of 25%, 50%, 75%, and 95%. The flower powder-to-solvent ratio was 1:20 (W/V). The mixture was extracted in a water bath shaker at 50°C for 120 min (Lambrecht et al., 2023) and then filtered. The extract codes were defined as D for dried or withered flowers and F for fresh flowers, followed by the solvent condition: W for water and 25, 50, 75, or 95 for ethanol concentration.

***2.2.2. Mordant preparation*:** Natural mordants were prepared from dried tea leaves, dried licorice root, and dried pomegranate peel. Each material was ground through a 1 mm sieve and extracted with water at 3 g/L at 50°C (Gironi & Piemonte, 2011; Lambrecht et al., 2023) for 120 min (Lambrecht et al., 2020; 2023). The extracts were filtered before use. Banana sap was used at 20 mL/L.

Metal mordants were prepared from analytical-grade $CuSO_45H_2O$ (Loba Chemie), $FeSO_47H_2O$ (Carlo Erba) and $KAl(SO_4)_212H_2O$ (Loba Chemie). The amount of each salt was calculated to provide an equivalent central metal ion concentration of 0.0001 mol Cu^{2+}, Fe^{2+}, or Al^{3+} per gram of fiber. This calculation was used to standardize the active central metal ion content, rather than to compare metal mordants based solely on total salt weight.

***2.2.3. Mordant treatments and dyeing procedure*:** Mordant treatments include the following: (1) no mordant, (2) tea leaves, (3) banana sap, (4) licorice root, (5) pomegranate fruit peel, (6) Cu^{2+} solution, (7) Fe^{2+} solution, (8) Al^{3+} solution, (9) tea/Cu^{2+}, (10) tea/Fe^{2+}, (11) tea/Al^{3+}, (12) banana sap/Cu^{2+}, (13) banana sap/Fe^{2+}, (14) banana sap/Al^{3+}, (15) licorice/Cu^{2+},(16) licorice/Fe^{2+}, (17) licorice/Al^{3+},(18) pomegranate /Cu^{2+}, (19) pomegranate/Fe^{2+} and (20) pomegranate/Al^{3+}.

For single mordant treatments i.e. sample (2) – (8), pre-mordanting was performed at a material-to-liquor ratio (MLR) of 1:25 at 50°C for 90 min in a water bath shaker. The specimens were dried in the shade for 2 days and then dyed with RI flower extract at 50°C (Lambrecht, et al., 2023) for 120 min in water bath shaker.

For combined natural and metal mordant treatments, specimens were first pre-mordanted with natural mordant at 50°C for 45 min and dried in the shade for 2 days. The specimens were then dyed with RI flower extract at 50°C for 120 min, dried again in the shade for 2 days, and post-mordanted with metal mordant solution at half concentration at 50°C for 45 min. Mordanting and dyeing were performed at an MLR of 1:25. After treatment, all specimens were rinsed under running tap water for 3 min, gently squeezed, and dried at 40°C for 12 h.

***2.2.4. Colorimetric measurement and technical replication*:** Colorimetric measurements were performed using a HunterLab UltraScan VIS colorimeter with D65 illumination, a 0.375-inch viewing area, and a reflectance specular excluded mode. The L*, a*, and b* values were recorded to represent lightness, red-green coordinates, and yellow-blue coordinates, respectively. The L* value ranges from 0 (black) to 100 (white), positive a* values indicate redness, negative a* values indicate greenness, positive b* values indicate yellowness, and negative b* values indicate blueness. An increase in both a* and b* values indicates a stronger orange tone.

ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
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For each treatment, one dyed cotton or silk specimen was prepared, and colorimetric values were measured at five different positions on each specimen. These five readings were treated as five technical replicate measurements per specimen. The technical replicate measurements were used to assess within-specimen color variation and to compare the relative effects of flower extract type, extraction solvent, mordant treatment, simulated washing and UVC irradiation.

***2.2.5. Wash fastness testing using simulated ultrasonic washing*:** Wash fastness was evaluated using a Cole-Parmer Model 08895-19 ultrasonic cleaner operated at 40 kHz and 300 W. Each treated dyed fiber specimen weighing approximately 1.0 g was immersed in 25 mL of 2 g/L sodium lauryl sulfate solution. The test tubes were placed in the ultrasonic bath, preheated to 30°C, and allowed to equilibrate for 10 min. Ultrasonic washing was then conducted for 30 min. After washing, each specimen was rinsed under running tap water for 3 min, dried at 40°C for 12 h, and measured again for L*, a*, and b* values.

