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ORIGINAL RESEARCH PAPER

OPTIMIZATION OF THE EXTRACTION OF ANTIOXIDANTS COMPOUNDS FROM THE *KHAYA SENEGALENSIS* PLANT

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Abstract: The present study evaluated the extraction of flavonoids, phenolics and antioxidants from the *Khaya senegalensis* plant. A Box-Behnken design implementing response surface methodology was employed to optimize the process. The process variables include time, temperature and concentration, while total phenolic content, flavonoid content, antioxidant activity and yield are the responses. The optimum yield of 15.2467 %, total phenolic content of 0.8939 $mg \cdot g^{-1}$, total flavonoid content of 12.1453 $mg \cdot g^{-1}$ and antioxidant activity of 0.991182 $mg \cdot g^{-1}$ were obtained at a temperature of 42.59 °C, time of 3.58 hours and solvent concentration of 0.02 $g \cdot mL^{-1}$. The ANOVA and parametric analysis demonstrate that the process variables significantly affect the yield, total flavonoid content, and antioxidant activity.

Keywords: *antioxidant activity, Box-Behnken design, flavonoids, Khaya senegalensis, phenolic compounds, response surface methodology, temperature, time*

INTRODUCTION

Due to the economic situation of developing countries, the society is turning to the traditional herbal system for primary health care. In Africa, medicinal plants supersede conventional drugs as remedies [1]. The therapeutic effect of the herbal formula is attributed to its synergetic property that results from the interaction of bioactive constituents from herbal medicines [2]. Thus, the need for extraction process design to obtain effective bioactive compounds from the herbal formula. The compounds can contribute to exerting the curative effect [3].

Khaya senegalensis (Desr.), also known as "epo agano" by the Yorubas, is a large deciduous tree native to sub-Saharan savannah from Senegal to Uganda. The tree is about 15–30 m tall and is easily recognized by its round evergreen crown of dark shiny foliage. It bears woody capsules as fruits [4]. It is a medicinal plant widely used to treat various diseases in Nigeria and other West African countries. It belongs to the family *Meliaceae* (mahogany family). The Nupes of Niger state of Nigeria values the tree for its medicinal uses. The stem bark extract is used to treat jaundice, malaria, dermatoses, and hookworm infections; the leaves treat headaches and fever; the oil is used to treat leprosy sores, syphilis and ulcers in adults. The ethanolic crude extract of the stem bark of *Khaya senegalensis* has been reported to possess free radical scavenging activity [5]. The seeds and leaves are also used to treat fever and headache, while the root extract treats mental illness, leprosy, and syphilis. Although *Khaya senegalensis* is of great medicinal value, information on its effects on hematology and biochemical parameters is very scanty [6].

Few researchers have worked on *Khaya senegalensis* extracts. Thus, de la Luz Cádiz-Gurrea *et al*. [4] studied the bioactivity assays and chemical characterization of *Khaya senegalensis extracts* and the results obtained showed that the extracts have remarkable antioxidants properties. Mache *et al.* [7] optimized polyphenols and tannins extractions from *Khaya senegalensis* bark at optimum conditions of 150 mL of infusion water, temperature 90 °C and time of 10-15 min. Koudoro *et al*. [8] compared the antibacterial potential of two plant extracts (*Khaya senegalensis* and *Pseudocedrela kotschuyi*) to treat gastrointestinal diseases in livestock; the ethanolic and hydroethanolic extracts obtained using the two barks showed bactericidal activity against *Staphylococcus aureus, Salmonella typh, and Escherichia coli*.

Recently, market studies have confirmed an increasing global demand for natural plant-derived products [9]. The bioactive compounds, mainly phenolic compounds obtained from plants in parallel with the rising interest in human health, have attracted the attention of scientists. Thus, they are widely used as antioxidants for various applications. However, herbal medicines' widespread use and popularity do not guarantee their efficacy and safety [10]. Therefore, there is a need for detailed scientific analyses and adequate information on commonly used herbal drugs [11]. Various researchers have reported on the plant herbal extraction optimization; their findings indicate that the desired extract is obtained at the best operation conditions [10, 12, 13]. Hence the aim of this study was to model and optimize the *Khaya senegalensis* plant (stem bark and leaves) herbal extract process conditions such as time, temperature and concentration on its yield, total phenolic content, total flavonoid content and antioxidant activity.

MATERIALS AND METHODS

Raw materials

Khaya senegalensis plant (stem bark and leaves) was purchased from the local market in Ogbomosho, Oyo State. The herbs were thoroughly screened to ensure they were fresh.

Reagents

Gallic acid, Folin-Ciocalteu reagent, ferric chloride, sodium acetate, 2,4,6-tris(2-pyridyl)-S-triazine (TPTZ) and anhydrous sodium carbonate solution (20 %) were supplied from Sigma Aldrich (Poole, England). Deionized water was obtained from the Chemical Engineering Analytical Laboratory of Michael Okpara University of Agriculture, Umudike, Nigeria. Rutin standard, aluminum chloride solution (10 %), potassium acetate and methanol (70 %) were purchased from GFS Chemicals Inc., USA. All the purchased chemicals were of analytical grade.

Preparation of *Khaya senegalensis* extract

The plant materials (stem barks and leaves) were dried in a shade for five days and then grounded using a laboratory mill. Extraction was carried out by adding 50 g of the sample into a 500 mL flask containing 250 mL of the solvent (ethanol). The mixture was allowed to stir continuously for maximum of 72 hours, varying the time and temperature. It was then filtered using a filter paper; the extracts were evaporated to dryness using a RE-2010 rotary evaporator (BIOBASE Meihua, China) at 40 °C.

Experimental design and statistical analysis

The hybrid design (HD) from design expert 6.0 by (Stat-Ease, Inc. USA) was used to investigate the optimum extraction conditions based on the dependent variables (total phenolic content, total flavonoid content, and antioxidant activity) in the *Khaya senegalensis* herb extract and the independent variables (solvent concentration, extraction temperature and extraction time).

