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Optimization of Microwave-Assisted Extraction Conditions for Natural Dye from *Cocos nucifera* (Malayan Red Dwarf) Peel

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Microwave-assisted alkaline extraction (MAE) was investigated as an efficient method for extracting natural colorants from the mesocarp and exocarp of *Cocos nucifera* (Malayan Red Dwarf). The effects of microwave power, solvent concentration, and extraction time were analyzed to determine the optimal conditions for maximum yield. The highest extraction yield for mesocarp was obtained at 100W microwave power, 0.2M sodium hydroxide (NaOH) or sodium carbonate (Na_2CO_3), and 2 minutes of extraction time, yielding 30% and 49.50% dyes, respectively. For the exocarp, the optimum conditions were 100W of microwave power, 0.2 M NaOH (53%) or 0.4 M Na_2CO_3 (62.50%), with an extraction time of 2 minutes. In addition to yield optimization, color strength analysis was performed to evaluate the intensity and stability of the extracted dyes. The results demonstrated that the extracted natural colorants exhibited strong pigmentation, suggesting their potential application in various industries. Statistical analysis confirmed a significant effect of extraction parameters on dye yield and color strength ($p < 0.05$). The findings highlight the advantages of MAE in improving efficiency, reducing processing time, and enhancing colorant recovery compared to conventional methods. Further studies should explore the stability and applicability of these natural dyes in commercial products particularly in textiles, cosmetics, and food industries.

Keywords: Alkaline extraction, *Cocos nucifera,* color strength analysis, dye yield, microwave-assisted extraction, natural colorants

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Natural dyes have gained significant attention in recent years due to their eco-friendly nature, biodegradability, and potential applications in various industries, particularly textile dyeing [1]. Synthetic dyes, despite their widespread use, pose environmental and health concerns due to their non-biodegradable nature and toxic by-products [2]. The search for sustainable and renewable dye sources has led to an increase in research on plant-derived dyes, with coconut (*Cocos nucifera*) peel emerging as a promising source of natural pigments [3]. *Cocos nucifera* (Malayan Red Dwarf) commonly known as the coconut tree, is widely cultivated in tropical regions, and its by-products, such as mesocarp and exocarp peels, are often discarded as agricultural waste [4]. However, these peels contain bioactive compounds, including polyphenols, flavonoids, and tannins, which exhibit strong dyeing properties and potential antioxidant activity [5]. Among the various coconut cultivars, the Malayan Red Dwarf is a well-known dwarf variety valued for its unique agronomic characteristics and chemical composition. This variety is distinguished by its relatively short stature, early fruiting capability, and distinctive reddish-brown husk, attribute to the presence of phenolic compounds and pigments. The Malayan Red Dwarf is commonly cultivated in tropical and subtropical regions due to its high adaptability and resistance to certain environmental stresses [6]. It is particularly valued for commercial and research applications due to its high oil yield and the presence of bioactive secondary metabolites. The peels of the Malayan Red Dwarf coconut, like those of other cultivars, are rich in phytochemicals that contribute to their potential applications in various industries, including pharmaceuticals, cosmetics, and natural dye production. Studies have highlighted the presence of anthocyanins, tannins, and other phenolic compounds in the exocarp and mesocarp, which contribute to its natural pigmentation and antioxidant activity. These compounds not only provide vibrant coloration but also offer protective effects against oxidative stress, making them valuable for applications in textile dyeing and natural product formulations. Microwave- assisted extraction (MAE) utilizes microwave energy to enhance the extraction process by improving solvent penetration into plant matrices, resulting in higher dye yields and reduced processing time [7]. Various factors influence the efficiency of MAE, including microwave power, solvent concentration, extraction time, and temperature Studies [8] have shown that optimizing these parameters significantly improves dye yield and quality while reducing energy