***2.2.6. Light fastness testing using short-wave ultraviolet radiation*:** Light fastness was evaluated using UVC irradiation as an accelerated comparative photodegradation stress test. The irradiation system consisted of two PHILIPS TUV36W SLV/6 UVC lamps with a primary wavelength of 253.7 nm. The two 120 cm T8 tubes were positioned parallel to each other, 20 cm apart, and the perpendicular distance from the lamp to the specimen was 20 cm. Each tube consumed 36 W and emitted 16.4 W of UVC radiation. Laboratory conditions were controlled at 25°C and 65 ± 5% relative humidity. The dyed fiber specimens were exposed to UVC irradiation for 24 h. The UVC unit and specimen panels were placed in a ventilated chamber to minimize ozone accumulation as a possible interfering factor. After irradiation, colorimetric measurements were performed again.

2.3. Statistical Analysis

The L*, a*, and b* data were analyzed using IBM SPSS Statistics version 21.0. One-way analysis of variance (ANOVA) was used to evaluate significant differences among flower extract types, extraction solvents, and mordant treatments. Statistical significance was set at $P<0.05$, and results were interpreted at a 95% confidence level. Mean separation was performed using Duncan's multiple range test to classify treatment means into homogeneous subsets. Homogeneity of variance was assessed before ANOVA. The main factors considered were flower condition, extraction solvent, mordant treatment, textile fiber type, simulated ultrasonic washing, and UVC irradiation exposure.

3. RESULTS AND DISCUSSION

Phytochemical screening showed that different parts of RI contained different dominant phytochemical groups (Table 1). Bark extracts showed highly positive results for anthraquinones and flavonoids, together with positive

Table 1: Phytochemical screening in the bark, leaves, and flowers of the RI Tree

Group of phytochemicals	Test method	Part of RI tree		
		Bark	Leaves	Flower
Tannins	$FeCl_3$ test-Braymer's test	++	++	++
	Lead subacetate test	+	++	++
	Gelatin test	+	+	+
Phlobatannins	HCl test	-	-	-
Saponins	Foam test	+	+++	-
Anthraquinones	Borntrager's test	+++	-	-
Flavonoids	Shinoda's test (Cyanidin test)/ Mg-HCl reduction test	+++	+	-
	Pew's test /Zinc-HCl reduction test	-	-	-
	Aqueous NaOH test	+++	++	+
	Sulfuric acid test	-	+/-	-
	Rao and Sheshadri test (Nitric acid)	-	+/-	-
	Boric acid + Acetic acid, (UV)	-	-	-
Coumarins	NaOH test, (UV)	+/-	++	++
Triterpenoids	Salkowski and Liebermann-Burchard's tests	+	++	+++
Steroids	Libermann-Burchard's test	+	+++	++
Deoxy sugars	Keller-Kiliani test	+	+++	++
Reducing sugars	Benedict's test	+	+	+++

Note: (-) This means a negative result, which means the substance may be absent or present in such small quantities that the difference from the control cannot be observed; (+/-) The experiment shows unclear results; (+) Detected and displays a slightly positive result; (++) Clearly positive; (+++) Highly positive.

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ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
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results for tannins. Leaves showed highly positive results for saponins, steroids, and deoxy sugars, while coumarins, triterpenoids, and tannins were also detected. Flowers showed highly positive results for triterpenoids and reducing sugars, while tannins, coumarins, steroids, and deoxy sugars were clearly detected. These findings indicate that RI bark, leaves, and flowers differ in their major phytochemical profiles, which may influence their potential uses as colorants or bioactive plant resources.

Phytochemical analysis of the bark of the RI tree revealed tannins or polyphenols and flavonoids, consistent with the work of Guo et al. (2007). They found naringenin, quercetin, and naringin, all of which are polyphenols with flavonoid structures. Furthermore, the bark of RI also showed positive results in triterpenoid, anthraquinone, and sterol tests, consistent with the analytical chemistry work of Guo et al. (2007); Phytochemical tests on the leaves of the RI Tree revealed the presence of flavonoids, consistent with the work of Hashem et al. (2007) and Shabana et al. (2013). Triterpenoids and sterols were also found in leaves, consistent with Hashem et al. (2012); the test results found steroids or phytosterols in the RI flower, consistent with the work of Sompong & Trakanrungroj (2010), who reported the presence of β-sitosterol and stigmasterol in the RI flower.

