MARI

MULTIDISCIPLINARY APPLIED RESEARCH AND INNOVATION
e-ISSN: 2773-4773

Vol. 7 No. 2 (2026) 16-27
https://publisher.uthm.edu.my/periodicals/index.php/mari

Evaluation of Mordanting Methods and Natural Dye Extraction from Mangosteen Peel for Fibre-Dyeing Applications Using Different Solvents

Aida Muhamad[1,2]*, Aina Naylisa Uyop[1], Ayu Zulaikha Idham Kadri[1], Aliya Nabila Mohammad Raswan[1]

[1] *Department of Science and Mathematics, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, Pagoh Higher Education Hub, 86000 Pagoh, Johor, MALAYSIA*

[2] *Sustainable and Renewable Resources Research Group (SURE), Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, Pagoh Higher Education Hub, 86000 Pagoh, Johor, MALAYSIA*

*Corresponding Author: aidamohd@uthm.edu.my
DOI: https://doi.org/10.30880/mari.2026.07.02.003

Article Info

Received: 01 March 2026
Accepted: 01 May 2026
Available online: 30 June 2026

Keywords

Natural dye, natural pigment extraction, mangosteen peel extract, fabric dyeing, anthocyanin, mordanting methods, colour fastness test

Abstract

Developing textile dyeing processes using natural products such as fruits is one way to promote sustainability in manufacturing. This research focuses on extracting natural dyes from mangosteen (*Garnicia mangostana L.*) peel waste for cotton fabric dyeing. The extraction was carried out using four different solvent systems: distilled water, 50% ethanol, 1% citric acid, and a mixture of 50% ethanol with 1% citric acid. Among these, ethanol yielded the highest anthocyanin content at 193.9 ppm, followed by ethanol + citric acid at 174.6 ppm, citric acid at 64.2 ppm, and distilled water at 48.8 ppm. The purpose of testing different solvents was to evaluate their effectiveness in extracting natural dyes from mangosteen peels. Extraction was performed using the air-drying method for all four solvents, followed by a mordanting process with zinc sulfate through three approaches: pre-mordanting, simultaneous mordanting, and post-mordanting. To confirm the presence of anthocyanins in mangosteen peel, UV-Vis and FTIR spectroscopy analyses were conducted. To assess colour fastness, two tests were performed: washing fastness and light fastness under sunlight. The vibrancy score for post-mordanting with ethanol was the highest at 22.8, indicating brighter and more attractive dyeing on cotton fabric. However, in terms of light fastness, pre-mordanting with distilled water and ethanol performed best, with scores of 8.37 and 9.11, respectively. Overall, post-mordanting with ethanol demonstrated superior dye absorption and colour vibrancy, while pre-mordanting provided greater resistance to colour fading under sunlight.

1. Introduction

Natural materials such as minerals, animals, and plants have been used for centuries as sources of textile dyes. Among them, plants are the most commonly used, including fruit skins, roots, leaves, bark, and wood, due to their biodegradability and non-toxicity. In contrast, most synthetic dyes used today are carcinogenic and non-biodegradable [1]. The dyeing process in the textile industry, which relies heavily on synthetic dyes, is a major contributor to water pollution, as the high levels of dye in wastewater make treatment challenging and lead to harmful byproducts.

This is an open access article under the CC BY-NC-SA 4.0 license.

Various methods exist for extracting dyes from natural sources, such as aqueous extraction [2], reflux, Soxhlet [3], solvent extraction, ultrasound-assisted, and microwave-assisted extraction [4]. These methods allow the separation of natural pigments to be used as dyes. To prevent fading, mordanting methods are applied, including pre-mordanting, simultaneous mordanting, and post-mordanting [1]. The choice of extraction and mordanting techniques depends on the type of natural source and the textile material used.

Different dyeing methods are also applied depending on the fiber type, dye properties, batch size, and quality requirements. Common approaches include dye bath [5], vat dyeing [6], and spray dyeing [7]. For example, cotton, wool, and silk require different processes to achieve desirable properties such as lightfastness and wash resistance.

Mangosteen (*Garcinia mangostana L.*) peels are often discarded as food waste, but they contain valuable pigments that can be used for dye production. The peel contains anthocyanins, which are water-soluble flavonoid pigments responsible for red, purple, and blue colours in many fruits and vegetables. The major anthocyanins in mangosteen are cyanidin-3-O-glucoside and cyanidin-3-O-sophoroside. These compounds are non-toxic, environmentally friendly, and biodegradable, with additional health benefits due to their antioxidant activity. Thus, they are valuable as functional colorants in textiles, foods, and cosmetics [8].

Since mangosteen peel pigments have no direct affinity for unmordanted fabrics, mordants or metal salts are required to fix the dye onto cotton fibers. In this study, aqueous extraction was carried out using different solvents, followed by three mordanting approaches: pre-mordanting (mordant applied before dyeing), simultaneous mordanting (mordant mixed with the dye bath), and post-mordanting (mordant applied after dyeing). Zinc sulfate was used as the mordant [1]. This approach demonstrates that mangosteen peel is a sustainable source for natural dye production. Its bioactive compounds, such as anthocyanins and xanthones, not only enhance brightness and eco-friendly properties but also support the circular economy by reducing waste and environmental impact [2].