Table 1. *Experimental design for the extraction of bioactive compounds from Khaya senegalensis herb*

Factor	Name	Units	Type	Level	
				-1	1
A	time	hours	numeric	3	4
B	temperature	^{o}C	numeric	40	70
C	concentration	$g \cdot mL^{-1}$	numeric	0.011465	0.018536

Determination of Total Phenolic Content (TPC)

The total phenolic content was determined using the Folin-Ciocalteu reagent and Na_2CO_3 described by Singleton and Rossi [14]. One milligram (1 mg) of the *Khaya*

senegalensis herb extract was introduced into a clean test tube, followed by 1 mL of Folin-Ciocalteu reagent with 2 mL of 20 % Na_2CO_3. The mixture was stirred using a centrifuge (Model No-800, Hunan Herexi Instrument & Equipment, China) for 20 minutes at 4000 rpm. The mixture was incubated for 2 hours at room temperature. Its absorbance was taken at 765 nm against a water blank using a UV spectrophotometer (UNICO 1100, Cole Parmer, USA). The standard curve was generated using gallic acid as standard in water (10 - 50 $mg \cdot L^{-1}$). TPC was measured and expressed in mg Gallic Acid Equivalent (GAE) per g dry sample extract.

Determination of Total Flavonoid Content (TFC)

The total flavonoid content of the sample was determined by the aluminum chloride method using rutin as standard. This method is based on the formation of flavonoid - aluminum complex [15]; 1 mL of the sample (extract) was introduced into a test tube, 3 mL of methanol then 0.2 mL of 10 % aluminum chloride and 0.2 mL of 1 M potassium acetate were introduced into a test tube. The calibration curve was prepared by dissolving 1 g of rutin in 1000 cm^3 and made up with methanol to be 1000 $mg \cdot L^{-1}$ which was used as the stock.

Determination of Antioxidant Activity (AA)

Antioxidant activity was determined using the FRAP (Ferric Reducing Antioxidant Power) method. FRAP reagent was formed using 0.3 M of sodium acetate solution, 0.02 M of ferric chloride solution, and 2,4,6-tri (2-pyridyl)-s-triazine (TPTZ) 0.01 M in 0.04 M HCl due to its strength. One milliliter (1 mL) of the filtrate was introduced into a test tube, followed by 1 mL of FRAP reagent. The mixture was allowed to stand for 5 minutes at room temperature before its absorbance was taken at 593 nm. The calibration curve was prepared with (10 - 50 $mg \cdot L^{-1}$) diluted concentration.

Determination of the yield of *Khaya senegalensis* extract

The yield is determined by the oven drying method. The samples were oven-dried at 40 °C for 24 hours. The extract was allowed in the oven (Binder Heating and Drying Oven, Tuttlingen, Germany) until completely dried. The percentage yield was calculated using the equation below:

$$Yield\ (\%) = \frac{W_1 - W_2}{W_1} \times 100 \quad (1)$$

where W_1 represents the wet weight of residue and W_2 represents the dry weight of residue.
All the analyses for TPC, TFC and AA and FRAP, were done in triplicates, and the average value was used for further analysis.

RESULTS AND DISCUSSION

Table 2 showed variability in the responses (yield, TPC, TFC, and AA), indicating that the extraction parameters significantly affect the response.

Table 2. *Experimental result for the extraction of bioactive compounds from Khaya senegalensis herb*

Run	Time [hours]	Temperature [°C]	Concentration [g·mL^{-1}]	Yield [%]	TPC [mg·g^{-1}]	TFC [mg·g^{-1}]	AA [mg·g^{-1}]
1	3.5	55	0.015	16	1.04	5.2	1.006
2	4.22	55	0.011465	16	1.03	12.27	0.925
3	3.5	76.21	0.011465	12	0.63	8.1	2.19
4	3.5	33.79	0.011465	19	0.44	39.57	1.798
5	3.5	55	0.022071	16	1.68	8.4	0.958
6	3	70	0.018536	17.5	1.505	7.25	1.425
7	4	40	0.018536	13.5	1.084	5.035	1.159
8	4	70	0.018536	18.5	1.27	5.52	1.129
9	3	40	0.018536	14	1.575	4.2	0.943
10	2.79	55	0.011465	16	1.657	10.29	2.175
11	3.5	55	0.007929	17.5	1.557	6.23	2.131

The maximum yield of 19 % was obtained at 33.79 °C for 3.5 hours at a solvent concentration of 0.011465 g·mL^{-1}, while the maximum TPC of 1.657 mg·g^{-1} was obtained at 55 °C for 2.79 hours at a concentration of 0.011465 g·mL^{-1}. The TFC has a maximum value of 39.57 mg·g^{-1} at 33.79 °C for 3.5 hours at a concentration of 0.011465 g·mL^{-1}, while AA has a maximum value of 2.19 mg·g^{-1} at 76.21 °C for 3.5 hours at a concentration of 0.011465 g·mL^{-1}. This result is consistent with the findings of Mache *et al*. [7] on the optimization of polyphenols and tannin content from *Khaya senegalensis* extract.

Statistical analysis for the yield of *Khaya senegalensis* herb

The statistical analysis for the yield of *Khaya senegalensis* herb extract was conducted using analysis of variance (ANOVA), as shown in Table 3.

