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Research Article

Optimization of Roasting Parameters for *Parkia biglobosa* Oilcake to Obtain a Coffee Substitute (Response Surface Methodology)

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Abstract

Parkia biglobosa is a non-wood forest product whose seeds contain an oil with interesting characteristics. Extracting this oil by pressing will produce a large quantity of oil cake. However, these cakes are not recovered and therefore constitute waste. This study therefore set out to transform this cake into a coffee substitute, using response surface methodology to optimise roasting conditions. The time and temperature varied from 10 to 20 minutes and from 190 ℃ to 210 ℃ respectively. Statistical analysis reveals that they have a significant influence on the response parameters (colour difference, polyphenol content and antioxidant activity) at the 95% confidence level. Colour difference, phenolic compound content and antioxidant activity increased from 32.499 to 54.608, from 53.406 mg/g to 79.036 mg/g and from 78.583% to 91.305% respectively. Roasting conditions (time and temperature) had an impact on phenolic compound content and antioxidant activity. This study revealed that antioxidant activity was correlated with polyphenol content, insofar as a decrease in polyphenol content with temperature led to a drop in antioxidant activity. So to produce the *Parkia* substitute with high nutritional potential, the response parameters must reach their maximum values. Under these experimental conditions, the optimum roasting parameters are 203 ℃ for 12 minutes, resulting in a colour difference of 49.190, a polyphenol content of 73.949 mg/g and an antioxidant activity of 86.021%.

Keywords

Parkia biglobosa, Oilcake, Roasting, Phenolic Compounds, Antioxidant Activity

1. Introduction

Parkia biglobosa, from its scientific name, or African locust bean, from its English, is a non-woody forest product that provides resources of high nutritional quality used for food and pharmacopoeia [1-3]. African locust bean fruits are long pods containing seeds coated with yellow pulp [4]. The pulp, which is rich in sugar, is consumed in its raw state and its

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transformation into nectar has been the subject of studies [5-7]. The seeds undergo fermentation to become a flavour enhancer in many preparations. Analysis of the chemical properties of *Parkia* seeds reveals average dry matter contents of 86.94-90.87%, average ash contents of 3.51-4.39% and average crude protein contents of 24.33-33.70% [8]. According to [9], the seeds have calcium, magnesium, zinc and iron concentrations of 942.6 ± 1.10mg/kg, 126.5 ± 1.18mg/kg, 411.8 ± 0.10mg/kg and 19.0 ± 0.01mg/kg respectively. The seeds also contain a significant oil content [10, 8, 11]. The oil is also rich in linoleic acid (*W6*) [10, 12]. Oti-Boakye et al [11] discovered interesting characteristics in the oil that could justify its use in food. It should be noted that extraction by pressing will generate a large quantity of oilcake. At present, there is no way of recovering this oil cake. The literature provides information on the use of seeds as a coffee substitute. The aim of this study is therefore to find the optimum conditions for roasting oilcake using response surface methodology to obtain an African locust bean substitute with high nutritional potential.

2. Materials and Methods

2.1. Raw Material

Parkia biglobosa fruits were harvested in July 2024 in Sédhiou (12°42'17.0 'N 15°33'22.4 'W), Senegal. After drying and hulling the fruit, the pulp was removed by hand and the seeds were then soaked in water to remove any residual pulp. The seeds are then dried at 65 ℃ for 24 hours and de-oiled using a VEVOR oil press. The oilcake is then recovered and reduced to a powder (Figure 1).

Figure 1. *Parkia biglobosa seeds (a) and oilcake (b).*

2.2. Experimental Design and Roasting Process

Many seed roasting studies use response surface methodology to determine optimal conditions [13-16]. In this work, the centred composite design with 13 trials (Table 1) was used to evaluate the effect of time (A) and temperature (B) on the response parameters (colour difference (Y1), polyphenol content (Y2) and antioxidant activity (Y3)). To do this, roasting times of 8, 10, 15, 20 and 22 minutes were associated with temperatures of 186 ℃, 190 ℃, 200 ℃, 210 ℃ and 214 ℃. The factors (time and temperature) chosen correspond relatively to the roasting conditions for conventional coffee [17].