2. Literature Review

2.1 Mangosteen Peel as A Natural Source

2.1.1 Chemical Composition

α-Mangostin derivatives and anthocyanins are the main components of mangosteen peel extract responsible for its dyeing properties. These compounds exhibit absorption in the range of 350–550 nm, showing strong UV-Vis absorbance that contributes effectively to colour production. Furthermore, the hydroxyl and carbonyl groups present in α-mangostin and anthocyanin derivatives enhance their applicability as natural dyes by facilitating strong binding to textile surfaces.

Mangosteen peel also contains hemicellulose and lignin, which support its use in chemical applications such as colour production. Functional group analysis through FTIR confirmed the presence of hydroxyl and carbonyl groups, which play a major role in dyeing performance and binding interactions [9]. The anthocyanins in mangosteen peel exhibited characteristic absorption peaks at 3398, 2926, 1708, and 1631 cm^{-1}, corresponding to their chromophoric structures that are responsible for vibrant colour properties. In addition, UV-Vis spectroscopy showed a maximum absorption wavelength at 512 nm, further confirming the suitability of mangosteen peel extract as a natural pigment [10].

2.1.2 Sustainable Applications

Mangosteen peel produces natural dyes that are environmentally friendly for textile and leather applications. These natural dyes are non-toxic, biodegradable, and derived from renewable sources, making them supportive of the circular economy and effective in reducing environmental pollution. In addition to textiles, they have potential applications in the food and cosmetic industries, where they can provide high functionality and consistent quality [10].

Furthermore, mangosteen-derived dyes are increasingly explored as biodegradable inks for printing, natural pigments in cosmetics, and colouring agents for medical products, owing to their bioactive and antioxidant properties. As food and agricultural waste, mangosteen peels offer both environmental and economic benefits by contributing to waste reduction and resource recovery. When combined with other fruit wastes, mangosteen peel extracts can also be applied in environmentally friendly solutions such as water purification [9].

2.2 Application of Mangosteen Dye on Cotton Fabrics

Mangosteen peels have no direct affinity for unmordanted materials; therefore, mordants are required during the dyeing process. Fixing agents such as metal salts serve as mordants, influencing both the shade and the colour fastness properties of the dyes [11].

Previous studies have demonstrated that natural dye extracted from mangosteen peel can be successfully applied to cotton fabric. According to Ridho Asra, mangosteen peel (*Garcinia mangostana L.*) contains anthocyanin pigments that play a crucial role in colouration. The results revealed that the yield of mangosteen peel extract contained a total anthocyanin content with λmax = 367 nm, corresponding to 9.58 mg/100 g, and λmax = 289 nm, corresponding to 52.43 mg/100 g [12].

2.3 Environmental Benefits

Natural dyes are preferable to synthetic dyes for colouring cotton fabrics because they help reduce chemical pollution. Derived primarily from plant sources such as mangosteen peel, natural dyes do not require the toxic chemicals typically used in synthetic dye production. As a result, they minimize the release of hazardous substances into water bodies. In addition, natural dyes promote sustainable practices for future generations and reduce dependency on petrochemicals, which are the main raw materials for synthetic dyes. Finally, natural dyes are biodegradable and decompose naturally, unlike synthetic dyes that persist in the environment and cause long-term pollution [13].

3. Methodology

3.1 Materials

Mangosteen peel (*Garcinia mangostana L.*) was used in powdered form, with a total of 156 g prepared for this study. On average, approximately 0.6 kg of peel can be obtained from 1 kg of mangosteen fruit. The chemicals used in this study were ethanol, citric acid, and zinc sulfate. The chemicals were sourced from the laboratory's available supplies. Mangosteen peel (*Garcinia mangostana L.*) was used in powdered form. The amount of powder used is 156g. Approximately, 0.6 kg of peel can be obtained per 1 kg of mangosteen fruit. The chemicals used in this study are Ethanol, Citric Acid and Zinc Sulfate were available in the laboratory.

3.2 Sample Preparation of Mangosteen Peel

A total of 3 kg of fresh mangosteen fruits was obtained from a local store in Pagoh, Johor. The fruits were thoroughly washed with distilled water and air-dried under shade to remove surface moisture. The outer peels were manually separated using a stainless-steel peeler. The peels were then oven-dried at 42 °C for 3 days until a constant weight was achieved. Dried peels were ground using a commercial blender and sieved through an 80-mesh sieve. The resulting powder was packed in aluminium foil–laminated pouches and stored in a freezer at 10 °C for 1 week. After storage, the powder was analysed using an FTIR spectrometer to confirm the presence of anthocyanins.

3.3 Pigment Extraction

Pigments were extracted using a conventional aqueous extraction method. A ratio of 1:20 (w/v) was applied, where 25 g of mangosteen peel powder was mixed with 500 mL of solvent. The mixture was stirred at 45 °C for 45 minutes using a magnetic stirring hot plate. Four types of solvents were used: distilled water, 1% citric acid solution (acidified aqueous), 50% ethanol, and a combination of 50% ethanol with 1% citric acid.

