

# Extraction process optimization for maximizing total polyphenol content in cashew nut testa (*Anacardium occidentale* L.) extract

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## ARTICLE INFO

## ABSTRACT

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Cashew nut testa (*Anacardium occidentale* L.) is a valuable source of polyphenols known for their strong bioactivities. This study optimized the extraction conditions to obtain polyphenol-rich extracts from cashew nut testa. The effects of three key factors, extraction time, material-to-solvent ratio, and temperature, on Total Polyphenol Content (TPC, mg GAE/g extract) were investigated. Response surface methodology, using a Box-Behnken design, was applied to design the experiments and optimize the extraction process. The results showed that the relationship between TPC and extraction conditions followed a second-order model with an  $R^2$  value of 0.9999. All three factors significantly influenced TPC ( $p < 0.05$ ), and their interactions were also significant. The model predicted optimal conditions for maximum TPC at an extraction time of 19.85h, a temperature of 58.80°C, and a material-to-solvent ratio of 1:16.39 (w/v). Validation experiments under the optimized conditions of 20h, 59°C, and a 1:16 ratio confirmed the model's accuracy, yielding a TPC of 534.67mg GAE/g extract, statistically equivalent to the predicted value. These findings demonstrate the efficacy of the optimized conditions in maximizing polyphenol extraction from cashew nut testa.

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## 1. Introduction

Cashew nut testa, the outer skin of cashew kernels (*Anacardium occidentale* L.), is an abundant byproduct of the cashew processing industry (Zafeer & Bhat, 2023). Despite its large-scale production, cashew nut testa remains underutilized, primarily discarded as waste or used for low-value purposes such as fuel or fertilizer. However, this material is a rich source of bioactive compounds, including polyphenols, flavonoids, terpenes, terpenoids, and tannins (Da Silva et al., 2023; Sharma et al., 2020; Sruthi & Naidu, 2023). These compounds are associated with various biological activities, such as antioxidant, anti-inflammatory, analgesic, anti-allergic, antimicrobial, anti-ulcer, and wound-healing effects (Sruthi & Naidu, 2023). Among these, polyphenol compounds are of significant interest due to their health-promoting properties and potential applications in the pharmaceutical, cosmetic, functional food, and chemical industries (Adebooye et al., 2018; Rathod et al., 2023).

Cashew nut testa accounts for approximately 1 - 3% of the total weight of cashew nuts, and the global scale of cashew nut production results in substantial amounts of this byproduct

(Oliveira et al., 2015). For every 80kg of raw cashew nuts processed, approximately 1kg of cashew nut testa is produced (Mohod et al., 2011). In Vietnam alone, the cashew industry generates over 1,000 tons of cashew nut testa annually, most of which is either discarded or burned, contributing to environmental pollution and the waste of valuable resources. The inefficient utilization of this byproduct underscores the need for further research into its bioactive potential and economic value, mainly through the extraction of polyphenol-rich compounds that could be applied across various industries.

Extraction is one of the most critical steps in studying plant-derived bioactive compounds (Patra et al., 2018; Sasidharan et al., 2011). The efficiency of the extraction process significantly influences both the yield and quality of the bioactive compounds obtained. Several factors affect the extraction process, including the physical characteristics of the plant material, the choice of solvent (solvent type, ratio, pH, viscosity, and polarity), temperature, pressure, particle size, and extraction time (Chuo et al., 2022; Oreopoulou et al., 2019). Among these, solvent selection, extraction time, and temperature are critical when targeting polyphenol compounds, as they directly impact the yield and purity of the extract (Alara et al., 2021; Sridhar et al., 2021). Therefore, optimizing extraction conditions is crucial for maximizing the recovery of total polyphenols from cashew nut testa.

There has been growing interest in applying response surface methodology to optimize extraction conditions in recent years. Response surface methodology is a statistical and mathematical tool used to model and analyze the effects of multiple variables on a response variable, allowing researchers to identify optimal conditions (Tirado-Kulieva et al., 2021; Weremfo et al., 2023). Box-Behnken design, one of the most commonly used experimental designs in response surface methodology, facilitates the investigation of the interaction between variables and helps determine the optimal extraction parameters for achieving the highest yield of bioactive compounds (Abd-El-Aziz et al., 2022; Martin-Garcia et al., 2020). For cashew nut testa, optimizing extraction conditions such as solvent-to-material ratio, extraction time, and temperature could significantly enhance the recovery of polyphenols, thereby increasing the economic value of this byproduct and reducing waste within the cashew industry.