The target color for RI flower dyeing was an orange tone, corresponding to the flower's natural color. In the L*, a*, and b* color system, orange development depends mainly on positive a* values, representing redness, and positive b* values, representing yellowness. Therefore, treatments that produced higher positive a* and b* values were considered more favorable for orange-tone development.

ANOVA showed that flower extract type significantly affected L*, a*, and b* values in both cotton and silk after dyeing (Table A1 and A2). Mordant treatment also significantly influenced L*, a*, and b* values in dyed cotton and silk (Table A3 and A4). These results indicate that both extraction condition and mordant selection played important roles in determining color development on textile fibers.

Table A1: Analysis of the total variance of the mean L*, a* and b* color values on cotton fibers after dyeing to compare the influence of different flower extracts

ANOVA

				Sum of Squares	df	Mean Square	F	Sig.
lightness	Between Groups	(Combined)		3018.865	9	335.429	11.388	.000
		Linear Term	Contrast	392.430	1	392.430	13.323	.000
			Deviation	2626.435	8	328.304	11.146	.000
	Within Groups			29159.686	990	29.454		
	Total			32178.551	999			
redness	Between Groups	(Combined)		272.811	9	30.312	14.182	.000
		Linear Term	Contrast	1.557	1	1.557	.729	.394
			Deviation	271.254	8	33.907	15.864	.000
	Within Groups			2116.019	990	2.137		
	Total			2388.830	999			
yellowness	Between Groups	(Combined)		1817.389	9	201.932	31.401	.000
		Linear Term	Contrast	77.067	1	77.067	11.984	.001
			Deviation	1740.322	8	217.540	33.829	.000
	Within Groups			6366.345	990	6.431		
	Total			8183.733	999			

Table A2: Analysis of the total variance of the mean L*, a*, and b* color values on silk fibers after dyeing to compare the influence of different flower extracts

ANOVA

				Sum of Squares	df	Mean Square	F	Sig.
lightness	Between Groups	(Combined)		4779.555	9	531.062	11.930	.000
		Linear Term	Contrast	3059.294	1	3059.294	68.724	.000
			Deviation	1720.262	8	215.033	4.830	.000
	Within Groups			44070.659	990	44.516		
	Total			48850.215	999			
redness	Between Groups	(Combined)		238.985	9	26.554	13.110	.000
		Linear Term	Contrast	88.783	1	88.783	43.832	.000
			Deviation	150.202	8	18.775	9.269	.000
	Within Groups			2005.266	990	2.026		
	Total			2244.251	999			
yellowness	Between Groups	(Combined)		1740.699	9	193.411	22.064	.000
		Linear Term	Contrast	997.817	1	997.817	113.830	.000
			Deviation	742.882	8	92.860	10.593	.000
	Within Groups			8678.182	990	8.766		
	Total			10418.880	999			

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ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
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After simulated ultrasonic washing, significant differences in L*, a*, and b* values remained among flower extract treatments for both cotton and silk (Table A5 and A6). Significant differences were also observed among mordant treatments after washing (Table A7 and A8). These findings suggest that the color retained after washing depended not only on the original dye extract but also strongly on the mordant type.

Table A3: Analysis of the total variance of the mean color values L*, a*, and b* on cotton fibers after dyeing to compare the influence of different mordants

ANOVA - Dyed Cotton /Treatment								
				SS	df	MS	F	Sig.
lightness	Between Groups	(Combined)		37358.757	19	1966.250	328.651	.000
		Linear Term	Contrast	1755.559	1	1755.559	293.435	.000
			Deviation	35603.198	18	1977.955	330.608	.000
	Within Groups			5863.128	980	5.983		
	Total			43221.885	999			
redness	Between Groups	(Combined)		810.367	19	42.651	69.055	.000
		Linear Term	Contrast	172.533	1	172.533	279.342	.000
			Deviation	637.834	18	35.435	57.372	.000
	Within Groups			605.287	980	.618		
	Total			1415.654	999			
yellowness	Between Groups	(Combined)		3871.395	19	203.758	56.504	.000
		Linear Term	Contrast	20.238	1	20.238	5.612	.018
			Deviation	3851.157	18	213.953	59.332	.000
	Within Groups			3533.934	980	3.606		
	Total			7405.329	999			