Different solvent systems were selected to evaluate their effectiveness in extracting anthocyanin pigments from mangosteen peel. Distilled water served as a neutral control, while 1% citric acid tested the effect of acidity. The 50% ethanol solution was chosen for its stronger extraction ability, and the combination of 50% ethanol with 1% citric acid was used to enhance both extraction efficiency and pigment stability. This comparison enabled the identification of the solvent system that produced the best colour yield and dyeing quality for fabric applications.

3.4 Total Anthocyanin Content Determination

The total anthocyanin content in the extract was determined using UV-Vis spectrophotometry. Extracts prepared with the four different solvents were placed in a quartz cuvette, and absorbance was measured across the wavelength range of 200–600 nm to identify the maximum absorption wavelength (λmax) [12]. The anthocyanin concentration was calculated using equation (1):

$$Total\ Anthocyanin\ (ppm) = \frac{A \times MW \times FP\ \times 1000}{\varepsilon\ \times b} \tag{1}$$

where A is the absorbance, MW is the molecular weight of cyanidin-3-O-glucoside, FP is the dilution factor, ε is the molar absorptivity (26,900 L/mol·cm), and b is the path length of the cuvette (1 cm).

3.5 Mordanting

To facilitate dye binding to the fabric, a mordant solution was prepared by dissolving 3 g of zinc sulphate in 100 mL of distilled water. Approximately 13 g of cotton fabric was immersed in the solution and heated at 90 °C for 10 minutes with continuous stirring. The fabric was then rinsed with distilled water and air-dried.

Three different mordanting methods were tested to evaluate their effectiveness. In the pre-mordanting method, the fabric was first soaked in the zinc solution prior to dyeing. In the simultaneous mordanting method, the zinc solution was mixed directly with the dye bath. In the post-mordanting method, the fabric was dyed first and subsequently soaked in the zinc solution. Each method was assessed to determine its effect on dye absorption and colour fastness of the cotton fabric.

3.6 Dye Application

Approximately 13 g of cotton fabric was dyed with mangosteen peel extract at 20% owf (on weight of fabric) using a water bath shaker. The dyeing process was conducted at 85 °C for 60 minutes with a material-to-liquor ratio of 1:20 (13 g fabric: 260 mL dye solution). After dyeing, the fabric was rinsed thoroughly with distilled water and air-dried prior to analysis.

3.7 Colour Fastness Test

To evaluate the dye fastness of the fabric, two tests were conducted: a Washing Test and a Light Test. In the Washing Test, the dyed fabric was immersed in 130 mL of tap water for 2 hours. The coloured solution was then analyzed using a DR6000 spectrophotometer to determine the amount of dye released from the fabric. In the Light Test, the dyed fabric was mounted on a holder and exposed to direct sunlight for 3 hours, after which the degree of colour fading was visually compared and recorded.

3.8 Colour Vibrancy

The vibrancy score is used to measure the intensity of a colour. It helps determine which solvent and mordanting method produces the most vibrant colour after dyeing, based on the colour code. The score is calculated by multiplying the colour's saturation and lightness values obtained from the colour code, and then dividing the result by 10 to keep the values manageable. Although this method is not scientifically standardized, it provides a quick and practical way to compare colour intensity.

4. Result and Discussion

4.1 Anthocyanin Content

Anthocyanins are a class of water-soluble flavonoids widely present in fruits and vegetables [14]. Fig. 1 shows the FT-IR spectrum of the mangosteen peel powder. The FTIR spectrum of mangosteen peel powder revealed characteristic functional groups corresponding to its major phytochemical constituents. A broad band at 3298 cm^{-1} indicated O–H stretching vibrations of phenolic compounds, tannins, and hydrogen-bonded water. Peaks at 2918 and 2851 cm^{-1} were assigned to aliphatic C–H stretching from cellulose, hemicellulose, and residual lipids. The absorption at 2109 cm^{-1} corresponded to aromatic ring overtones, confirming the presence of substituted benzene rings associated with flavonoids, xanthones, and lignin. A strong band at 1603 cm^{-1} was attributed to aromatic C=C stretching and conjugated carbonyl groups, while the band at 1435 cm^{-1} represented CH_2/CH_3 bending vibrations of lignin and phenolics. The 1278 cm^{-1} peak was linked to C–O stretching of phenolic aryl–O and ester/ether linkages, typical of flavonoids and xanthones. Finally, the prominent absorption at 1032 cm^{-1} was associated with C–O–C and C–O stretching of polysaccharides such as cellulose, hemicellulose, pectin, and glycosidic bonds, highlighting the lignocellulosic nature of the peel matrix.