A Memmert oven was used to carry out the 13 roasting tests. Once the temperature had been set, it was left to run until the probe built into the oven indicated the desired temperature. From then on, the unroasted oilcake powder, spread out on aluminium foil at a rate of 50 g per test, was placed in the oven and as soon as the desired temperature was again reached, the stopwatch was started. At the end of the time required for roasting, the powder is removed from the oven and cooled to room temperature. The roasted powders thus obtained are ground, sieved and stored in an airtight container for analysis in triplicate of the response parameters.

Table 1. *Experimental design for optimising African locust bean oilcake roasting conditions.*

Tests	Time (min)	Temperature (℃)
1	15	200
2	20	190
3	15	200
4	15	214.142 ≈ 214
5	10	210
6	15	200
7	10	190
8	7.92893 ≈ 8	200
9	15	200
10	20	210
11	22.0711 ≈ 22	200
12	15	185.858 ≈ 186
13	15	200

2.3. Physico-chemical Analyses

2.3.1. Colour Difference

Colour difference was determined using a Konica Minolta colorimeter. The colour parameters L^*, a^* and b^* were measured on roasted oilcake powders. L^* represents brightness or luminance and varies from black to white. a^*, on the other hand, represents the difference between green ($-a^*$) and red ($+a^*$). In addition, b^* indicates the difference between yellow ($+b^*$) and blue ($-b^*$). Taking the colour parameters of the unroasted powder as a reference (L_0=66.845, a_0=-1.045, b_0=20.725), the colour difference is calculated using equation (1):

$$Colour\ difference = \sqrt{(L^* - L_0)^2 + (a^* - a_0)^2 + (b^* - b_0)^2} \quad (1)$$

2.3.2. Polyphenol Content

The polyphenol content was determined using the method described by Georgé et al [18] with a few modifications. A decoction of Parkia biglobosa coffee in distilled water was carried out at 50 ℃ for one hour using a 1:10 ratio (1 g of coffee in 10 ml of water). The solution obtained was then filtered. 50 µL of filtrate was mixed with 450 µL of distilled water. 2.5 mL of 10% diluted Folin-Ciocalteu reagent was added to the mixture. The mixture was vortexed. 2.5 mL of 75 g/L sodium carbonate was added to the mixture, which was stirred again and incubated at 50 ℃ for 15 minutes. After cooling, the absorbance was read at 760 nm using a brand-name spectrophotometer Cary UV-VIS 60 against distilled water, which was used as a blank.

2.3.3. Antioxidant Activity

This was carried out using the method developed by Brand-Williams et al [19]. After extraction in distilled water by decoction of 1 g of coffee in 10 mL of water, 100 µL of the extract was mixed with 3 mL of 2,2-diphenyl 1-pycrilhydrazyl (DPPH) solution and then vortexed for 5 minutes. The resulting solution was incubated in the dark for 30 minutes. In addition, a control in which 100 µL of methanol and 3 mL of DPPH are mixed is prepared under the same conditions to obtain the control absorbance value ($A_{control}$). The absorbance of the samples is read at 517 nm using a spectrophotometer of the brand Cary UV-VIS 60. Equation (2) is used to calculate the antioxidant activity:

$$\%\ inhibition\ of\ DPPH = 1 - \frac{A_{sample}}{A_{control}} \quad (2)$$

2.4. Statistical Analysis

Design Expert version 13 was used to carry out a statistical analysis of the data. Analysis of variance (ANOVA) and regression surface analysis were performed to determine the regression coefficients, to understand the statistical significance of the model terms and to fit the mathematical data with the experimental data. In addition, the quadratic model was chosen by default. An empirical relationship linking each response parameter (colour difference (Y1), polyphenol content (Y2) or antioxidant activity (Y3)) as a function of factors (time (A) and temperature (B)) is obtained using equation (3):

$$Y = \beta_0 + \beta_1.A + \beta_2.B + \beta_{12}.A.B + \beta_{11}.A^2 + \beta_{22}.B^2 \quad (3)$$

Where β_0 is a constant, β_1 and β_2 are the linear coefficients, β_{11} and β_{22} are the quadratic coefficients and β_{12} is the interaction coefficient.

3. Results and Discussion

3.1. Statistical Analysis

The results of the response parameters are given in Table 2. They show that colour difference, polyphenol content and antioxidant activity vary respectively from 32.4987 to 54.6076, from 53.4064 mg/g to 79.0355 mg/g and from 78.583% to 91.3047%. Statistical analysis reveals that the factors (time (A) and temperature (B)) have a significant impact on colour difference, polyphenol content and antioxidant activity at the 95% confidence level.