Table A4: A total variance analysis of the mean L*, a*, and b* color values on silk fibers after dyeing was performed to compare the influence of different mordants

ANOVA - Dyed Silk /Treatment								
				Sum of Squares	df	Mean Square	F	Sig.
lightness	Between Groups	(Combined)		41510.556	19	2184.766	291.713	.000
		Linear Term	Contrast	1761.067	1	1761.067	235.140	.000
			Deviation	39749.489	18	2208.305	294.856	.000
	Within Groups			7339.658	980	7.489		
	Total			48850.215	999			
redness	Between Groups	(Combined)		1271.712	19	66.932	67.446	.000
		Linear Term	Contrast	568.791	1	568.791	573.155	.000
			Deviation	702.921	18	39.051	39.351	.000
	Within Groups			972.538	980	.992		
	Total			2244.251	999			
yellowness	Between Groups	(Combined)		5530.935	19	291.102	58.364	.000
		Linear Term	Contrast	1006.844	1	1006.844	201.865	.000
			Deviation	4524.091	18	251.338	50.392	.000
	Within Groups			4887.945	980	4.988		
	Total			10418.880	999			

Table A5: A total variance analysis of the mean L*, a*, and b* color values on cotton fibers after simulated ultrasonic washing was performed to compare the influence of different flower extracts

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
lightness	Between Groups	1553.727	9	172.636	5.549	.000
	Within Groups	30802.622	990	31.114		
	Total	32356.349	999			
redness	Between Groups	107.423	9	11.936	5.776	.000
	Within Groups	2045.643	990	2.066		
	Total	2153.066	999			
yellowness	Between Groups	877.584	9	97.509	16.251	.000
	Within Groups	5940.078	990	6.000		
	Total	6817.662	999			

After UVC irradiation, flower extract type continued to significantly affect L*, a*, and b* values in both cotton and silk (Tables A9 and A10). Mordant treatment also significantly affected colorimetric values after UVC exposure (Tables A11 and A12). These results confirm that extract composition and mordant chemistry contributed to differences in relative light stability under accelerated photodegradation stress.

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Table A6: shows the overall analysis of variance of the mean L*, a*, and b* color values on silk fibers after simulated ultrasonic washing, comparing the influence of different flower extracts

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Lightness	Between Groups	3944.008	9	438.223	11.045	.000
	Within Groups	39277.877	990	39.675		
	Total	43221.885	999			
Redness	Between Groups	124.161	9	13.796	10.575	.000
	Within Groups	1291.493	990	1.305		
	Total	1415.654	999			
Yellowness	Between Groups	1255.280	9	139.476	22.452	.000
	Within Groups	6150.049	990	6.212		
	Total	7405.329	999			

Following significant ANOVA results, Duncan's multiple range test was used for mean separation and to classify treatment means into homogeneous subsets. Because the target color of RI flowers is orange, treatments with relatively higher positive a* values were interpreted as contributing to stronger red tones, whereas treatments with higher positive b* values were interpreted as contributing to stronger yellow tones. The extract and mordant treatments associated with higher redness and yellowness in cotton and silk before and after fastness testing are summarized in Table 2.

Table A7: Analysis of the total variance of the mean color values L*, a*, and b* on cotton fibers after simulated ultrasonic washing to compare the influence of different mordants

ANOVA

				Sum of Squares	df	Mean Square	F	Sig.
lightness	Between Groups	(Combined)		27621.056	19	1453.740	300.861	.000
		Linear Term	Contrast	363.058	1	363.058	75.137	.000
			Deviation	27257.998	18	1514.333	313.401	.000
	Within Groups			4735.293	980	4.832		
	Total			32356.349	999			
redness	Between Groups	(Combined)		1765.900	19	92.942	235.256	.000
		Linear Term	Contrast	55.186	1	55.186	139.688	.000
			Deviation	1710.713	18	95.040	240.565	.000
	Within Groups			387.167	980	.395		
	Total			2153.066	999			
yellowness	Between Groups	(Combined)		4071.522	19	214.291	76.473	.000
		Linear Term	Contrast	28.619	1	28.619	10.213	.001
			Deviation	4042.903	18	224.606	80.154	.000
	Within Groups			2746.140	980	2.802		
	Total			6817.662	999			