This study aims to optimize the extraction conditions for obtaining a polyphenol-rich extract from cashew nut testa, focusing on key factors such as extraction temperature, extraction time, and solvent-to-material ratio. By employing response surface methodology with Box-Behnken design, this research seeks to identify the optimal conditions for maximizing Total Polyphenol Content (TPC) in the extract. The findings will provide valuable insights into using cashew nut testa for high-value applications in cosmetics, functional foods, and pharmaceuticals, contributing to the sustainable development of the cashew industry and the reduction of environmental pollution associated with this byproduct.

## **2. Materials and methods**

### **2.1. Sample collection and preparation**

Cashew nut testa samples were collected from a Binh Phuoc Province, Vietnam processing facility. The samples were thoroughly washed upon collection to eliminate dirt, dust, and foreign materials. The cleaned cashew nut testa was dried at 60°C to reduce moisture content and inhibit microbial growth during storage. After drying, the testa was ground into a fine powder with particle sizes less than 1mm using a laboratory mill. The powdered cashew nut testa was stored in airtight containers at 4°C to maintain stability and preserve the bioactive compounds for subsequent experiments. To ensure sample integrity, the storage duration was limited to three months.

## 2.2. Preliminary study of extraction conditions

After processing, the cashew nut testa samples were extracted using 99.5% ethanol (Meck, Germany) under varying time, temperature, and material-to-solvent ratios (w/v), as specified by the experimental design. The extraction parameters - temperature, time, and material-to-solvent ratios - were initially investigated using a one-factor-at-a-time experimental approach to identify the optimal range for each. Each factor was assessed independently, while the other variables were held constant at predetermined levels. Specifically, extraction temperatures ranging from 40°C to 100°C, extraction times from 08 to 32h, and material-to-solvent ratios from 1:10 to 1:25 (w/v) were evaluated. Each experiment was conducted with 30g of cashew nut testa. The extraction process was repeated three times to ensure exhaustive recovery of bioactive compounds.

Following extraction, the ethanol extract was filtered through filter paper to remove solid residues, and the filtrate was concentrated under reduced pressure at 50°C using a rotary evaporator (Buchi, Switzerland). Subsequently, the concentrated extract was freeze-dried to obtain a powdered form, following the guidelines of the Vietnamese Pharmacopoeia V (Ministry of Health, 2017). The extraction efficiency was assessed by determining the TPC, expressed as mg of Gallic Acid Equivalents (GAE) per gram of extract (mg GAE/g extract). This preliminary study aimed to establish the optimal conditions for maximizing the efficiency of bioactive compound extraction from cashew nut testa.

## 2.3. Optimization of the extraction procedure

Response surface methodology was employed to predict the optimal conditions for extracting polyphenol-rich cashew nut testa extract. The experimental design and statistical analysis were performed using Design-Expert software (version 11.0.4.0, Stat-Ease Inc., Minneapolis, MN, USA). The experimental setup followed a Box-Behnken design with three independent variables: extraction time (A), material-to-solvent ratio (B), and extraction temperature (C). The dependent variable was the TPC (Y) of the extract. The factor levels for the optimization process were selected, as shown in Table 1. A quadratic regression model was used to describe the relationship between the independent variables and the dependent variable, represented by the following equation (1):

$$Y = b_0 + b_1A + b_2B + b_3C + b_{12}AB + b_{13}AC + b_{23}BC + b_{11}A^2 + b_{22}B^2 + b_{33}C^2 \quad (1)$$

Where Y is the dependent variable; A, B, and C are the levels of the independent variables;  $b_0$  is the regression coefficient at the center point;  $b_1$ ,  $b_2$ , and  $b_3$  are the linear coefficients;  $b_{12}$ ,  $b_{13}$ , and  $b_{23}$  are the second-order interaction coefficients; and  $b_{11}$ ,  $b_{22}$ , and  $b_{33}$  are the quadratic coefficients. Analysis of Variance (ANOVA) was conducted to assess the significance of the model and the fit of the experimental data to the quadratic regression equation. This statistical approach optimized the extraction conditions by evaluating the effects of each variable and their interactions on TPC.