Table 3. *Statistical analysis for the yield of Khaya senegalensis herb extract*

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	27.22072	6	4.536786	11.54121	0.0352	significant
A	0.030503	1	0.030503	0.077596	0.7987	
B	0.124043	1	0.124043	0.315555	0.6135	
C	1.017266	1	1.017266	2.587839	0.2061	
AB	0.5625	1	0.5625	1.430953	0.3175	
AC	0.032711	1	0.032711	0.083215	0.7918	
BC	17.94806	1	17.94806	45.65837	0.0066	
Residual	1.179284	3	0.393095			
Cor Total	28.4	9				
Std. Dev.	0.626973		R-Squared	0.958476		
Mean	16.4		Adj R-Squared	0.875428		
C.V.	3.823003		Pred R-Squared	N/A		
PRESS	N/A		Adeq Precision	10.44195		

The multiple regression analysis of the yield of *Khaya senegalensis* herb gave a 2FI model equation depicted in Equation 2.

$$Yield = +16.17 + 0.088A + 0.23B - 0.55C + 0.76AB + 0.18AC + 5.58BC \quad (2)$$

The ANOVA result showed that the model was significant, with a standard deviation of 0.626973, a mean of 16.4, and a CV value of 3.823003. Furthermore, a correlation coefficient (R^2) of 0.958476 and an adjusted R-squared value of 0.875428 indicate the adequacy and significance of the model as supported by Adeniyi *et al.* [16], the F-value of 11.54121 with a correspondingly low probability value of 0.0352, less than 0.05 indicates the significance of the model. Furthermore, the adequate precision value of 10.44195 is more significant than four which is also desirable for the model signifying that the model is strong enough for optimization [17].

Figure 1 shows the contour and 3D plot of the effect of extract temperature and time on the yield of *Khaya senegalensis* herb extract. The result showed that an increase in the extraction temperature leads to a subsequent increase in the yield. In contrast, the increase in the extraction time decreases the yield of *Khaya senegalensis* herb extract.

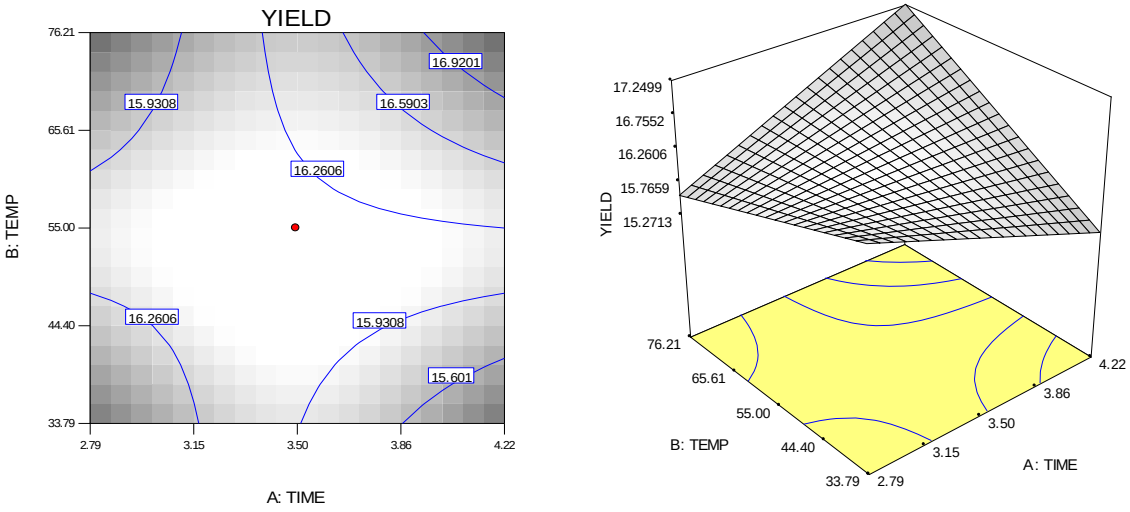

Figure 1. *Effect of extraction temperature and time on the yield of Khaya senegalensis herb extract*

The contour and 3D surface plot of the effect of solvent concentration and extraction time on the yield of *Khaya senegalensis* herb extract, as depicted in Figure 2, revealed that a decrease in the solvent concentration increases the *Khaya senegalensis* yield. In contrast, at a constant time of 3.50 hours, the *Khaya senegalensis* yield increased from 16.5903 to 16.2606, which later decreased to 15.9308 as the extraction time increased.

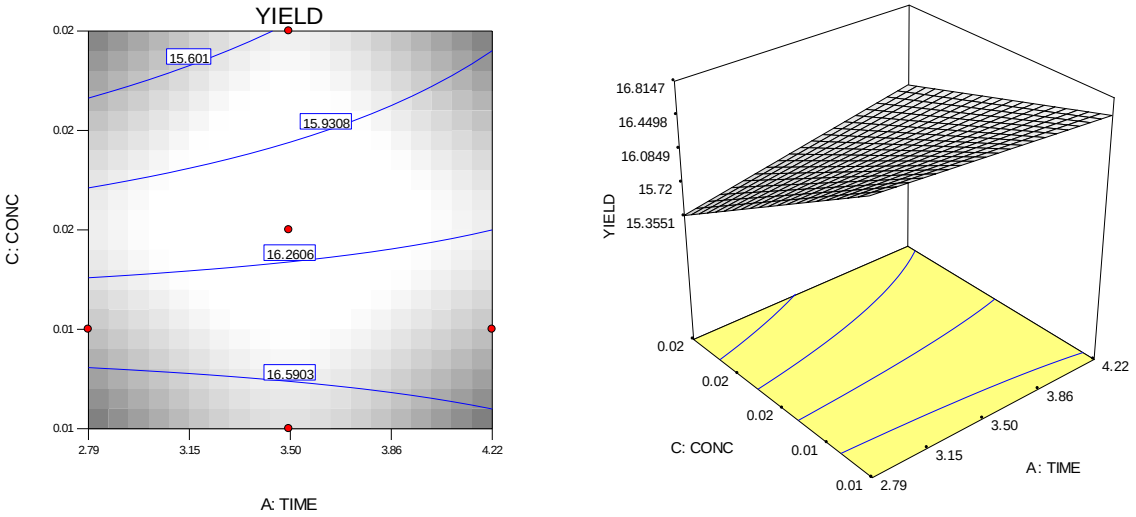

Figure 2. *Effect of solvent concentration and extraction time on the yield of Khaya senegalensis herb extract*

The effect of solvent concentration and extraction temperature on the yield of *Khaya senegalensis* herb extract was examined using contour and a 3D surface plot, as depicted in Figure 3. The result showed that a decrease in the solvent concentration decreases the yield of *Khaya senegalensis* herb extract. Also, the result showed that increase in the extraction temperature results in a reduction of the yield of *Khaya senegalensis* herb extract. The findings agree with reports on the efficient extraction of antioxidants from *Vernonia cinerea* leaves using response surface methodology by Alara *et al*. [18].