Table A8: Shows the overall analysis of variance of the mean color values L*, a*, and b* on silk fibers after simulated ultrasonic washing to compare the influence of different mordants

ANOVA

				Sum of Squares	df	Mean Square	F	Sig.
Lightness	Between Groups	(Combined)		37358.757	19	1966.250	328.651	.000
		Linear Term	Contrast	1755.559	1	1755.559	293.435	.000
			Deviation	35603.198	18	1977.955	330.608	.000
	Within Groups			5863.128	980	5.983		
	Total			43221.885	999			
Redness	Between Groups	(Combined)		810.367	19	42.651	69.055	.000
		Linear Term	Contrast	172.533	1	172.533	279.342	.000
			Deviation	637.834	18	35.435	57.372	.000
	Within Groups			605.287	980	.618		
	Total			1415.654	999			
Yellowness	Between Groups	(Combined)		3871.395	19	203.758	56.504	.000
		Linear Term	Contrast	20.238	1	20.238	5.612	.018
			Deviation	3851.157	18	213.953	59.332	.000
	Within Groups			3533.934	980	3.606		
	Total			7405.329	999			

The results summarized in Table 2 indicate that RI flower extracts produced measurable red and yellow color components on both cotton and silk; however, the overall dyeing performance was limited. Because the natural color of RI flowers is orange, desirable dyeing performance should involve the simultaneous development of

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ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
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positive a* and b* values, representing red and yellow tones, respectively. Among the tested extracts, D75 was the most frequently associated with higher redness or yellowness, particularly in cotton, suggesting that 75% ethanol extraction of withered flowers may recover pigment-related compounds that contribute to dull orange-brown coloration.

Table A9: Analysis of the total variance of the mean L*, a*, and b* color values on cotton fibers after testing for lightfastness with short-wave UV irradiation, comparing the influence of different flower extracts

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Lightness	Between Groups	986.241	9	109.582	3.073	.001
	Within Groups	35300.544	990	35.657		
	Total	36286.785	999			
Redness	Between Groups	94.627	9	10.514	4.968	.000
	Within Groups	2095.264	990	2.116		
	Total	2189.891	999			
Yellowness	Between Groups	588.756	9	65.417	8.146	.000
	Within Groups	7950.724	990	8.031		
	Total	8539.480	999			

Table A10: Analysis of the total variance of the mean L*, a*, and b* colors on silk fibers after testing for lightfastness using short-wave UV irradiation, comparing the influence of different flower extracts

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Lightness	Between Groups	2250.884	9	250.098	4.219	.000
	Within Groups	58687.114	990	59.280		
	Total	60937.998	999			
Redness	Between Groups	129.016	9	14.335	7.623	.000
	Within Groups	1861.633	990	1.880		
	Total	1990.649	999			
Yellowness	Between Groups	1209.541	9	134.393	18.050	.000
	Within Groups	7371.088	990	7.446		
	Total	8580.629	999			

Table A11: Analysis of the total variance of the mean L*, a*, and b* color values on cotton fibers after passing the lightfastness test with short-wave UV irradiation to compare the influence of different mordants

ANOVA

				Sum of Squares	df	Mean Square	F	Sig.
Lightness	Between Groups	(Combined)		32216.526	19	1695.607	408.253	.000
		Linear Term	Contrast	426.088	1	426.088	102.590	.000
			Deviation	31790.438	18	1766.135	425.234	.000
	Within Groups			4070.259	980	4.153		
	Total			36286.785	999			
Redness	Between Groups	(Combined)		1783.101	19	93.847	226.088	.000
		Linear Term	Contrast	185.607	1	185.607	447.147	.000
			Deviation	1597.494	18	88.750	213.807	.000
	Within Groups			406.790	980	.415		
	Total			2189.891	999			
Yellowness	Between Groups	(Combined)		6158.527	19	324.133	133.413	.000
		Linear Term	Contrast	6.907	1	6.907	2.843	.092
			Deviation	6151.621	18	341.757	140.667	.000
	Within Groups			2380.952	980	2.430		
	Total			8539.480	999			

Natural and metal mordants showed different effects on color development and retention. Tea leaves and banana sap were more frequently associated with higher redness, indicating that natural mordants may support red-tone development or retention through hydrogen bonding or weak interactions with dye components. In contrast, Cu^{2+} and Fe^{2+} mordants were more frequently associated with higher yellowness, suggesting that metal ions may enhance or stabilize yellow-tone components through coordination with available functional groups in the dye–fiber system. However, these mordant effects were not sufficient to fully overcome the limited fixation and stability of RI flower pigments.