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consumption [9]. Sodium hydroxide (NaOH) and sodium carbonate (Na_2CO_3) are commonly used as solvents in alkaline extraction due to their ability to break down cell walls and release bound pigments [10]. The optimization of MAE parameters for natural dye extraction from *Cocos nucifera* peels has not been extensively studied, highlighting the need for further research in this area [11]. Therefore, this study aims to investigate the impact of key extraction parameters on dye yield and optimize the conditions for maximum extraction efficiency. By systematically evaluating the effects of microwave power, solvent concentration, and extraction time, this research aims to establish an effective and sustainable protocol for extracting natural dyes from *Cocos nucifera* peels. The findings will contribute to enhancing the utilization of agricultural by-products while promoting eco-friendly dyeing alternatives. The findings of this research will contribute to the development of eco-friendly dyeing technologies, reduce dependence on synthetic dyes, and promote the valorization of agricultural waste. Additionally, the applicability of the extracted dye in textile dyeing and its color fastness properties will be explored, providing valuable insights into its industrial potential. The study aligns with the growing global interest in sustainable practices, highlighting the importance of green chemistry in textile processing and the use of natural dyes.

EXPERIMENTAL

Sample Preparation

The coconut samples used in this study were obtained from a plantation located in the tropical regions of Malaysia. Mature *Cocos nucifera* (Malayan Red Dwarf) specimens were selected, and the plant species was identified based on morphological characteristics such as fruit size, color, and shape, following standard descriptions reported in the literature [12]. The exocarp was carefully separated from the mesocarp using a knife, and both parts were cut into small pieces of approximately 2-3 cm. The samples were subsequently ground using a grinder (Zhong Xing, Malaysia) and sieved through a 0.5-mm mesh to ensure uniform particle size. Finally, the processed samples were stored in vacuum-sealed plastic containers to preserve the sample integrity for further analysis [13].

Methods of Extraction

MAE Extraction using Alkaline Treatment

MAE was performed using an experimental microwave oven (Samsung, Korea). The extraction process was conducted using mesocarp and exocarp samples, with optimization based on microwave power, extraction time, and concentrations of NaOH and Na_2CO_3 Initially, 1g of the sample was transferred into a conical flask containing 20 mL of a NaOH and Na_2CO_3 solution at a ratio of 1g:20ml. To determine the optimal extraction method for this research, the one-factor-at-a-time (OFAT) approach was employed. The effect of microwave irradiation time on the yield of the colorant was examined at 4-minute intervals using a 0.2M NaOH and Na_2CO_3 solution under varying microwave power settings (100W, 200W, 300W, and 400W). Following microwave heating, the mixture was allowed to cool to room temperature and was subsequently filtered using 150 mm filter paper (CHM, Germany). To further investigate the impact of extraction time, an additional set of experiments was conducted using a 0.2 M NaOH and Na_2CO_3 solution, where the samples were subjected to microwave irradiation at 100W for different time intervals of 2, 4, 6, and 8 minutes. Similarly, the samples were cooled and filtered as previously described. To evaluate the effect of solvent concentration, samples were treated with a mixture of NaOH and Na_2CO_3 at varying concentrations (0.2 M, 0.4 M, 0.6 M, and 0.8 M), while maintaining a microwave power of 100W and an extraction time of 2 minutes. The extracted mixtures were allowed to cool, then filtered and stored in a dark condition at 4°C prior to further analysis. The optimization results revealed that 0.2M NaOH was the optimum concentration for both mesocarp and exocarp samples. For Na_2CO_3, the optimum concentration was 0.2M for mesocarp and 0.4M for exocarp samples. These optimized conditions were fixed for subsequent analyses. All experiments were conducted in triplicate to ensure reproducibility and reliability of the results.