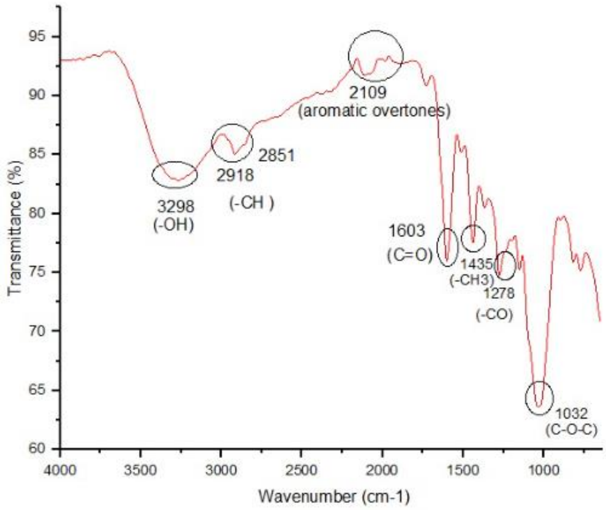


Fig. 1 *FT-IR Spectrum of mangosteen peel powder*

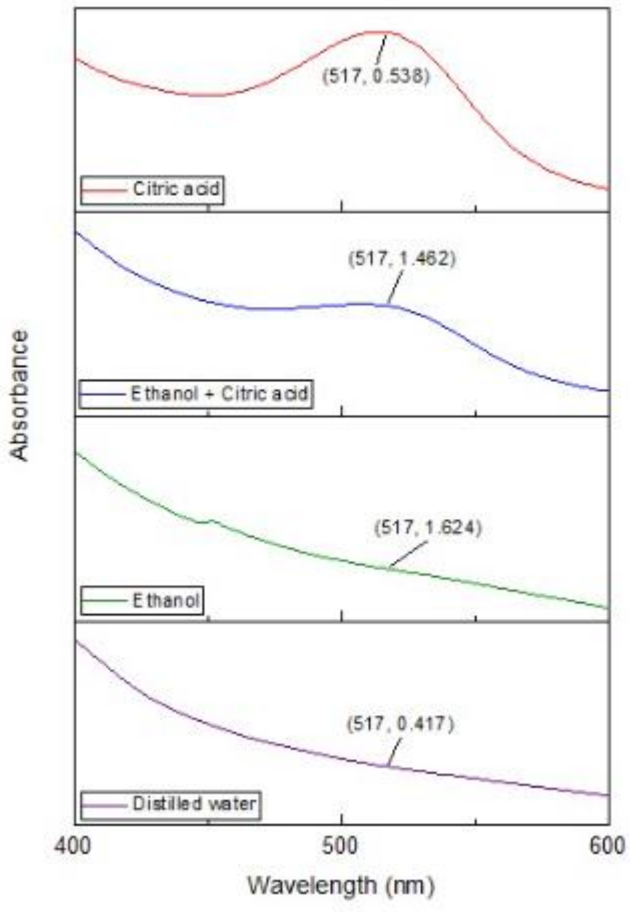


Fig. 2 *UV-Vis absorption spectra of extracted mangosteen peel powder using various solvents*

Fig. 2 shows the UV–Vis spectra of extracted mangosteen peel powder using citric acid, ethanol-citric acid mixture, ethanol and distilled water. The UV-VIS spectra revealed a characteristic absorption maximum at around 517 nm, which corresponds to anthocyanins, the major pigments in mangosteen peel. The absorbance intensity at this wavelength reflects the relative concentration of extracted anthocyanins in each solvent system:

i. Ethanol extract showed the highest absorbance (1.624 at 517 nm), indicating ethanol is the most effective solvent for extracting anthocyanins from mangosteen peel. This is consistent with ethanol's ability to solubilize both polar and moderately non-polar phytochemicals.

ii. Ethanol + Citric Acid extract produced the second highest absorbance (1.462 at 517 nm), suggesting that citric acid acts as a stabilizer of anthocyanins but does not enhance extraction efficiency beyond ethanol alone.
iii. Citric Acid extract had lower absorbance (0.538 at 517 nm), indicating limited extraction capacity, though citric acid can maintain pigment stability in aqueous solution.
iv. Distilled Water extract exhibited the lowest absorbance (0.417 at 517 nm), confirming that water alone is the least effective solvent for anthocyanin extraction due to poor solubility and stability of anthocyanins in neutral aqueous media.

As a conclusion, ethanol was the most effective solvent for extracting anthocyanins from mangosteen peel powder, followed by ethanol + citric acid, citric acid alone, and distilled water. While citric acid contributed to anthocyanin stabilization, it was less efficient than ethanol in terms of extraction yield. These findings suggest that ethanol-based solvents, possibly combined with organic acids, are optimal for recovering anthocyanins and related phenolic compounds from mangosteen peel. Based on the wavelength obtained from Fig. 2, the total anthocyanin content in the solvent used was calculated using equation (1). Fig. 3 shows the calculated total anthocyanin extracted in selected solvents used.

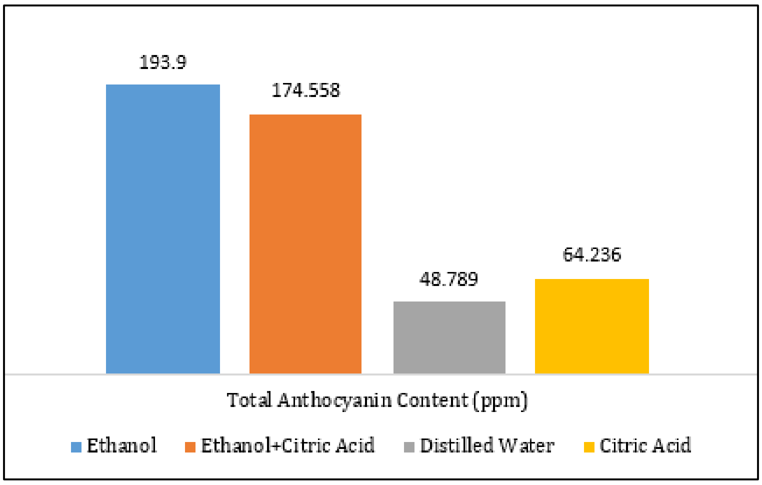


Fig. 3 *Total anthocyanin content in selected solvent*

Based on Fig. 3, ethanol extracted the highest anthocyanin content (193.900 ppm), followed by ethanol mixed with citric acid (174.558 ppm). In contrast, distilled water (48.789 ppm) and citric acid alone (64.236 ppm) were far less effective. This indicates that ethanol is the most efficient solvent for extracting anthocyanins from mangosteen peel, while water-based solvents show limited extraction capacity.