**Table 1**

*Experimental Factors with their Levels Used in the Experiment*

Factor	Symbol	Level		
		-1	0	+1
Time (h)	A	8	16	24
Material-to-solvent ratio (w/v)	B	1:10	1:15	1:20
Temperature (°C)	C	40	60	80

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## 2.4. Determination of Total Polyphenol Content (TPC)

The TPC of the extracts was determined using a modified Folin-Ciocalteu method (Vuong et al., 2013). The extract was first dissolved in methanol to a concentration of 1 mg/mL. A 0.1mL aliquot of the extract was mixed with 0.5mL of 10% Folin-Ciocalteu reagent and allowed to react for 10min. Then, 0.4mL of 7.5% sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) solution was added, and the mixture was incubated in the dark at 30°C for 1h. The absorbance of the reaction mixture was measured at 765nm using an ELISA reader (VersaMAX, USA). Each sample was analyzed in triplicate to ensure the reliability of the results. A standard curve was constructed using gallic acid at concentrations of 500, 250, 125, 62.5, 31.25, and 15.625  $\mu\text{g}/\text{mL}$  to quantify the TPC. The TPC of the samples was calculated from the standard curve and expressed as mg GAE/g extract.

## 2.5. Statistical analysis

All experiments were performed in triplicate, and the data were statistically analyzed using Minitab 16.2.2.4 software and Microsoft Excel 2013. The results were reported as mean values  $\pm$  standard deviations. Differences between experimental treatments were evaluated using appropriate statistical methods to ensure the accuracy and validity of the findings.

## 3. Results and discussion

### 3.1. Preliminary study of extraction conditions

The single-factor experiments formed the basis for evaluating the efficiency of TPC extraction under varying conditions. These experiments provided crucial insights into selecting the most impactful factors for further optimization using multi-factor analysis. The results of TPC under different extraction conditions are summarized in Table 2.

Temperature is a critical factor affecting the yield and activity of natural compounds during extraction. Higher temperatures can soften plant tissues, accelerate solvent penetration, and increase diffusion rates, thereby enhancing extraction efficiency (Antony & Farid, 2022; Madrau et al., 2009). However, excessive heat may denature sensitive bioactive compounds, reducing their activity (Antony & Farid, 2022; Madrau et al., 2009). As shown in Table 2, the TPC increased from 471.80mg GAE/g at 40°C to 516.70mg GAE/g at 60°C but decreased to 406.27mg GAE/g at 80°C and dramatically dropped to 105.07mg GAE/g at 100°C. These findings align with previous studies, such as those by Le et al. (2019), who observed a similar trend in TPC extraction from *Glycine max*, and Huynh et al. (2022), who found that the optimal extraction temperature for TPC from *Rhodomyrtus tomentosa* leaves was 60°C. The significant decline at higher temperatures suggests the degradation of polyphenolic compounds, indicating that moderate temperatures are crucial for maintaining polyphenol integrity.

**Table 2**

*Total Polyphenol Content (TPC) in Cashew Nut Testa Extracts under different Extraction Conditions*

Factors		Total polyphenol content (mg GAE/g extract)
Temperature (°C)	40	471.80 <sup>b</sup> $\pm$ 0.90
	60	516.70 <sup>a</sup> $\pm$ 0.72
	80	406.27 <sup>c</sup> $\pm$ 0.61
	100	105.07 <sup>d</sup> $\pm$ 1.46

Factors		Total polyphenol content (mg GAE/g extract)
Time (h)	08	503.10 <sup>d</sup> ± 0.40
	16	508.97 <sup>c</sup> ± 0.38
	24	517.83 <sup>a</sup> ± 0.31
	32	513.87 <sup>b</sup> ± 1.12
Material-to-solvent ratio (w/v)	1:10	516.30 <sup>c</sup> ± 0.66
	1:15	529.03 <sup>b</sup> ± 0.70
	1:20	533.37 <sup>a</sup> ± 0.55
	1:25	534.27 <sup>a</sup> ± 0.55

*Note.* In the same column of a group, values followed by different letters are significantly different ( $p < 0.05$ )

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Prolonged extraction times can sometimes lead to the degradation of natural compounds, reducing their bioactivity (Mokrani & Madani, 2016). This study investigated extraction times ranging from 08 to 32h (Table 2). The TPC increased from 503.10mg GAE/g at 8h to 517.83mg GAE/g at 24h, with a slight decline to 513.87mg GAE/g observed at 32h. These results are consistent with Huynh et al. (2022), who found that TPC extraction from *Rhodomyrtus tomentosa* peaked at 24h and gradually decreased with longer durations. This suggests that 24h is the optimal extraction time for maximizing TPC while preventing degradation from prolonged extraction times.