Table 2. *Experimental data on response parameters for different roasting conditions.*

Tests	Colour difference	Polyphenol content (mg/g)	Antioxidant activity (%)
1	49.928	72.979	86.470
2	38.486	71.641	83.899
3	51.060	75.142	86.498
4	54.608	53.479	82.707
5	52.182	74.874	84.837
6	49.898	72.589	86.708

Tests	Colour difference	Polyphenol content (mg/g)	Antioxidant activity (%)
7	32.499	64.312	91.305
8	43.254	68.494	87.967
9	48.686	75.323	81.314
10	53.495	53.406	78.583
11	47.908	55.836	80.794
12	35.622	79.036	87.358
13	47.731	74.915	82.288

It should be noted that the quadratic contributions (A^2 and B^2) have a significant influence on the colour difference. In addition, the quadratic contribution (A^2) and the interaction (AB) had a significant impact on the polyphenol content. However, the interaction (AB) and the quadratic contributions (A^2 and B^2) had no significant influence on antioxidant activity (Table 3).

Table 3. *Analysis of variance in colour difference, polyphenol content and antioxidant activity.*

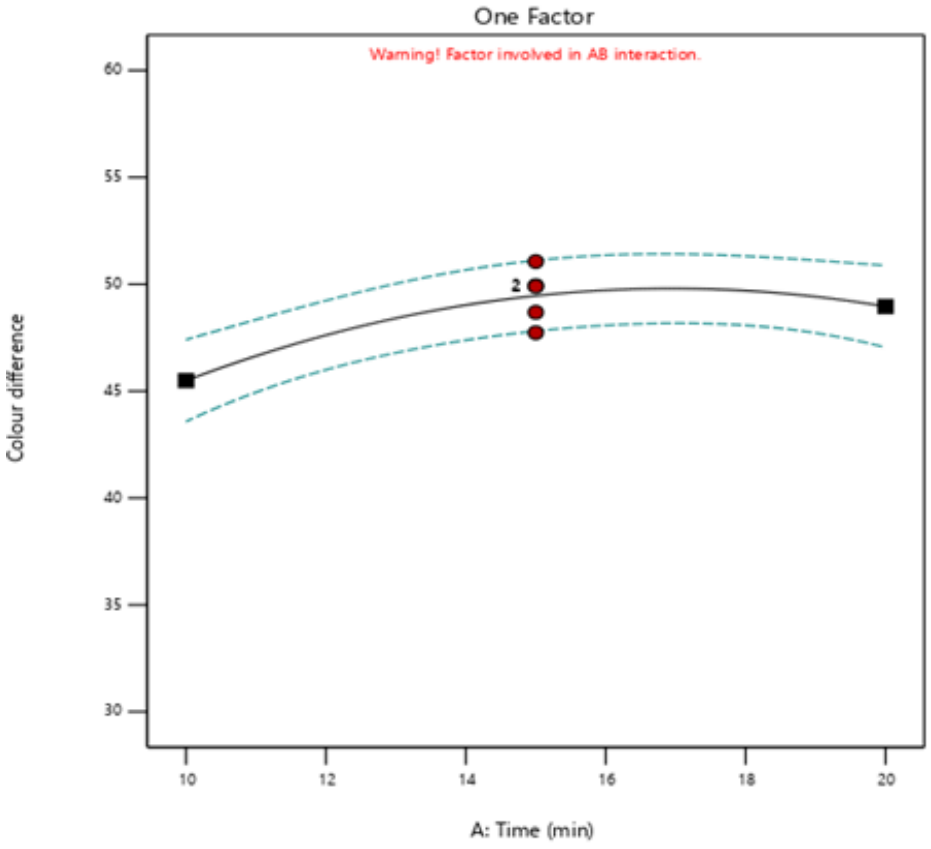
Colour difference						
Source	**Sum of squares**	**df**	**Mean square**	**F-value**	**p-value**	
Model	571.27	5	114.25	46.74	< 0.0001	significatif
A-Time	24.09	1	24.09	9.86	0,0164	
B-Temperature	473.41	1	473.41	193.67	< 0.0001	
AB	5.46	1	5.46	2.23	0,1786	
A ²	34.76	1	34.76	14.22	0,0070	
B ²	42.39	1	42.39	17.34	0,0042	
Pure Error	6.56	4	1.64			
R^2 = 0.9709			R^2 adjusted = 0.9501			
polyphenol content						
Source	Sum of squares	df	Mean square	F-value	p-value	
Model	844.63	5	168.93	10.14	0.0042	significatif
A-Time	128.32	1	128.32	7.70	0.0275	
B-Temperature	239.96	1	239.96	14.40	0.0068	
AB	207.33	1	207.33	12.44	0.0096	
A ²	214.32	1	214.32	12.86	0.0089	
B ²	85.43	1	85.43	5.13	0.0580	
Pure Error	6.75	4	1.69			
R^2 =0.8786			R^2 adjusted = 0.7920			
antioxidant activity						
Source	Sum of squares	df	Mean square	F-value	p-value	
Model	113.73	5	22.75	4.88	0.0305	significatif