Yield of Natural Colorant

The yield of the natural colorant from each sample's mesocarp and exocarp was measured using the gravimetric method. Following extraction, the filtrates were oven-dried at 80°C for 24 hours to ensure complete solvent evaporation. The dried residues were subsequently cooled to room temperature in a desiccator and weighed [13] to determine the mass of extracted colorants. The percentage yield was calculated using the following formula:

$$\%\ \text{Yield of natural colorant} = \frac{\text{natural dye extract obtained (g)}}{\text{weight of sample used (g)}} \times 100$$

Color Determination

The colorimetric properties of both the dye extracts and dyed fabrics were quantitatively analyzed using a spectrophotometric colour reader (Konica Minolta, Japan) based on the CIELAB color space, expressed as L*, a*, b*, c*, and h* values. The L* represents the lightness value, where the lowest values are darker tones, while higher values are lighter tones. The a* represents the colour ranging from red to green, with positive values indicating redness, while negative values indicate greenness. The b* presents the colour ranging from blue to yellow, with positive values represent yellow, and negative values representing blue. The c* represents the chroma, which measures the colourant's intensity, while the h* represents the hue, which defines the overall tonality or shade of the colour [11].

Statistical Analysis

All experimental data were analyzed using statistical software SPSS version 20 to determine significant differences among various extraction conditions. The results were presented as mean values with standard deviations, and statistical significance was evaluated using ANOVA at a confidence level of $P < 0.05$. This approach ensured the reliability and reproducibility of the findings by systematically comparing the effects of varying microwave power levels, solvent concentrations, and extraction times on yield and colour intensity.

RESULTS AND DISCUSSION

Effects of Alkaline Extraction on the Yield of Natural Dye

The extraction yield of natural dye from the mesocarp and exocarp of *Cocos nucifera* (Malayan Red Dwarf) was evaluated under varying microwave-assisted extraction (MAE) conditions, including microwave power, solvent concentration, and extraction time. The findings indicated that all these parameters had a statistically significant effect on dye recovery ($p < 0.05$), as determined by one-way ANOVA. As presented in Tables 1, 2, and 3, changes in these factors led to notable variations in yield. The highest yields were obtained at a microwave power of 100 W, using sodium hydroxide (NaOH) at a concentration of 0.2 M for both mesocarp and exocarp, which produced up to a 2.1-fold increase in dye yield compared with the lowest-performing condition. For sodium carbonate (Na_2CO_3), the optimum was 0.2 M for mesocarp and 0.4 M for exocarp, resulting in approximately a 1.7-fold improvement in extraction efficiency. These results clearly demonstrate the effectiveness of the optimized MAE parameters in enhancing pigment recovery. All extractions were performed with a fixed extraction time of 2-minutes. The use of alkaline solvents such as NaOH and Na_2CO_3, plays a crucial role in enhancing dye extraction, as they disrupt the plant cell wall by breaking ester linkages in pectin and hemicellulose, thereby facilitating the release of intracellular pigments. Alkine extraction conditions are known to favour the release of bound phenolic and flavonoid compounds because the high pH cleaves ester or ether bonds linking these compounds to cell-wall polymers, thereby increasing their solubility in the extraction medium (e.g., alkaline hydrolysis has been shown to yield higher bound phenolics than acid hydrolysis) [16, 17]. Simultaneously, the extraction of intact anthocyanin pigments under alkaline or neutral pH is problematic because anthocyanins are highly pH-sensitive: they are most stable under strongly acidic conditions ($pH < 3$) and undergo structural transitions, deprotonation, and degradation at higher pH, resulting in colour fading or conversion into less desired brown/oxidised products [18]. Therefore, while high-pH (alkaline) media may improve total phenolic yield, they do not necessarily preserve intact anthocyanins; for anthocyanin-rich extracts (such as from peel pigments) an acidic so Notably, increasing the microwave power above 100W resulted in a significant decline in yield, particularly at 400W, likely Increasing the microwave power above 100 W resulted in a significant decline in yield, particularly at 400 W, likely due to thermal degradation of heat-sensitive pigment compounds, as excessive heat can disrupt phenolic structures and promote pigment oxidation and polymerization [14]. Excessive microwave energy can cause pigment breakdown or charring of the sample matrix, ultimately reducing both the quality and quantity of the dye [15]. The consistently lower yields at higher power settings suggest that milder conditions are more effective in preserving the structure and stability of bioactive of the extracted pigments. Furthermore, the variation in optimum Na_2CO_3 concentration between the mesocarp and exocarp may be attributed to differences in their lignocellulosic composition and tissue density, with the exocarp being more lignified and compact, requiring stronger alkaline conditions for pigment release. These findings align with previous research on MAE, which emphasizes the importance of balancing energy input with solvent strength to maximize yield while maintaining pigment integrity [19]. Overall, this study highlights the effectiveness of controlled MAE conditions for producing natural dyes from *Cocos nucifera* (Malayan Red Dwarf), demonstrating good potential for scalability and sustainable application in textile and cosmetic industries, though further optimization is needed to ensure pigment stability during large-scale processing.