The material-to-solvent ratio is another key factor affecting extraction efficiency. An appropriate ratio not only enhances solvent utilization but also reduces the cost of extraction (Nguyen et al., 2020). This study examined material-to-solvent ratios ranging from 1:10 to 1:25 (w/v) (Table 2). The TPC increased significantly from 516.30mg GAE/g at a 1:10 ratio to 533.37mg GAE/g at a 1:20 ratio. However, no significant difference was observed between the 1:20 and 1:25 ratios. Previous studies, such as those by Espinosa-Muñoz et al. (2017) and Bouafia et al. (2021), have demonstrated that once the material-to-solvent ratio reaches a saturation point, further increases results in little to no improvement in extraction efficiency. Similarly, Bindes et al. (2019) found that the optimal material-to-solvent ratio for polyphenol extraction from green tea leaves was 1:20. Therefore, in this study, the ratio of 1:20 was identified as optimal for efficient solvent utilization and TPC.

The results indicate that extraction temperature, time, and material-to-solvent ratio statistically affect TPC ( $p < 0.05$ ). Based on these findings, the temperature ranges of 40°C to 80°C, extraction time of 08 to 24h, and a material-to-solvent ratio of 1:10 to 1:20 were selected for further multi-factor optimization to determine the optimal conditions for TPC extraction from cashew nut testa.

### 3.2. Optimization of the extraction procedure

The experimental trials were designed using Design Expert software based on a Box-Behnken design, as outlined in Table 3. This section aims to identify the optimal combination of variables for maximizing TPC extraction from cashew nut testa. A three-factor (A, B, and C), three-level (-1, 0, +1) Box-Behnken design was employed to determine the optimal levels of

extraction time (A, h), sample-to-solvent ratio (B, w/v), and extraction temperature (C, °C). The design included 17 runs with 05 center points. The TPC content obtained from the cashew nut testa ranged from 404.90mg GAE/g extract to 531.90mg GAE/g extract, resulting in a 127mg GAE/g extract variation between the highest and lowest values. The five central trials consistently yielded high TPC values, with no significant difference compared to trial 09, which utilized an extraction time of 16h, a temperature of 60°C, and a sample-to-solvent ratio of 1:15 (w/v).

Based on the experimental results, a second-order polynomial equation (2) was developed to predict TPC under different conditions:  $Y = 528.40 + 8.66 \times A + 5.46 \times B - 30.65 \times C + 2.9 \times A \times B - 12.43 \times A \times C - 0.675 \times B \times C - 7.3 \times A^2 - 6 \times B^2 - 81.58 \times C^2$ . (2)

**Table 3**

*Experimental Design and Responses Showing Total Polyphenol Content (TPC) in Cashew Nut Testa Extracts*

No.	Factors			Total polyphenol content (mg GAE/g extract)	
	A (h)	B (w/v)	C (°C)	Experimental	Predicted
1	16	1:10	40	464.90 <sup>h</sup> ± 1.28	465.3
2	24	1:10	60	515.50 <sup>c</sup> ± 0.61	515.4
3	16	1:15	60	527.90 <sup>b</sup> ± 1.65	528.4
4	8	1:15	80	412.30 <sup>j</sup> ± 0.56	412.6
5	16	1:15	60	529.10 <sup>ab</sup> ± 0.46	528.4
6	16	1:15	60	528.40 <sup>b</sup> ± 0.69	528.4
7	8	1:15	40	449.30 <sup>i</sup> ± 0.60	449.1
8	16	1:10	80	405.50 <sup>k</sup> ± 0.87	405.4
9	24	1:20	60	531.90 <sup>a</sup> ± 1.61	532.1
10	16	1:15	60	528.70 <sup>ab</sup> ± 1.51	528.4
11	16	1:15	60	527.90 <sup>b</sup> ± 1.28	528.4
12	16	1:20	40	477.50 <sup>g</sup> ± 0.66	477.6
13	24	1:15	40	491.60 <sup>f</sup> ± 1.14	491.3
14	8	1:10	60	504.10 <sup>e</sup> ± 0.44	503.9
15	24	1:15	80	404.90 <sup>k</sup> ± 1.74	405.1
16	16	1:20	80	415.40 <sup>j</sup> ± 0.62	415.0
17	8	1:20	60	508.90 <sup>d</sup> ± 1.74	509.0