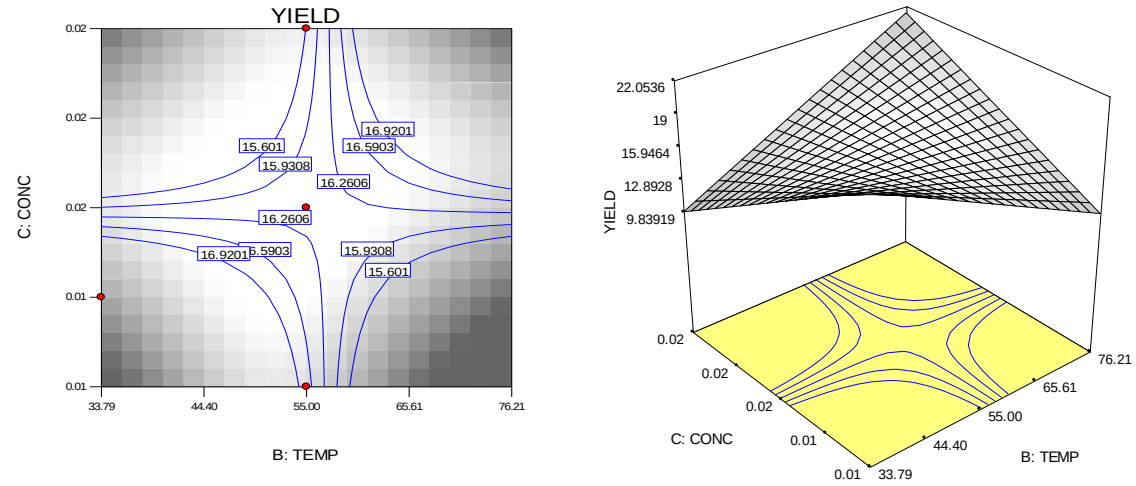

Figure 3. *Effect of solvent concentration and extraction temperature on the yield of Khaya senegalensis herb extract*

Statistical analysis for the TPC of *Khaya senegalensis* herb

The analysis of variance for the Total Phenolic Content of *Khaya senegalensis* herb extract is shown in Table 4.

Table 4. *Statistical analysis for the TPC of Khaya senegalensis herb extract*

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	1.639016	9	0.182113	1.399157	0.5802	not significant
A	0.319583	1	0.319583	2.455328	0.3616	
B	0.018992	1	0.018992	0.145916	0.7677	
C	0.234762	1	0.234762	1.803653	0.4075	
A^2	0.138572	1	0.138572	1.064632	0.4900	
B^2	0.199093	1	0.199093	1.529613	0.4329	
C^2	0.22123	1	0.22123	1.699689	0.4165	
AB	0.016384	1	0.016384	0.125877	0.7830	
AC	0.003527	1	0.003527	0.027097	0.8961	
BC	0.002916	1	0.002916	0.022402	0.9054	
Residual	0.130159	1	0.130159			
Cor Total	1.769175	10				
Std. Dev.	0.360776		R-Squared	0.92643		
Mean	1.224364		Adj R-Squared	0.264295		
C.V.	29.46637		Pred R-Squared	-1117.66		
PRESS	1979.105		Adeq Precision	3.866904		

The statistical analysis of the TPC of *Khaya senegalensis* herb gave a second-order polynomial equation as represented in Equation 3.

$$TPC = +1.04 - 0.28A + 0.069B + 0.24C + 0.37A^2 - 0.44B^2 + 0.58C^2 + 0.13AB + + 0.060AC - 0.054BC \quad (3)$$

The ANOVA result showed that the quadratic model was insignificant, with a standard deviation of 0. 360776, a mean of 1.224364, and a CV value of 29.46637. A correlation coefficient (R^2) of 0.92643 and a very low adjusted R-squared value of 0.264295 imply that the overall mean is a better predictor than the quadratic model. An adequate precision ratio of 3.87 indicates an inadequate signal. Hence the model is not strong enough for optimization.

The surface and 3D surface plots shown in Figure 4 revealed the effect of extraction temperature and time on the TPC of *Khaya senegalensis* herb extract. The result showed that a slight increase in the extraction temperature results in to decrease in the TPC of the herb. Similarly, an increase in the extraction time results in a decrease in the herb's total phenolic content [18].

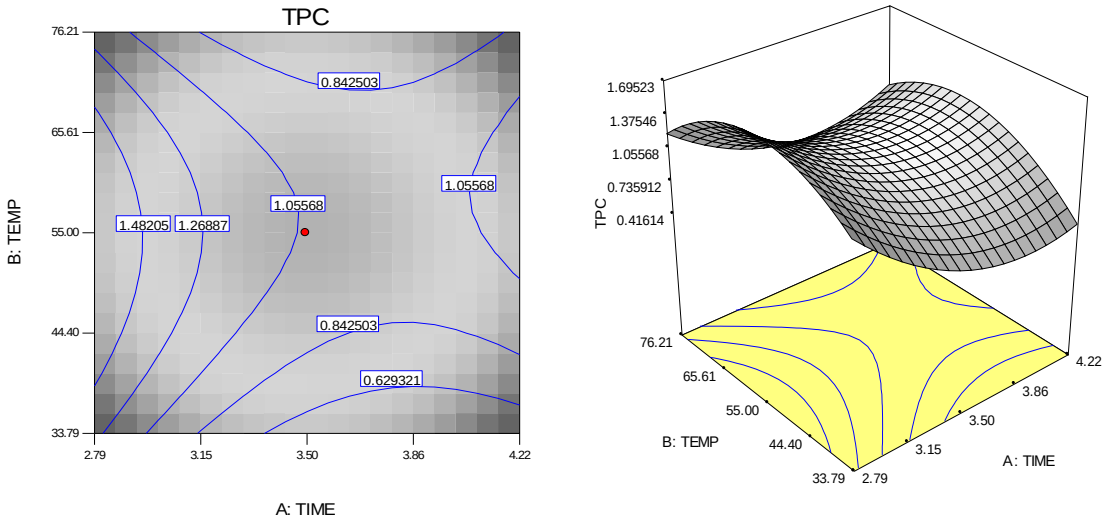

Figure 4. *Effect of extraction temperature and time on the TPC of Khaya senegalensis herb extract*

Figure 5 revealed with contour and 3D surface plot the effect of solvent concentration and extraction time on the total phenolic content of *Khaya senegalensis* herb extract. The result showed that an increase in solvent concentration leads to a subsequent rise in the TPC. Also, an increase in the extraction time results in to decrease in the TPC of *Khaya senegalensis* herb extract.