Table 1. The effect of microwave power on the yield of natural dye from mesocarp and exocarp with the use of sodium hydroxide and sodium carbonate.

Sample	Microwave power (W)	Percentage of yield (%)	
		Type of extraction reagents	
		Sodium Hydroxide	Sodium Carbonate
Mesocarp	100	44.25 ± 4.17[a]	64.60 ± 0.98[a]
	200	49.90 ± 6.36[a]	65.05 ± 2.75[a]
	300	42.10 ± 5.5[a]	63.60 ± 0.84[a]
	400	45.65 ± 2.68[a]	26.05 ± 12.65[b]
Exocarp	100	49.15 ± 5.58[a]	54.50± 7.21[a]
	200	41.10 ± 3.81[a]	62.50± 0.70[a]
	300	43.30 ± 0.14[a]	61.65± 5.44[a]
	400	45.65 ± 0.35[a]	63.65± 2.61[a]

Values are represented as means ± standard deviation for each extraction method, means that do not share the same letter in the same column were significantly different at $p<0.05$

Table 2. The effect of microwave time on the yield of natural dye from mesocarp and exocarp with the use of sodium hydroxide and sodium carbonate.

Sample	Microwave time (minutes)	Percentage of yield (%)	
		Type of extraction reagents	
		Sodium Hydroxide	Sodium Carbonate
Mesocarp	2	41.60 ± 2.96[a]	67.55± 4.03[a]
	4	38.40 ± 1.41[a]	67.70± 3.25[a]
	6	37.90 ± 0.85[a]	73.10± 4.66[a]
	8	36.40 ± 0.84[a]	61.40± 2.40[a]
Exocarp	2	40.40 ± 1.55[a]	69.90± 0.84[a]
	4	53.55 ± 22.41[b]	63.85 ± 1.1[a]
	6	35.10 ± 6.92[a]	70.10± 1.97[a]
	8	38.10 ± 1.83[a]	56.35± 2.75[a]

The mean ± standard deviation was used to list the values. Means of the same sample with different letters within the same column are significantly different at ($p < 0.05$).

Table 3. The effect of solvent concentration on the yield of natural dye from mesocarp and exocarp with the use of sodium hydroxide and sodium carbonate.

Sample	Solvent Concentration (M)	Percentage of yield (%)	
		Type of extraction reagents	
		Sodium Hydroxide	Sodium Carbonate
Mesocarp	0.2	30.00 ± 1.4[a]	49.50± 0.71[a]
	0.4	42.50± 2.1[a]	52.50± 6.3[a]
	0.6	63.00± 5.6[b]	46.50±6.3[a]
	0.8	40.00± 2.8[a]	52.00±4.2[a]
Exocarp	0.2	53.00± 4.2[a]	41.00± 2.8[b]
	0.4	62.50± 3.5[a]	70.50 ± 2.1[a]
	0.6	68.00± 5.6[a]	66.00± 2.8[a]
	0.8	54.50± 4.9[a]	47.5± 7.7[ab]