*Note.* A: Time (h), B: Material-to-solvent ratio (w/v), C: Temperature (°C). In the same column, values followed by different letters are significantly different ( $p < 0.05$ )

*Source.* Created by the authors

The predicted and experimental TPC were nearly identical, as shown in Table 3. The results of the variance analysis for the response surface quadratic model are summarized in Table 4. A high F-value with a very low  $p$ -value ( $p < 0.0001$ ) demonstrated that the generated model was

statistically significant and suggests that the optimization for TPC of cashew nut testa could be well described with this model. The total determination coefficient ( $R^2 = 0.9999$ ) indicated that the model could explain 99.99% of the variation in the TPC. In comparison, the low value of the coefficient of the variation ( $CV = 0.1085\%$ ) indicated a high degree of precision in the reliability of the experimental values. Furthermore, the lack-of-fit value (0.463406), more significant than 0.05, confirms that the model fits well with the experimental data. Studies by Karabegović et al. (2013) and Ngamkhae et al. (2021) suggest that extraction models with an  $R^2$  value greater than 0.9, a CV below 10%, and a lack-of-fit greater than 0.05 are highly applicable in practice.

**Table 4**

*Analysis of the Variance (ANOVA) for the Response Surface Quadratic Model*

Source	Sum of squares	Degrees of freedom	Mean square	F-value	p-value
<b>Model</b>	38,100.41	9	4,233.379	15,374.14	< 0.0001
<b>A-Time</b>	600.3113	1	600.3113	2,180.119	< 0.0001
<b>B-Ratio</b>	238.7113	1	238.7113	866.915	< 0.0001
<b>C-Temperature</b>	7,515.38	1	7,515.38	27,293.21	< 0.0001
<b>AB</b>	33.64	1	33.64	122.1686	< 0.0001
<b>AC</b>	617.5225	1	617.5225	2,242.624	< 0.0001
<b>BC</b>	1.8225	1	1.8225	6.618677	0.0369
<b>A<sup>2</sup></b>	224.3789	1	224.3789	814.8652	< 0.0001
<b>B<sup>2</sup></b>	151.5789	1	151.5789	550.4813	< 0.0001
<b>C<sup>2</sup></b>	28,018.87	1	28,018.87	1.018E+05	< 0.0001
<b>Residual</b>	1.9275	7	0.275357		
<b>Lack of Fit</b>	0.8475	3	0.2825	1.046296	0.463406
<b>Pure Error</b>	1.08	4	0.27		
<b>Cor Total</b>	38,102.34	16			
<b>Std. Dev.</b>	0.5247				
<b>Mean</b>	483.75				
<b>CV %</b>	0.1085				
<b>R<sup>2</sup></b>	0.9999				
<b>Adjusted R<sup>2</sup></b>	0.9999				
<b>Predicted R<sup>2</sup></b>	0.9996				
<b>Adeq Precision</b>	315.5896				

*Note.* A: Time (h), B: Material-to-solvent ratio (w/v), C: Temperature (°C)