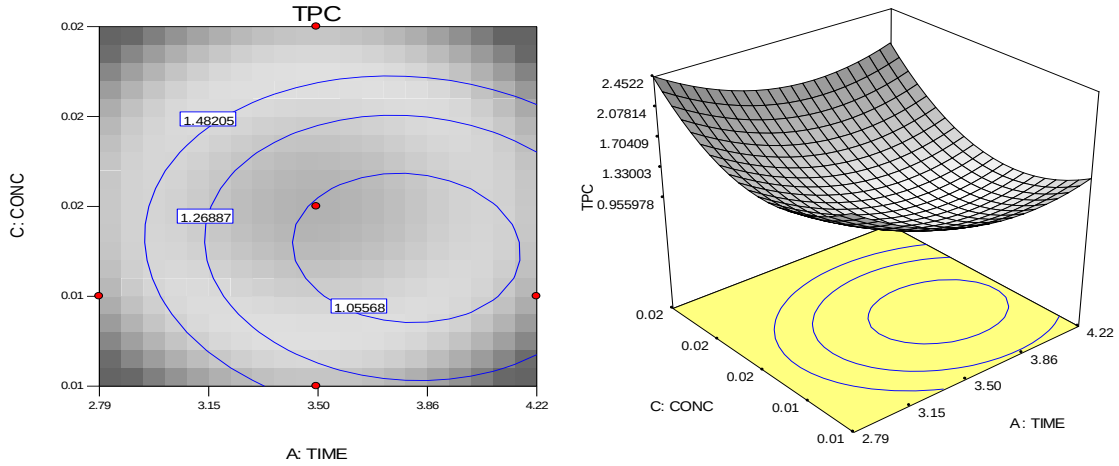

Figure 5. *Effect of solvent concentration and extraction time on the TPC of Khaya senegalensis herb extract*

Figure 6 shows the contour and 3D surface plot of the effect of solvent concentration and extraction temperature on the TPC of *Khaya senegalensis* herb extract.

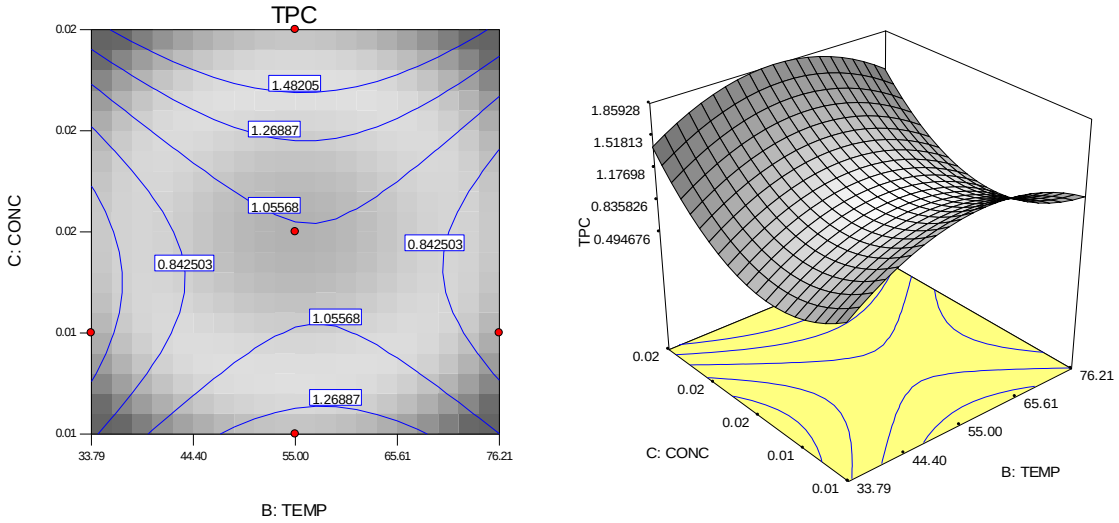

Figure 6. *Effect of solvent concentration and extraction temperature on the TPC of Khaya senegalensis herb extract*

The result showed that a decrease in the solvent concentration increases the TPC of *the Khaya senegalensis* herb. In contrast, increasing the extraction temperature increases the TPC of *Khaya senegalensis* herb extract. This agrees with a report on optimizing polyphenol and tannin content from *Khaya senegalensis* by Mache *et al*. [7].

Statistical analysis for the TFC of *Khaya senegalensis* herb

The analysis of variance for the TFC of *Khaya senegalensis* herb extract is shown in Table 5.