Colour difference					
Source	**Sum of squares**	**df**	**Mean square**	**F-value**	**p-value**
A-Time	70.83	1	70.83	15.20	0.0059
B-Temperature	42.13	1	42.13	9.04	0.0197
AB	0.3316	1	0.3316	0.0712	0.7973
A^2	0.1574	1	0.1574	0.0338	0.8594
B^2	0.2153	1	0.2153	0.0462	0.8359
Pure Error	27.67	4	6.92		
$R^2 = 0.7772$			R^2 adjusted = 0.6180		

3.2. Evolution of the Colour Difference

The colour difference increases slightly as the roasting time increases. It also increases significantly with increasing temperature (Figure 1). In fact, these two parameters (time and temperature) have a significant impact on the colour difference, with a linear and quadratic effect. In addition, roasting induces a change in colour that increases with temperature and time. The changes in colour are in fact the result of the formation of certain Maillard reaction products that can confer functionality and appearance to the roasted beans [20]. It should be noted that the highest colour difference is obtained by roasting the cake powder at 214 ℃ for 15 minutes. The results obtained corroborate with those of *Nakilcioğlu-Taş et al* [21] who indicate that the total colour difference between coffee samples increases as the degree of coffee roasting increases. Equation (4) relating the colour difference (Y1) with time (A) and temperature (B) is obtained for the prediction of Y1 values.

$$Y1 = -1187.230 + 7.703 \times A + 10.994 \times B - 0.023 \times A \times B - 0.089 \times A^2 - 0.025 \times B^2 \quad (4)$$