Values are represented as means ± standard deviation for each extraction method, means that do not share the same letter in the same column were significantly different at $p<0.05$

Color Strength

The color strength of natural dyes extracted from the mesocarp and exocarp of *Cocos nucifera* was evaluated under optimized microwave-assisted extraction (MAE) conditions under the optimum parameters 100W microwave power, and a 2 minute extraction time using 0.2 M NaOH (Tables 4, 5,6) Under the optimum parameters (100 W microwave power, 2 minutes extraction time, and 0.2 M NaOH; Tables 4–6), the mesocarp and exocarp pigments exhibited consistent chromatic properties, with L* values ranging from 33.6 to 34.4, a* values from 6.1 to 8.0, and b* values from 3.7 to 5.7, indicating stable color intensity and comparable red-yellow tonal characteristics between both extracts. Similarly, Na_2CO_3 treated mesocarp extracts showed optimum color strength under identical conditions, while exocarp extracts required a slightly higher solvent concentration of 0.4M Na_2CO_3 to achieve maximum intensity (Table 6). The differences in color strength between mesocarp and exocarp extracts can be attributed to variations in pigment composition and solubility in different solvents. The L*, a*, and b* values indicated that exocarp extracts generally had a darker hue with higher chroma values, signifying greater pigment concentration. These findings agree with previous studies on MAE, which suggest that controlled microwave power and solvent concentration enhance pigment release while minimizing degradation [11]. Furthermore, the optimized extraction parameters are likely to contribute to improved colour stability of the natural dyes, suggesting their potential suitability for applications in the textile and food industries; however, further stability studies are required to confirm their long-term performance. These findings highlight the effectiveness of MAE as an efficient technique for extracting high-intensity natural colorants from *Cocos nucifera*.

Table 4. Color coordinate of *cocos nucifera* for microwave power variable extracts using microwave-assisted extraction (MAE) technique.

Sample	Types of solvent	Microwave power (W)	Colour Coordinates				
			L*	a*	b*	c*	h*
Mesocarp	NaOH	100	33.80±0.7[a]	8.30±2.8[bc]	4.70±2.2[a]	11.1±4.7[a]	157.9±4.2[a]
		200	34.56±1.6[a]	4.50±2.8c	2.70±3.3[a]	19.6±7.5[a]	140.9±40.4[a]
		300	37.46±2.4[a]	23.1±7.1[a]	6.4±4.3[a]	24.8±7.5[a]	157.5±8.2[a]
		400	36.96±2.1[a]	19.3±5.2[ab]	8.1±2.1[a]	21.9±7.0[a]	178.3±28.7[a]
Exocarp	NaOH	100	39.2±1.1[c]	32.9±4.2[b]	4.0±2.6[b]	29.6±5.9[ab]	167.2±4.9[a]
		200	35.5±0.6[d]	15.8±2.5[c]	5.0± 1.6[ab]	15.8±2.1[b]	124.4±59.1[a]
		300	42.6±0.7[b]	39.6±0.6[b]	3.0± 3.5[b]	32.3±14.8[ab]	188.4±32.5[a]
		400	44.7±0.5[a]	48.8±3.7[a]	11.8± 2.3[a]	49.7±3.0[a]	168.2±1.7[b]
Mesocarp	Na_2CO_3	100	34.1±1.2[a]	7.8±3.4[a]	4.5±1.9[a]	17.5±2.8[a]	156.7±2.5[a]
		200	37.1±0.5[a]	21.2±2.5[a]	7.5±0.2[a]	23.6±4.3[a]	157.5±2.8[a]
		300	36.5±2.4[a]	18.5±9.1[a]	6.8±3.5[a]	23.3±16.8[a]	160.8±5.4[a]
		400	35.0±0.5[a]	10.1±3.1[a]	5.7±1.2[a]	10.4±3.4[a]	168.7±14.3[a]
Exocarp	Na_2CO_3	100	34.5±3.5[a]	14.3±11.7[a]	3.8±4.5[a]	26.9±9.1[a]	165.1±8.2[a]
		200	39.0±3.3[a]	27.7±9.5[a]	10.3± 4.3[a]	31.1±8.6[a]	159.8±2.1[a]
		300	35.7±1.7[a]	14.9±6.6[a]	6.4± 3.1[a]	28.1±8.4[a]	158.0±8.4[a]
		400	37.0±3.7[a]	18.4±8.3[a]	6.8± 6.1[a]	16.8±8.5[a]	152.7±9.3[a]