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ISSN: 2708-7182 (Print); ISSN: 2708-7190 (Online)
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Table A12: Analysis of the total variance of the mean L*, a*, and b* color values on silk fibers after passing the lightfastness test with short-wave UV irradiation to compare the influence of different mordants

ANOVA								
				Sum of Squares	df	Mean Square	F	Sig.
Lightness	Between Groups	(Combined)		56253.133	19	2960.691	619.330	.000
		Linear Term	Contrast	3637.609	1	3637.609	760.931	.000
			Deviation	52615.524	18	2923.085	611.463	.000
	Within Groups			4684.865	980	4.780		
	Total			60937.998	999			
Redness	Between Groups	(Combined)		1351.223	19	71.117	108.996	.000
		Linear Term	Contrast	237.032	1	237.032	363.280	.000
			Deviation	1114.191	18	61.900	94.869	.000
	Within Groups			639.426	980	.652		
	Total			1990.649	999			
Yellowness	Between Groups	(Combined)		4877.164	19	256.693	67.925	.000
		Linear Term	Contrast	61.797	1	61.797	16.352	.000
			Deviation	4815.367	18	267.520	70.790	.000
	Within Groups			3703.466	980	3.779		
	Total			8580.629	999			

Table 2: Duncan's multiple range classification of RI flower extracts and mordant treatments associated with higher redness (a*) and yellowness (b*) values in cotton and silk before and after fastness testing

Process	Fiber	Statistical classification of subsets	Factor: flower extracts [1]	Factor: Mordants
Dyed	cotton	most red value	*D75*	tea leaves
		most yellow value	*D75, f75*	Cu^{2+} or Fe^{2+} solution
	silk	most red value	*D50, D75*	tea leaves, banana sap
		most yellow value	*Dw, D25, D75*	Cu^{2+} or Fe^{2+} solution
After US simulation washing	cotton	most red value	*D75*	banana sap
		most yellow value	*D75, F75*	licorice/Fe^{2+} sol.
	silk	most red value	*Dw, D50, D75*	tea leaves
		most yellow value	*Dw, D25, D75*	Cu^{2+} or Fe^{2+} solution
After UV radiation testing.	cotton	most red value	*D75*	banana sap
		most yellow value	*D25, D75, D95, F75*	Cu^{2+} solution
	silk	most red value	*F25, F50, F95*	tea leaves, banana sap
		most yellow value	*F25, F50, F75, F95*	Cu^{2+} solution

[1] *D* = dried or withered flowers; *F* = fresh flowers; *w* = water extraction; 25, 50, 75, and 95 = ethanol concentrations used for extraction. Higher redness and yellowness were interpreted based on positive a* and b* values, respectively.

The limited dyeing performance may be related to the chemical nature of the major orange pigment in RI flowers. Sompong &Trakanrungroj (2010) reported that zeaxanthin is a major pigment in RI flowers. Zeaxanthin belongs to the xanthophyll group of carotenoids, which are oxygen-containing yellow-to-orange plant pigments. Although zeaxanthin contains hydroxyl groups, its overall structure remains largely hydrophobic and relatively less polar than many polyphenolic natural dyes. This characteristic may reduce its affinity for hydrophilic textile fibers and water-soluble mordants, resulting in weak dye fixation and poor resistance to washing or light exposure.

This interpretation is consistent with previous studies on carotenoid-based textile coloration. Carotenoid extracts from orange peel, carrot peel, and similar plant materials have been reported to produce attractive initial colors but limited wash and light fastness, especially on cotton fibers. Such limitations are commonly attributed to the low polarity, limited functional groups, and weak dye–fiber interactions of carotenoid pigments. Therefore, RI flower extract may behave similarly to other carotenoid-rich natural colorants: it can provide visible coloration but requires additional stabilization strategies to improve textile fastness.