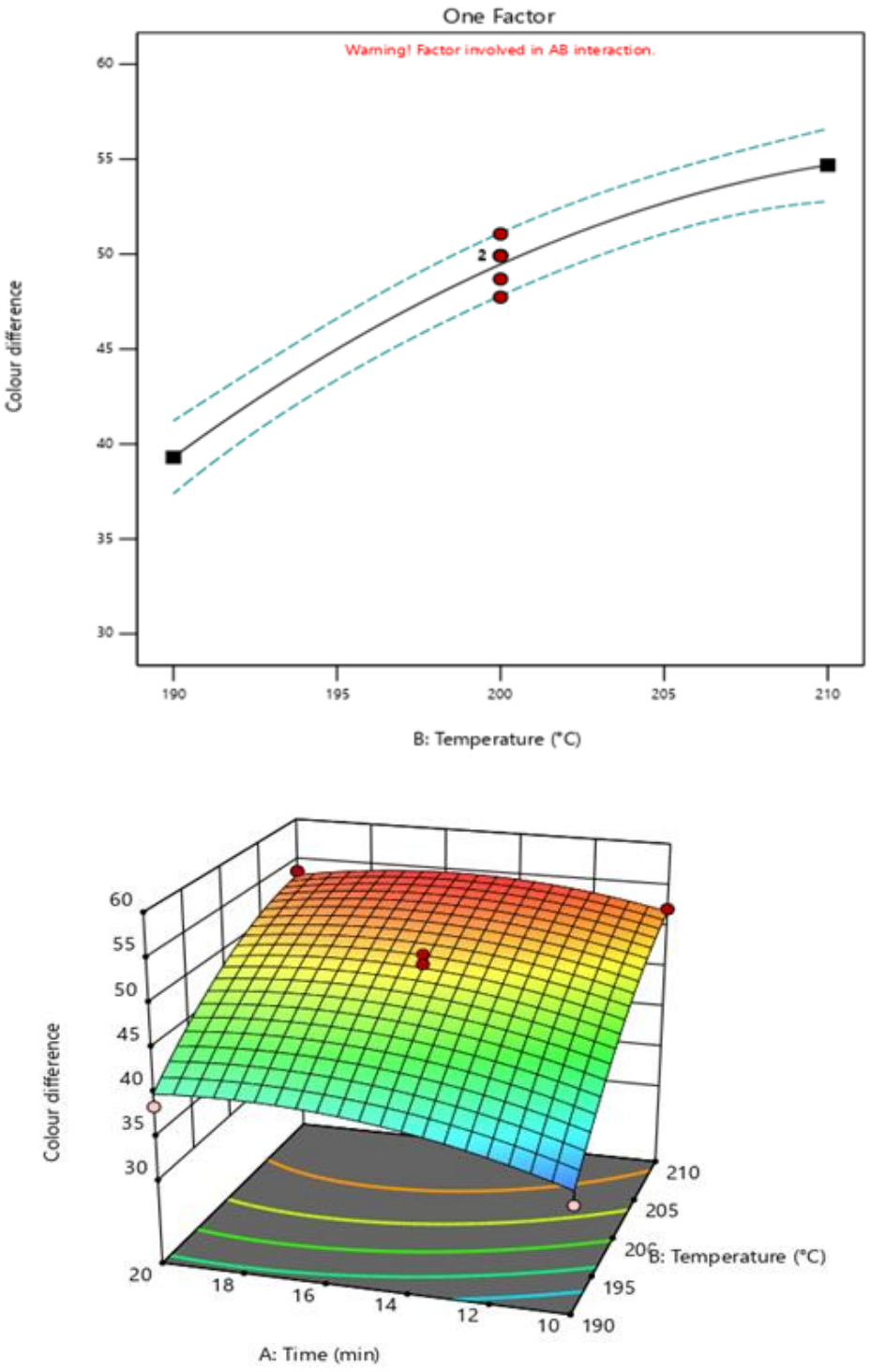


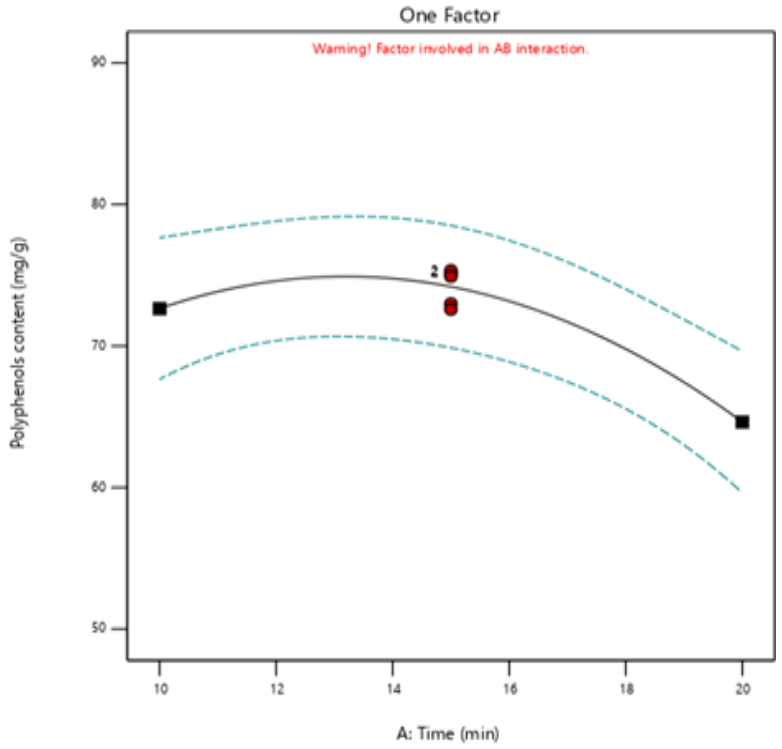
Figure 2. *Colour difference response surface as a function of time and temperature.*