*Source.* Created by the authors

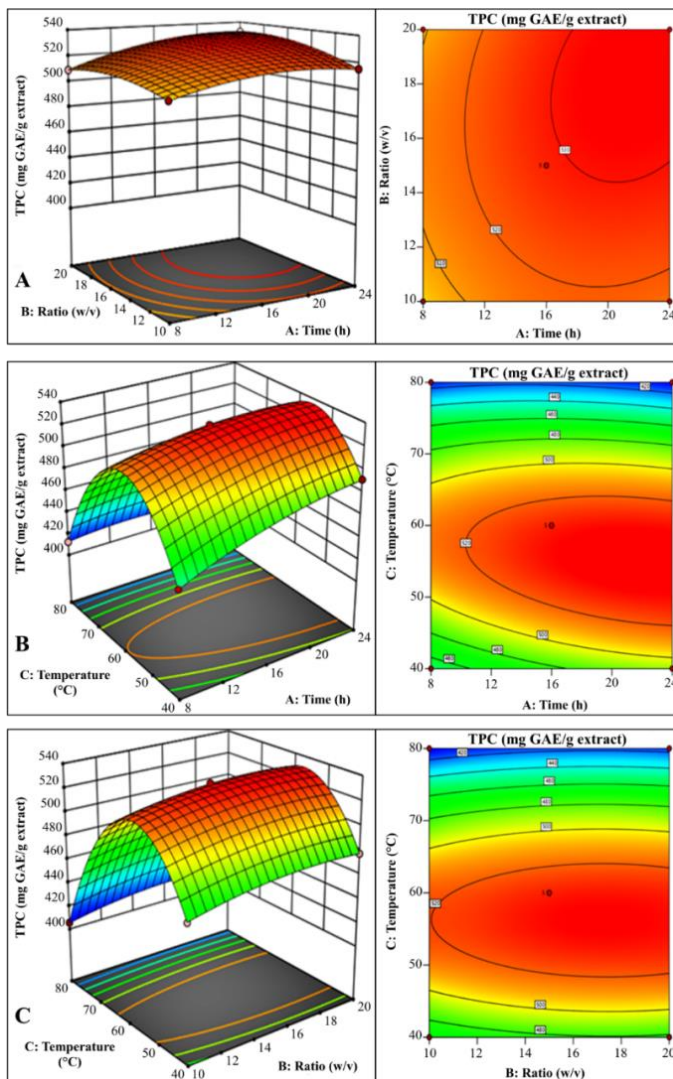
The interactions between the factors influencing TPC extraction are detailed in Table 4. The analysis of the linear terms (A, B, C), quadratic terms (A<sup>2</sup>, B<sup>2</sup>, C<sup>2</sup>), and interaction terms (AB, AC, BC) all showed statistical significance ( $p < 0.05$ ), indicating that these interactions had

a strong effect on TPC. Proper combinations of time (A), material-to-solvent ratio (B), and temperature (C), as well as the interaction between time and material-to-solvent ratio (AB), increased TPC. Conversely, excessive levels of time ( $A^2$ ), material-to-solvent ratio ( $B^2$ ), temperature ( $C^2$ ), or prolonged interactions between time and high temperature (AC) or material-to-solvent ratio and temperature (BC) reduced the TPC.

The three-dimensional response surface plots and two-dimensional contour plots are valuable tools for visualizing the combined effects of two factors on a response variable (Karabegović et al., 2013). They are handy for identifying the optimal values of independent variables to achieve the maximum response. Figure 1 presents the response surface and contour plots, illustrating the interactions between factors influencing TPC. The saddle-shaped curves suggest that maximum TPC is achieved at specific combinations of extraction time, temperature, and material-to-solvent ratio.

**Figure 1**

*Response Surface Plot and Contour Plot of the Combined Effects of Time and Material-to-solvent Ratio (A), The Combined Effects of Time and Temperature (B), and The Combined Effects of Material-to-solvent Ratio and Temperature (C) on Total Polyphenol Content (TPC) of Cashew Nut Testa Extract*