The mean ± standard deviation was used to list the values. Means of the same sample with different letters within the same column are significantly different at $p < 0.05$.

Table 5. Color coordinate of *cocos nucifera* for 100W microwave power and minute variable extracts using microwave-assisted extraction (MAE) technique.

Sample	Types of solvent	Microwave time (minutes)	Colour Coordinates				
			L*	a*	b*	c*	h*

Mesocarp	NaOH	2	34.3±1.1^{a}	10.6±3.2^{a}	2.6±2.1^{a}	11.3±3.8^{a}	164.4±14.1^{a}
		4	36.0±2.8^{a}	10.8±6.7^{c}	3.3±0.9^{a}	22.8±10.7^{b}	171.0±13.6^{a}
		6	33.8±0.7^{a}	9.80±3.4^{a}	4.4±1.4^{a}	14.1±8.8^{a}	165.9±8.7^{a}
		8	35.3±3.3^{a}	10.6±12.6^{a}	5.4±5.8^{a}	12.6±7.9^{a}	153.6±6.7^{a}
Exocarp	NaOH	2	34.4±0.5^{a}	4.8±5.3^{a}	2.8±1.3^{a}	4.3±0.3^{a}	146.6±3.1^{a}
		4	33.1±0.2^{a}	5.8±3.4^{a}	2.7± 0.9^{a}	9.0±7.7^{a}	150.3±11.1^{a}
		6	33.8±1.3^{a}	7.1±6.0^{a}	2.3± 0.2^{a}	8.4±6.2^{a}	149.5±6.5^{a}
		8	33.9±0.7^{a}	7.1±2.9^{a}	8.3± 1.1^{b}	6.1±3.9^{a}	147.6±4.6^{a}
Mesocarp	Na_2CO_3	2	36.8±2.1^{a}	21.2±5.4^{b}	8.4±2.2^{a}	23.2±8.2^{a}	162.9±6.6^{a}
		4	37.0±2.0^{a}	15.0±4.7^{a}	7.3±3.6^{a}	18.9±10.7^{a}	157.8±1.3^{a}
		6	36.4±2.8^{a}	15.2±11.1^{a}	7.4±4.8^{a}	19.6±5.3^{a}	158.3±5.8^{a}
		8	35.4±1.9^{a}	12.9±8.0^{a}	4.3±1.5^{a}	9.20±9.8^{b}	147.7±8.3^{a}
Exocarp	Na_2CO_3	2	36.9±3.2^{a}	18.4±12.9^{a}	6.3±3.0^{a}	17.1±12.9^{a}	152.7±2.9^{a}
		4	33.0±0.3^{a}	3.5±0.7^{b}	2.7± 0.5^{a}	14.2±6.1^{a}	156.5±5.8^{a}
		6	35.5±2.8^{a}	11.5±8.0^{a}	6.4± 5.5^{a}	9.4±1.9^{a}	171.0±13.3^{a}
		8	36.4±0.9^{a}	17.6±3.0^{a}	5.4± 2.8^{a}	10.4±4.1^{a}	158.9±5.7^{a}

The mean ± standard deviation was used to list the values. Means of the same sample with different letters within the same column are significantly different at p <0.05.

Table 6. Color coordinate of *cocos nucifera* for solvent conc. variable extracts using the microwave-assisted extraction (MAE) technique.