Table 5. *Statistical analysis for the TFC of Khaya senegalensis herb*

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	960.8492	6	160.1415	11.18889	0.0367	significant
A	0.473856	1	0.473856	0.033108	0.8672	
B	531.1579	1	531.1579	37.11136	0.0089	
C	8.242329	1	8.242329	0.575882	0.5031	
AB	1.644806	1	1.644806	0.114921	0.7570	
AC	1.754935	1	1.754935	0.122615	0.7494	
BC	621.9731	1	621.9731	43.45651	0.0071	
Residual	42.93763	3	14.31254			
Cor Total	1003.787	9				
Std. Dev.	3.783192		R-Squared	0.957224		
Mean	10.3965		Adj R-Squared	0.871673		
C.V.	36.38909		Pred R-Squared	N/A		
PRESS	N/A		Adeq Precision	10.84299		

The multiple regression analysis of the TFC of *Khaya senegalensis* herb gave a 2FI model equation as represented in Equation 4:

$$TFC = +7.33 + 0.35A - 15.12B - 1.57C - 1.30AB - 1.34AC + 32.85BC \quad (4)$$

The ANOVA result showed that the model was significant, with a standard deviation of 3.783192, a mean of 10.3965, and a CV value of 36.38909. The correlation coefficient (R^2) of 0.957224, adjusted R-squared value of 0.871673, F-value of 11.18889, and a p-value of 0.0367 indicate that the model is significant. Furthermore, the adequate precision value of 10.84299 is greater than 4, indicating that the model can be optimized.

Figure 7 revealed the contour and 3D plot of extract temperature and time effect on the TFC of *Khaya senegalensis* herb extract. The result showed an increase in the extraction temperature leads to a subsequent decrease in the TFC. In contrast, at a constant extraction time of 3.50, the TFC of *Khaya senegalensis* herb extract decreases.

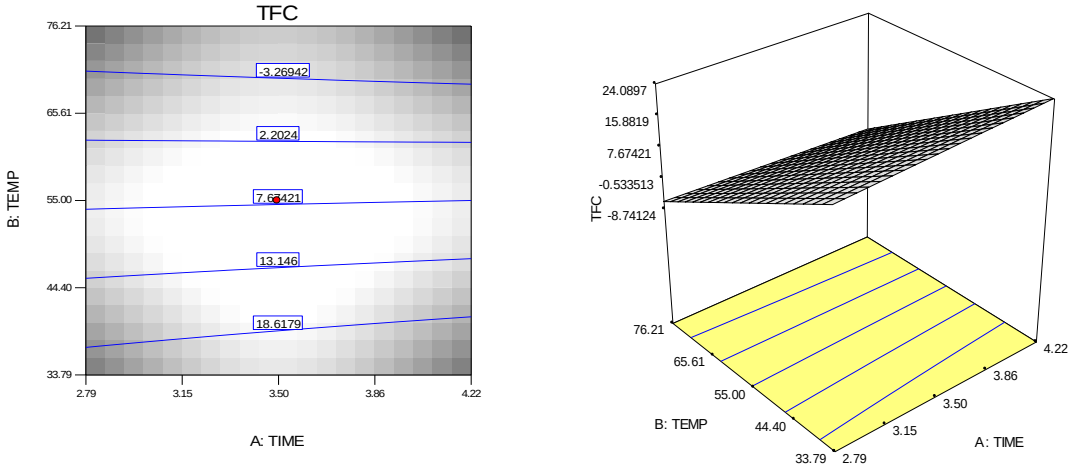

Figure 7. *Effect of extraction temperature and time on TFC of Khaya senegalensis herb extract*

The contour and 3D surface plot of the effect of solvent concentration and extraction time on the TFC of *Khaya senegalensis* herb extract, as depicted in Figure 8, revealed a stagnant value of TFC of the *Khaya senegalensis* as the solvent concentration and extraction time increased.

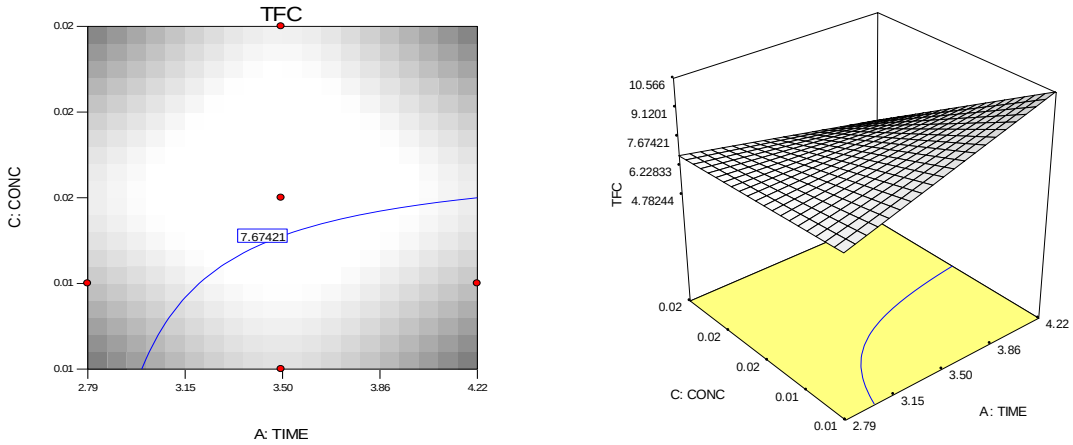

Figure 8. *Effect of solvent concentration and extraction time on TFC of Khaya senegalensis herb extract*

The effect of solvent concentration and extraction temperature on the TFC of *Khaya senegalensis* herb extract was examined using contour and 3D surface plots, as depicted in Figure 9.

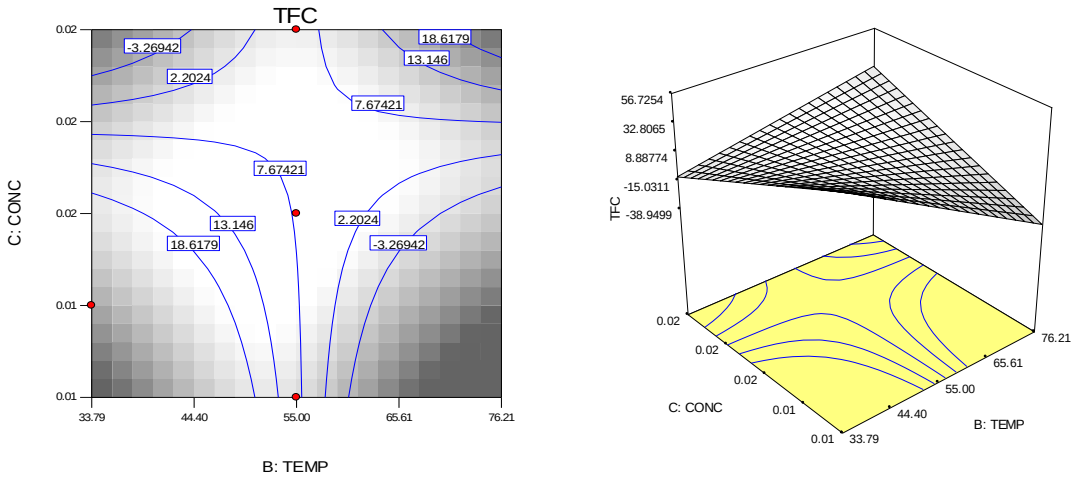

Figure 9. *Effect of solvent concentration and extraction temperature on TFC of Khaya senegalensis herb extract*