4.2 Colourfastness Test Results

4.2.1 ADMI Colour Testing Results Using DR6000 HACH

The washing test was conducted on dyed fabrics subjected to different mordanting methods. For each method, 100 mL of tap water was used, resulting in a total of 12 samples. The residual colour from all samples, expressed as colour intensity, was evaluated using American Dye Manufacturers Institute (ADMI) values using HACH DR6000 spectrophotometer. Higher ADMI values indicate poorer dye fixation, as more colour is released into the wash water. In this study, ADMI values were measured only after washing the fabrics. Table 1 presents the ADMI values for each mordanting method.

Both pre-mordanting and post-mordanting methods, particularly when combined with ethanol and citric acid, showed the lowest ADMI values of 130 and 115, respectively. These low readings suggest strong dye–fibre interactions and minimal dye leaching, indicating that the dye was effectively bonded to the fabric surface. In contrast, simultaneous mordanting with ethanol alone resulted in the highest ADMI value of 544, demonstrating that a large amount of dye was not retained on the fibres and was instead lost during washing. This finding confirms that ethanol alone in simultaneous mordanting is ineffective in enhancing dye fixation.

Overall, the results indicate that combining mordanting processes, particularly in post-mordanting with ethanol and citric acid, significantly improves dye fastness and reduces dye loss during washing. While pre-mordanting also produced favourable results, post-mordanting provides a more reliable outcome, as the dye is first absorbed by the fabric before the mordant is applied. This sequence allows the mordant to “lock in” the dye molecules and form a more stable bond with the fibre.

Table 1 *ADMI Values for Different Mordanting Methods and Agents*

Mordanting Agent	Pre-Mordanting	Simultaneous Mordanting	Post-Mordanting
Distilled Water	202	160	395
Ethanol	151	544	208
Citric Acid	299	268	275
Ethanol + Citric Acid	130	290	115

4.2.2 Colour Difference Analysis Based on RGB Values

The colour code for the three mordant methods for each fabric is shown in Tables 2, Table 3, and Table 4 in Appendix A. Colour code was used to determine the distance between colours on the fabric. For this study, this colour code was used to find the most vibrant colour obtained after dye application. For before sunlight and after sunlight, it uses the value for three colours consisting of red, green, and blue. Based on the colour code, values for these three colours can be obtained. Using Red, Green, Blue (RGB) Euclidean Distance formula, it can determine the distance between colours for each fabric before and after sunlight [15].

4.2.3 Colour Vibrancy Score After Dye Application

Equation (2) shows the formula used for calculating Vibrancy Score:

$$Vibrancy\ Score = \frac{saturation\ \% \times lightness\ \%}{10} \tag{2}$$

Based on the colour codes for 'before washing' the vibrancy score can be calculated using equation (2) and the most vibrant colour obtained after dye application can be compared.

Table 5 *Colour vibrancy score after dye application*

Solvent	Colour code	Saturation %	Lightness %	Vibrancy score	Description
Pre mordanting method					
Distilled Water	#9d8b6a	20%	52%	10.4	Muted olive-brown
Ethanol	#ab9e8b	16%	61%	9.8	Soft beige
Citric Acid	#bbb397	25%	66%	16.5	Light khaki
Citric Acid + Ethanol	#b9af97	20%	65%	13.0	Pale taupe
Simultaneous mordanting method					
Distilled Water	#a6966f	24%	54%	12.9	Dusty golden brown
Ethanol	#b19c6c	33%	57%	18.8	Golden brown
Citric Acid	#aca08e	17%	62%	10.5	Grayish beige
Citric Acid + Ethanol	#b9a276	30%	60%	18.0	Warm tan
Post mordanting method					
Distilled Water	#b59c68	35%	56%	19.6	Warm sand gold
Ethanol	#b19c6c	35%	65%	22.8	Wheat gold
Citric Acid	#c7b491	31%	68%	21.1	Light golden beige
Citric Acid + Ethanol	# ab9f86	19%	60%	11.4	Muted stone brown

Table 5 shows the colour properties of fabrics dyed with mangosteen peel extract using different mordanting methods and solvents. The colours were analyzed in terms of colour code, saturation, lightness, vibrancy score, and visual description.

For pre-mordanting, distilled water produced a muted olive-brown shade with low vibrancy (10.4). Ethanol yielded a soft beige tone (vibrancy 9.8), while citric acid improved vibrancy slightly (16.5) with a light khaki appearance. The combination of citric acid and ethanol produced a pale taupe shade (vibrancy 13.0).