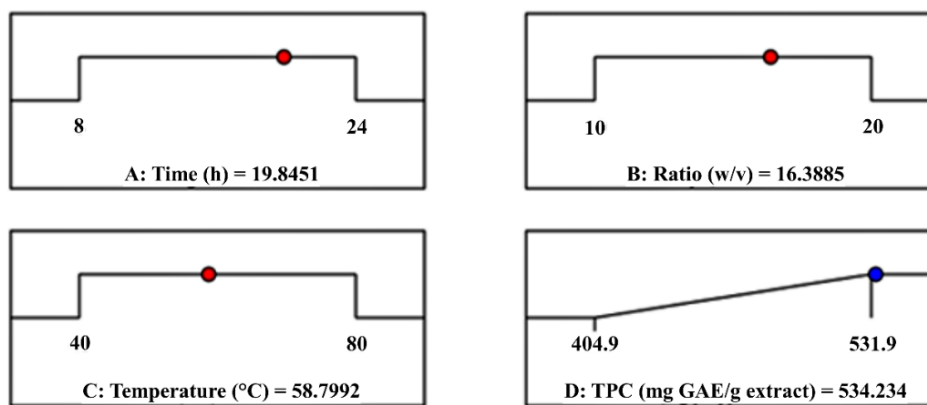


Source. Created by the authors

Based on the experimental data, the Box-Behnken design identified the optimal extraction conditions for TPC from cashew nut testa (Figure 2). The optimal conditions were extracting the cashew nut testa in 99.5% ethanol for 19.85h at 58.80°C, with a material-to-solvent ratio of 1:16.39 (w/v), predicting a TPC of 534.23mg GAE/g extract. These conditions were validated experimentally, where extracting the cashew nut testa in 99.5% ethanol for 20h at 59°C with a 1:16 (w/v) ratio yielded an actual TPC of 534.67mg GAE/g extract. The minimal difference between the predicted and experimental values confirms the model's accuracy.

**Figure 2**

*Ramp Function Plot of Combined Objective (Showing the Optimal Input Parameter Values and Predicted Output Responses, Red Point Represents the Optimal Input Parameter and Blue Point Represents the Optimal Output Value)*



Source. Created by the authors

Overall, the TPC obtained in this study after optimization was notably higher than previously reported. Chandrasekara and Shahidi (2011) found TPC in roasted cashew nut testa extracts ranging from 308.51 to 347.99mg GAE/g extract, while Kamath and Rajini (2007) reported a TPC of 243mg GAE/g. Sruthi et al. (2023) observed TPC levels in free, esterified, and bound phenolic fractions at  $202.98 \pm 8.4$ ,  $1.09 \pm 0.24$ , and  $4.08 \pm 0.18$ mg GAE/g extract, respectively. A study by Mac et al. (2018) demonstrated that optimizing microwave-assisted extraction yielded a TPC of 193.83mg GAE/g. Additionally, enzyme-assisted extraction under specific conditions - pH 4.0, 50°C, a 60-min extraction time, a solid-to-solvent ratio of 1:55, and an enzyme concentration of 0.2% (v/v) - achieved a TPC of 168.84g GAE/kg (Phuong & Huan, 2024). The higher TPC in this study may be attributed to the precise optimization of extraction parameters, particularly temperature and extraction time, which play crucial roles in preserving and recovering polyphenols. These findings suggest that proper tuning of extraction conditions can significantly enhance TPC, positioning the results of this study as a valuable improvement over previously reported methods. Previous studies have analyzed the chemical constituents of cashew nut testa extract, noting that polyphenols - especially catechin, epicatechin, catechin gallate, and procyanidin - are abundant in cashew nut testa (Sruthi & Naidu, 2023). These compounds are well known for their potent antioxidant, antimicrobial, anticancer, hepatoprotective, anti-obesity, and neuroprotective effects and their role in preventing cardiovascular diseases (Sruthi & Naidu, 2023).

Despite the promising results, a key limitation of this study is that it did not investigate the specific characteristics of individual phenolic compounds or assess the biological activities of the extracted compounds. Future research should focus on conducting comprehensive chemical analyses to identify and quantify the specific phenolic compounds in the extract. This would

provide a deeper understanding of the bioactive components responsible for its health benefits. Furthermore, evaluating the biological activities of the extract in both *in vitro* and *in vivo* models will be crucial to establishing its therapeutic potential.

#### 4. Conclusions

The optimal extraction conditions for maximizing the TPC from cashew nut testa were determined to be extraction with 99.5% ethanol for 20h at 59°C, with a material-to-solvent ratio of 1:16 (w/v). Under these conditions, the TPC obtained from the cashew nut testa extract reached 534.67mg GAE/g. These results highlight the potential of cashew nut testa extract as a natural, rich source of polyphenols, with promising applications in cosmetics, pharmaceuticals, functional foods, and other industries. Future studies should evaluate the biological activities of cashew nut testa extract obtained under these optimal conditions. Additionally, it is essential to analyze and identify the specific phenolic compounds present in the extract and investigate their role in contributing to its valuable bioactive properties. These efforts could further enhance the potential of cashew nut testa as a valuable bioresource.

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