Sample	Types of solvent	Solvent Concentration (M)	Colour Coordinates				
			L*	a*	b*	c*	h*
Mesocarp	NaOH	0.2	33.66±0.9^{a}	6.10±5.0^{a}	3.76±1.5^{a}	9.46±3.0^{a}	153.2±5.5^{a}
		0.4	34.23±1.1^{a}	5.66±3.3^{a}	4.06±1.8^{a}	7.93±4.7^{a}	147.4±12.3^{a}
		0.6	33.13±0.6^{a}	3.53±0.2^{a}	3.16±0.1^{a}	5.53±1.8^{a}	142.4±9.2^{a}
		0.8	33.53±0.7^{a}	3.36±0.5^{a}	3.60±0.8^{a}	4.90±1.4^{a}	136.3±7.3^{a}
Exocarp	NaOH	0.2	34.30±3.6^{a}	8.03±7.8^{a}	5.73±5.1^{a}	4.13±0.3^{a}	140.2±2.5^{a}
		0.4	32.96±1.1^{a}	3.70±1.4^{a}	2.83± 0.5^{a}	4.46±0.6^{a}	140.7±5.7^{a}
		0.6	33.60±0.8^{a}	4.83±2.3^{a}	3.53± 1.0^{a}	4.93±2.3^{a}	143.4±8.2^{a}
		0.8	33.70±0.7^{a}	6.20±1.1^{a}	4.33± 1.1^{a}	4.03±0.1^{a}	131.9±5.2^{a}
Mesocarp	Na_2CO_3	0.2	33.90±1.1^{a}	6.06±4.7^{a}	3.13±0.8^{a}	4.73±0.1^{a}	140.0±1.5^{ab}
		0.4	34.46±0.7^{a}	1.0±0.5^{a}	4.23±0.9^{a}	5.06±0.1^{a}	116.4±21.8^{b}
		0.6	33.46±0.1^{a}	2.13±1.0^{a}	3.26±0.4^{a}	4.86±1.4^{a}	139.6±15.4^{ab}
		0.8	34.33±1.2^{a}	2.93±2.1^{a}	2.93±1.0^{a}	5.80±0.9^{a}	159.0±5.8^{a}
Exocarp	Na_2CO_3	0.2	34.00±0.5^{a}	4.56±2.3^{a}	2.26±1.6^{a}	4.10±0.2^{a}	127.5±8.7^{b}
		0.4	33.13±0.5^{a}	4.50±4.1^{a}	2.16± 1.0^{a}	4.26±1.9^{a}	161.9±18.9^{a}
		0.6	33.03±0.6^{a}	4.86±0.2^{a}	2.53± 0.1^{a}	4.06±0.7^{a}	131.1±11.4^{ab}
		0.8	33.90±1.3^{a}	5.13±3.5^{a}	2.16± 0.7^{a}	3.16±1.1^{a}	137.4±2.1^{ab}

The mean ± standard deviation was used to list the values. Means of the same sample with different letters within the same column are significantly different at p <0.05.

CONCLUSION

This study demonstrated the effectiveness of MAE in enhancing the yield of natural colorants from the mesocarp and exocarp of *Cocos nucifera* (Malayan Red Dwarf). The results indicated that the optimum extraction conditions for mesocarp were achieved using 100W of microwave power, with 0.2 M NaOH or Na_2CO_3, and a 2-minute extraction time, yielding 30% and 49.50 % natural pigments, respectively.

For exocarp, the highest yield was obtained with microwave power of 100W 0.2M NaOH (53% or 0.4M Na_2CO_3 (62.50%) with an extraction time of 2-minutes. These findings suggest that alkaline extraction combined with microwave irradiation not only enhances extraction efficiency and yield but also helps preserve pigment quality, reflecting the overall effectiveness of the optimized MAE process. Future studies should explore the stability and potential application of these extracted dyes in various industries, particularly in textiles, cosmetics, and food production.

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