The result showed that increasing the solvent concentration decreases the TFC of *Khaya senegalensis* herb extract. Also, the result showed that increase in the extraction temperature results in a decrease in the TFC of *Khaya senegalensis* herb extract. The findings from Figure 7 to 9 are consistent with the findings of Mache *et al*. [7].

Statistical analysis for the AA of *Khaya senegalensis* herb extract

The analysis of variance for the AA of *Khaya senegalensis* herb extract is shown in Table 6.

The statistical analysis of the antioxidant activities of *the Khaya senegalensis* herb gave a second-order polynomial equation as represented in Equation 5.

$$AA = +1.00 - 0.33A + 0.18B - 0.60C + 0.11A^2 + 0.55B^2 + 0.54C^2 - 0.26AB + \\ + 0.60AC - 0.036BC \quad (5)$$

The ANOVA result showed that the quadratic model was significant, with a standard deviation of 0.02257, a mean of 1.439909, and a CV value of 1.567494. The result also showed a correlation coefficient (R^2) of 0.999819 and an adjusted R-squared value of 0.998192, indicating the adequacy and significance of the model. Additionally, the F-value of 614.3464 with a correspondingly low probability value of 0.0313 emphasized the significance of the model. A negative "Pred R-Squared" of 1.74954 implies that the overall mean is a better predictor of your response than the current model. The adequate precision value of 58.77455, which is greater than 4, is desirable for the model to be optimized.

Table 6. *Statistical analysis for the AA of Khaya senegalensis herb extract*

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	2.816681	9	0.312965	614.3464	0.0313	significant
A	0.420377	1	0.420377	825.1954	0.0222	
B	0.124012	1	0.124012	243.4345	0.0407	
C	1.409072	1	1.409072	2765.994	0.0121	
A2	0.012233	1	0.012233	24.01284	0.1282	
B2	0.309467	1	0.309467	607.4812	0.0258	
C2	0.193437	1	0.193437	379.7158	0.0326	
AB	0.065536	1	0.065536	128.6465	0.0560	
AC	0.353415	1	0.353415	693.7499	0.0242	
BC	0.001312	1	0.001312	2.575328	0.3548	
Residual	0.000509	1	0.000509			
Cor Total	2.817191	10				
Std. Dev.	0.02257		R-Squared	0.999819		
Mean	1.439909		Adj R-Squared	0.998192		
C.V.	1.567494		Pred R-Squared	-1.74954		
PRESS	7.745984		Adeq Precision	58.77455		

The surface and 3D surface plots shown in Figure 10 revealed the effect of extraction temperature and time on the AA of *Khaya senegalensis* herb extract. The result showed that increase in the extraction temperature results in a simultaneous increase in the AA of the herb. Similarly, an increase in the extraction time results in a decrease in the herb's AA.

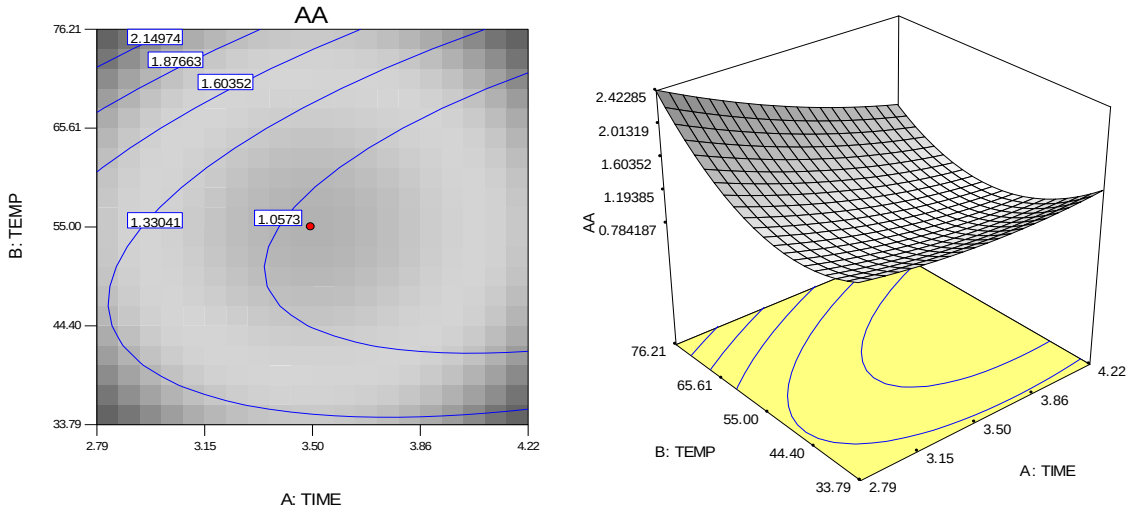

Figure 10. *Effect of extraction temperature and time on the AA of Khaya senegalensis herb extract*

Figure 11 revealed with contour and 3D surface plot the effect of solvent concentration and extraction time on the antioxidant activities of *Khaya senegalensis* herb extract. The

result showed that a decrease in solvent concentration leads to a subsequent increase in antioxidant activities. Also, an increase in the extraction time results in to decrease in the antioxidant activities of *Khaya senegalensis* herb extract.