In the simultaneous mordanting method, ethanol resulted in the highest vibrancy (18.8) with a golden brown shade, followed closely by the citric acid + ethanol combination (18.0), producing a warm tan. Distilled water gave a dusty golden brown tone with moderate vibrancy (12.9), while citric acid alone yielded a grayish beige with lower vibrancy (10.5).

The post-mordanting method showed the strongest colour outcomes. Ethanol produced the most vibrant shade (22.8), described as wheat gold, while citric acid also gave a high vibrancy (21.1) with a light golden beige appearance. Distilled water resulted in a warm sand gold with vibrancy 19.6. However, the citric acid + ethanol combination gave a muted stone brown with a lower vibrancy (11.4), unlike the strong effect observed in the simultaneous method.

Overall, post-mordanting, particularly with ethanol and citric acid individually, produced the most vibrant and visually appealing colours, while pre-mordanting gave more muted tones. This suggests that mordanting after dye absorption enhances dye–fibre interaction and improves colour intensity.

4.2.4 Result RGB Euclidean Distance for Sunlight Test

Equation 3 shows the formula used to find the value of Euclidean Distance (ΔE):

$$\Delta E = \sqrt{(R_2 - R_1)^2 + (G_2 - G_1)^2 + (B_2 - B_1)^2} \quad (3)$$

where:
R_1, G_1, B_1 = Red, Green, and Blue colour component values of the reference (original) colour;
R_2, G_2, B_2 = Red, Green, and Blue colour component values of the dyed fabric (after treatment/test).

The calculated ΔE represents the overall difference between the two colours in the RGB colour space. A lower ΔE value indicates a smaller difference (closer colour match), while a higher ΔE value indicates a larger difference (greater colour change).

Table 6 *RGB Euclidean Distance for Pre- mordanting method*

Solvent	RGB Euclidean Distance	Visual Colour Difference
Pre- mordanting method		
Distilled water	8.37	Slight difference
Ethanol	9.11	Slight difference
Citric Acid	11.36	Noticeable difference
Ethanol + Citric Acid	13.75	Noticeable difference
Simultaneous mordanting method		
Distilled water	28.50	Moderate to strong
Ethanol	10.44	Slight difference
Citric Acid	30.36	Strong difference
Ethanol + Citric Acid	39.22	Strong difference
Post- mordanting method		
Distilled water	32.26	Strong difference
Ethanol	35	Strong difference
Citric Acid	63.16	Very strong difference
Ethanol + Citric Acid	20.47	Moderate difference

Table 6 presents the RGB Euclidean Distance values and corresponding visual colour differences for fabrics dyed with mangosteen peel extract under different mordanting methods. Lower distance values indicate minimal colour changes, while higher values reflect stronger visual differences.

For the pre-mordanting method, distilled water (8.37) and ethanol (9.11) showed only slight colour differences, while citric acid (11.36) and the ethanol + citric acid combination (13.75) led to noticeable differences. In the simultaneous mordanting method, the ethanol treatment showed only a slight difference (10.44), whereas distilled water (28.50), citric acid (30.36), and the ethanol + citric acid combination (39.22) produced moderate to strong or strong visual differences. The post-mordanting method yielded the highest overall differences. Distilled water (32.26) and ethanol (35.00) both caused strong colour differences, while citric acid produced the largest shift (63.16), categorized as a very strong difference. The ethanol + citric acid treatment, however, resulted in only a moderate difference (20.47).

Overall, the results suggest that pre-mordanting maintains colours closer to the original shade with only slight differences, while simultaneous and post-mordanting methods lead to stronger colour variations. Post-mordanting with citric acid in particular created the most distinct visual change.

5. Conclusion

The overall findings indicate that the most effective method is post-mordanting, where the mordant is applied after dyeing, and the most suitable solvent is ethanol. Post-mordanting with ethanol achieved the highest colour vibrancy score (22.8), producing brighter and more visually appealing colours, which is highly desirable for fabric applications. Ethanol also enhanced pigment extraction and improved absorption into cotton fibres, leading to more efficient dye utilisation and reduced wastage. In terms of colour fastness, the ADMI value of 208 recorded for post-mordanting with ethanol remained within an acceptable range, reflecting moderate to good dye fixation. This performance was superior compared to the simultaneous mordanting method, which exhibited much higher dye loss during washing. Although the sunlight exposure test revealed that ethanol-treated samples under post-mordanting showed some fading, this limitation can be addressed. The use of UV-resistant finishing agents, blended mordants, or protective surface coatings after dyeing could improve light fastness without compromising colour vibrancy. Therefore, post-mordanting with ethanol is concluded to be the most effective combination, balancing strong colour vibrancy, good wash fastness, and practical adaptability for improvement in sunlight resistance.