The UVC irradiation results further suggest that RI flower pigments have limited photostability under accelerated oxidative stress. Carotenoids such as zeaxanthin are known to be sensitive to light, heat, and oxidation, which can lead to structural degradation and color fading. Therefore, the UVC test in this study should be interpreted as an accelerated comparative stress condition rather than a direct simulation of natural sunlight exposure. The observed color changes after UVC exposure indicate that further stabilization approaches, such as encapsulation, binder-assisted fixation, bio-mordant optimization, or formulation with protective matrices, may be necessary before RI flower pigments can be applied in practice for sustainable textile coloration.

Overall, RI flower extract showed measurable dyeing effects on cotton and silk, particularly when D75 extract was combined with selected natural or metal mordants. Nevertheless, the results indicate that RI flower pigments are not well-suited as standalone textile dyes due to weak fixation and poor photostability. From a practical perspective, RI flowers may be more suitable as a source of high-value, carotenoid-rich extracts for functional,

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nutritional, or pharmaceutical applications, whereas textile applications would require further stabilization and formulation development.

4. CONCLUSION

This study demonstrated that different parts of *Radermachera ignea* contain distinct phytochemical groups. RI bark showed strong responses for flavonoids and anthraquinones, leaves were characterized by saponins and steroids, and flowers showed prominent triterpenoids and reducing sugars. However, these findings were based on preliminary qualitative screening of crude extracts; therefore, further purification and instrumental analysis, such as HPLC or LC-MS, are required for definitive compound identification.

For textile dyeing, RI flower extracts produced measurable red and yellow color components on cotton and silk, but the overall fixation and fastness performance were limited. Among the tested treatments, D75 extract was the most consistently favorable extract for cotton, particularly when combined with banana sap, licorice/Fe^{2+}, or Cu^{2+} mordanting systems. For silk, Dw and D75 extracts were more favorable after washing, whereas F25, F50, and F95 extracts showed better relative performance after UVC irradiation. Tea leaves and Cu^{2+} mordants were the most useful mordanting options for improving color retention in silk.

The limited adhesion and photostability of RI flower pigments suggest that RI flower extract has limited suitability as a standalone textile dye without further stabilization. Future research should focus on improving fixation through bio-mordant optimization, encapsulation, binder-assisted dyeing, or protective formulations to support sustainable textile applications. In addition, because RI flowers may contain carotenoid-type pigments such as zeaxanthin, further investigation of high-value extract applications may be considered as an alternative pathway for maximizing the value of this plant resource.

Declarations

Funding: This work was supported by (i) Suranaree University of Technology (SUT), (ii) Thailand Science Research and Innovation (TSRI), and (iii) National Science, Research and Innovation Fund (NSRF) under Project No. 4773896

Acknowledgement: The authors would like to express their sincere gratitude to the Center for Plant Genetic Conservation Project under the Royal Initiative of Her Royal Highness Princess Maha Chakri Sirindhorn, Suranaree University of Technology, Thailand, for providing plant materials, laboratory facilities, and technical support throughout this study.

Conflicts of Interest: The authors declare no conflict of interest.

Data Availability: All data are available in the article.

Ethics Statement: This research did not require ethics statement approval because there were no human and animal participants.

Author's Contributions: Khatha Wathakit: Conceptualization, methodology, supervision, project administration, data interpretation, and writing–original draft. Sakaya Sombatpraiwan: Investigation, experimental work, sample preparation, phytochemical screening, dyeing experiments, colorimetric measurements, and data collection. Khongdet Phasinam: Statistical analysis, validation, manuscript preparation, writing-review and editing, and corresponding author responsibilities.

Generative AI Statements: The authors declare that no Gen AI/DeepSeek was used in the writing/creation of this manuscript.

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Citation: Wathakit K, Sombatpraiwan S and Phasinam K, 2026. Phytochemical screening and fastness evaluation of natural textiles dyed with *Radermachera ignea* extracts. Agrobiological Records 24: 152-164. https://doi.org/10.47278/journal.abr/2026.033

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Citation: Wathakit K, Sombatpraiwan S and Phasinam K, 2026. Phytochemical screening and fastness evaluation of natural textiles dyed with *Radermachera ignea* extracts. Agrobiological Records 24: 152-164. https://doi.org/10.47278/journal.abr/2026.033