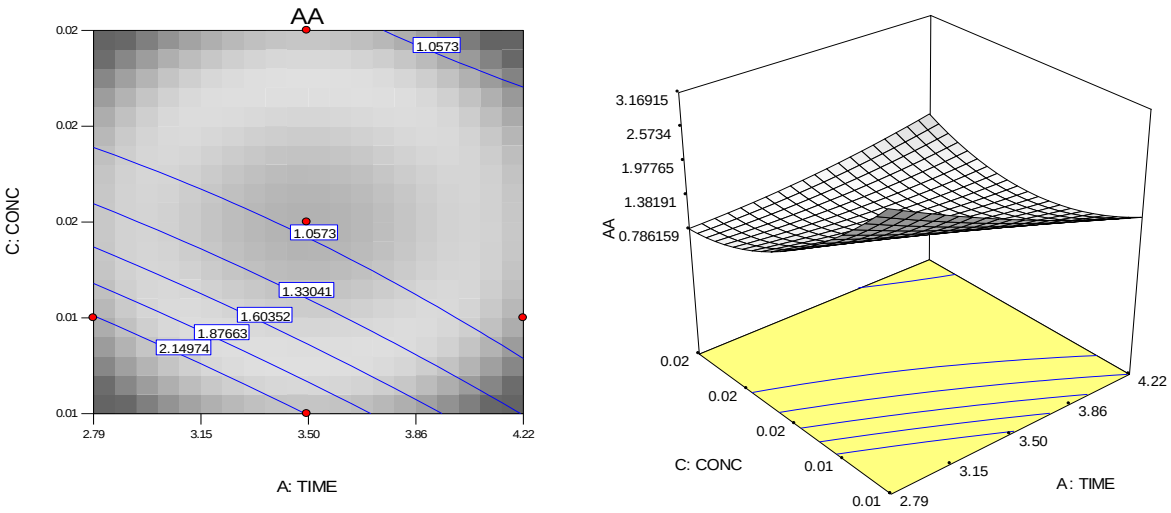

Figure 11. *Effect of solvent concentration and extraction time on the AA of Khaya senegalensis herb extract*

Figure 12 shows the contour and 3D surface plot of solvent concentration and extraction temperature on the antioxidant activities of *Khaya senegalensis* herb extract. The result showed that a decrease in the solvent concentration increases the antioxidant activities of *the Khaya senegalensis* herb. In contrast, an increase in the extraction temperature increases the antioxidant activities of *Khaya senegalensis* herb extract.

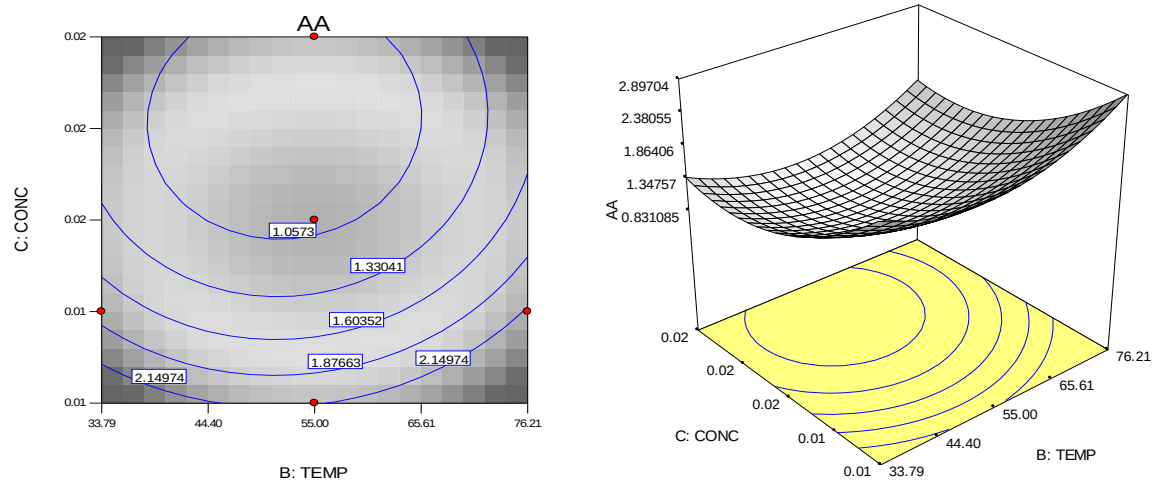

Figure 12. *Effect of solvent concentration and extraction temperature on the AA of Khaya senegalensis herb extract*

The findings presented in Figures 10 - 12 corroborate the conclusions of de la Luz Cádiz-Gurrea *et al*. [4].

Optimization of *Khaya senegalensis* extracts

The determination of the optimum yield and bioactive compounds was based on numerical optimization using Design-Expert software. The optimum yield of 15.2467 %, total phenolic content of 0.8939 $mg \cdot g^{-1}$, total flavonoid content of 12.1453 $mg \cdot g^{-1}$ and antioxidant activity of 0.991182 $mg \cdot g^{-1}$ were obtained at the extraction temperature, extraction time and solvent concentration of 42.59 °C, 3.58 hours and 0.02 $g \cdot mL^{-1}$, respectively, with the desirability of 1.000 % [7, 18, 19].

CONCLUSIONS

This study examined the optimum conditions for extracting *Khaya senegalensis* herbal extract. The relationship between the independent variables (temperature, time, and solid to liquid ratio) and the dependent variables (yield, Total Phenolic Content (TPC), Total Flavonoid Content (TFC), and Antioxidant Activity (AA)) was investigated. The optimum conditions that maximize the yield of TPC, TFC, and AA were examined using the desirability function technique. As a result, the optimum yield of 15.2467, total phenolic content of 0.8939, total flavonoid content of 12.1453 and antioxidant activity of 0.991182 were obtained at the extraction temperature, extraction time and solvent concentration of 42.59 °C, 3.58 hours and 0.02 $g \cdot mL^{-1}$, this information is necessary for the exploitation *Khaya senegalensis* herbal extract on a large scale.

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