Acknowledgement

The authors would like to thank the Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia for its support

Conflict of Interest

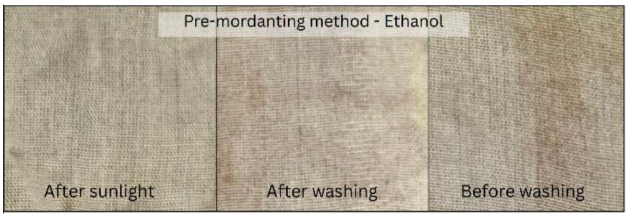
Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Aina Naylisa, Ayu Zulaikha, Aliya Nabila;* ***data collection:*** *Aina Naylisa, Ayu Zulaikha, Aliya Nabila;* ***analysis and interpretation of results:*** *Aina Naylisa, Ayu Zulaikha, Aliya Nabila, Aida Muhamad;* ***conclusion:*** *Aina Naylisa, Aliya Nabila;* ***draft manuscript preparation:*** *Aina Naylisa, Ayu Zulaikha, Aliya Nabila, Aida Muhamad. All authors reviewed the results and approved the final version of the manuscript.*

Appendix A

Table 2 *Colour code for Pre-mordanting method*

Pre-mordanting method	Colour code		
	After sunlight	After washing	Before washing
	#bbad93	#b5a890	#9d8b6a
	#aea691	#b5a996	#ab9e8b

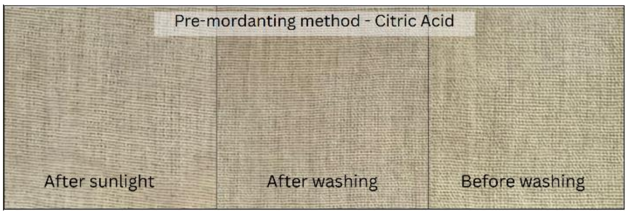
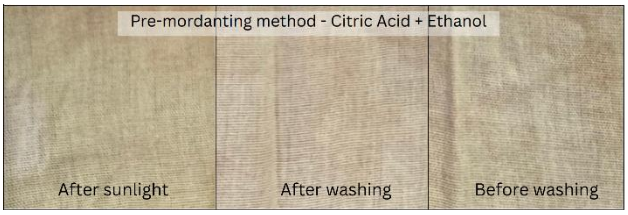
	#b3a993	#afa28b	#bbb397
	#bbb090	#c3b29b	#b9af97

Table 3 *Colour code for Simultaneous mordanting method*

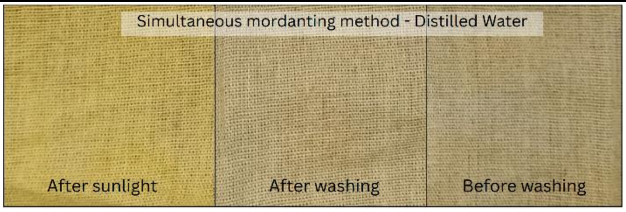
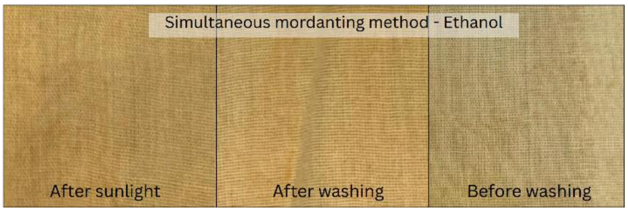
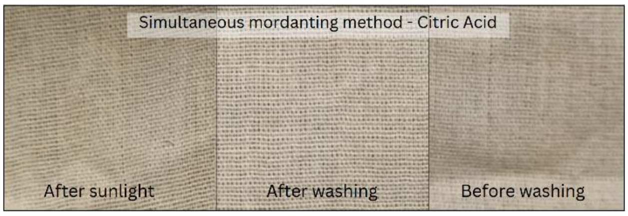
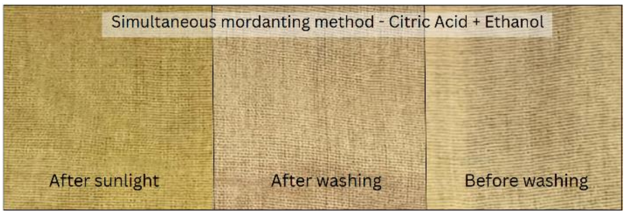
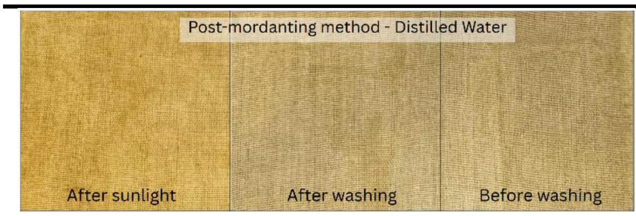
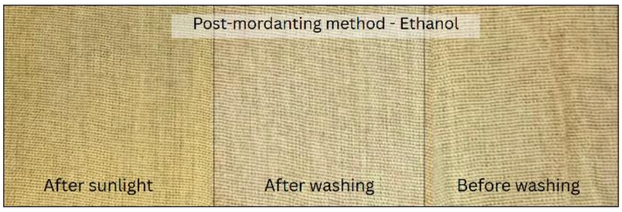
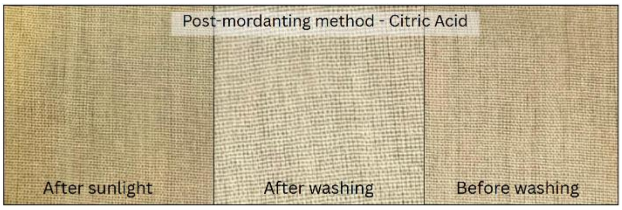
Simultaneous mordanting method	Colour code		
	After sunlight	After washing	Before washing
	#bea75b	#b4a175	#a6966f
	#ae8d52	#b69355	#b19c6c
	#ada18b	#bcb1a0	#aca08e
	#b69d57	#c3a97a	#b9a276

Table 4 *Colour code for Post-mordanting method*

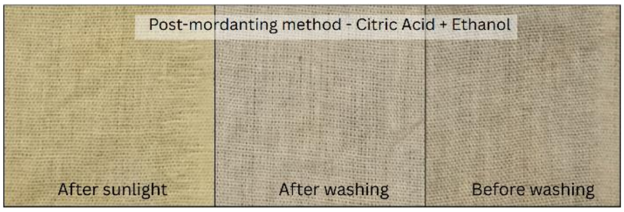
Post-mordanting method	Colour code		
	After sunlight	After washing	Before washing
	#c9a14d	#b9a069	#b59c68



#c5af75 #cfc098 #c3b081



#b4a47a #d0c5a8 #c7b491



#bcad81 #b5aa94 #ab9f86

References

[1] L. Chungkrang, S. Bhuyan, and A. R. Phukan, "*Natural dyes: extraction and applications*," Int. J. Curr. Microbiol. Appl. Sci., vol. 10, no. 1, pp. 1669–1677, Jan. 2021, doi: 10.20546/ijcmas.2021.1001.195.

[2] M. M. Rahman, J. Koh, and K. H. Hong, "*Coloration and multi-functionalization of cotton fabrics using different combinations of aqueous natural plant extracts of onion peel, turmeric root, and pomegranate rind*," Ind. Crops Prod., vol. 188, Nov. 2022, doi: 10.1016/j.indcrop.2022.115562.

[3] P. D. Sutrisna, R. P. Hadi, J. J. Valentina, H. R. Priyantini, P. W. Waluyo, and I. M. Ronyastra, "*Natural dyes extraction intended for coloring process in fashion industries*," in IOP Conf. Ser.: Mater. Sci. Eng., vol. 833, Jun. 2020, doi: 10.1088/1757-899X/833/1/012093.

[4] B. Pizzicato, S. Pacifico, D. Cayuela, G. Mijas, and M. Riba-Moliner, "*Advancements in natural dyes extraction*," 2023. [Online]. Available: https://encyclopedia.pub/entry/48484

[5] E. Werede, S. A. Jabasingh, H. D. Demsash, N. Jaya, and G. Gebrehiwot, "*Eco-friendly cotton fabric dyeing using a green, sustainable natural dye from Gunda Gundo (Citrus sinensis) orange peels*," 2023, doi: 10.1007/s13399-021-01550-6.

[6] P. Manickam and D. Vijay, "*Chemical hazards in textiles*," in Chemical Management in Textiles and Fashion, Elsevier, 2020, pp. 19–52, doi: 10.1016/B978-0-12-820494-8.00002-2.

[7] A. N. M. A. Haque and M. Naebe, "*Zero-water discharge and rapid natural dyeing of wool by plasma-assisted spray-dyeing*," J. Clean. Prod., vol. 402, May 2023, doi: 10.1016/j.jclepro.2023.136807.

[8] R. T. I. Defri, "*Chemical compounds and pharmacological activities of mangosteen*," 2022.

[9] S. A. Irwan, A. H. Jawad, R. R. R. Deris, S. A. Musa, R. Wu, and Z. A. Al Othman, "*Blended mangosteen/pomegranate peels as a precursor for porous carbon material via microwave-assisted potassium carbonate activation: Box–Behnken design optimization for fuchsin basic and methylene violet dyes removal*," Diam. Relat. Mater., vol. 151, Jan. 2025, doi: 10.1016/j.diamond.2024.111846.

[10] C. Kurinjimalar, N. Usharani, B. Kanimozhi, G. C. Jayakumar, and S. V. Kanth, "*Extraction and optimization of natural colorant from Garcinia mangostana Linn peels for leather dyeing*," Clean Eng. Technol., vol. 7, Apr. 2022, doi: 10.1016/j.clet.2022.100423.

[11] A. Authors and A. A. Mar, "*Extraction of natural dye from mangosteen peel for application on dyeing of cotton fabric*," 2016. [Online]. Available: www.elservier.com/locate/foodchemtox

[12] R. Asra, Rusdi, and R. Nofrianti, "*Physicochemical study of mangosteen (Garcinia mangostana L.) peel extract*," J. Pharm. Sci. (JPS), vol. 3, no. 1, pp. 22–32, 2020.

[13] B. Dulo, K. Phan, J. Githaiga, K. Raes, and S. De Meester, "*Natural quinone dyes: A review on structure, extraction techniques, analysis and application potential*," Waste Biomass Valor., Dec. 2021, doi: 10.1007/s12649-021-01443-9.

[14] R. Mattioli, A. Francioso, L. Mosca, and P. Silva, "*Anthocyanins: A comprehensive review of their chemical properties and health effects on cardiovascular and neurodegenerative diseases*," Molecules, vol. 25, no. 17, p. 3809, 2020.

[15] J. Finn, "*How is color measured? Calculating Delta E*," 2020. [Online]. Available: www.alpolic-americas.com