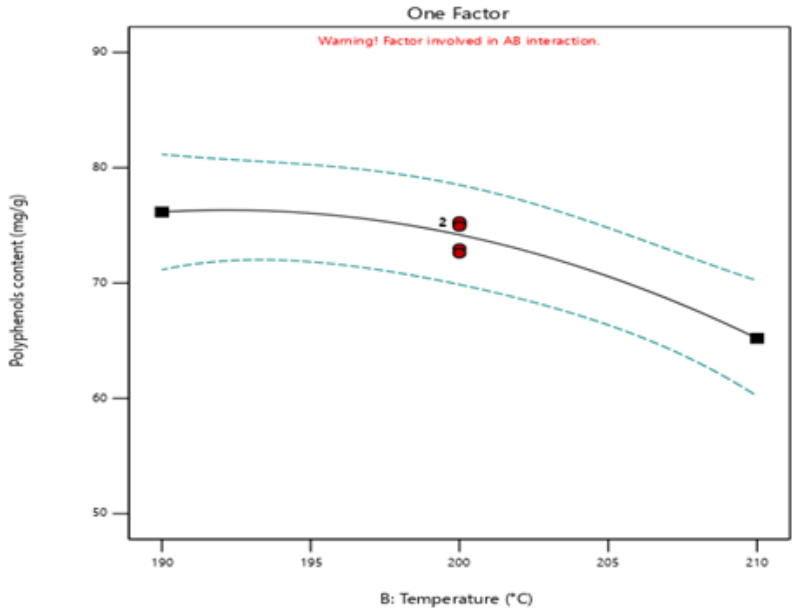
3.3. Evolution of Polyphenol Content

Analysis of Figure 2 shows that polyphenol content is inversely proportional to temperature. In fact, temperature has a significant impact on polyphenol content in a linear, quadratic and interactive way. In this study, polyphenol content was highest at 186 ℃ (79.036 mg/g). According to *Król et al* [22], roasting conditions have an impact on the composition of phenolic compounds. They conclude that light roasting (190 ℃/25 min) results in better preservation of polyphenols than medium roasting (220 ℃/25 min). This decrease in polyphenols as a function of temperature has been confirmed by several authors [23-25]. As for the variation in polyphenol content as a function of roasting time, it increases slightly and decreases when the time exceeds 15 minutes. Like temperature, polyphenol content changed significantly with roasting time, with a linear, quadratic and interactive effect. This slight

increase in phenolic compounds could be explained on the one hand by the effect of roasting, which leads to the destruction of cellular structures favouring the release of other polyphenols [26], and on the other hand by the formation of compounds (such as pyrroles and furans) derived from the Maillard reaction, which can react with the Folin-Ciocalteu reagent [27, 13]. In addition, roasting can generate other compounds with a structure similar to that of polyphenols, leading to an increase in polyphenol content [28]. *Dybkowska et al* [25] show that longer roasting times lead to greater degradation of polyphenols, compared with the observed decrease in polyphenol content. Equation (5) predicts the phenolic compound content (Y2) as a function of time (A) and temperature (B).

$$Y2 = -1687.896 + 34.657 \times A + 15.629 \times B - 0.144 \times A \times B - 0.222 \times A^2 - 0.035 \times B^2 \quad (5)$$





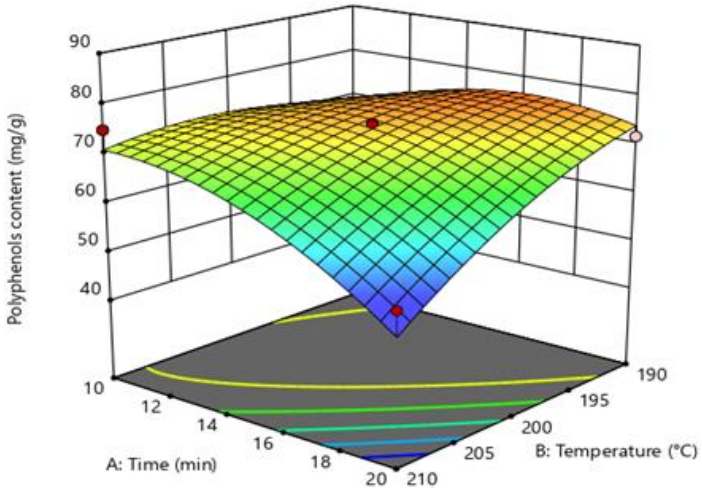
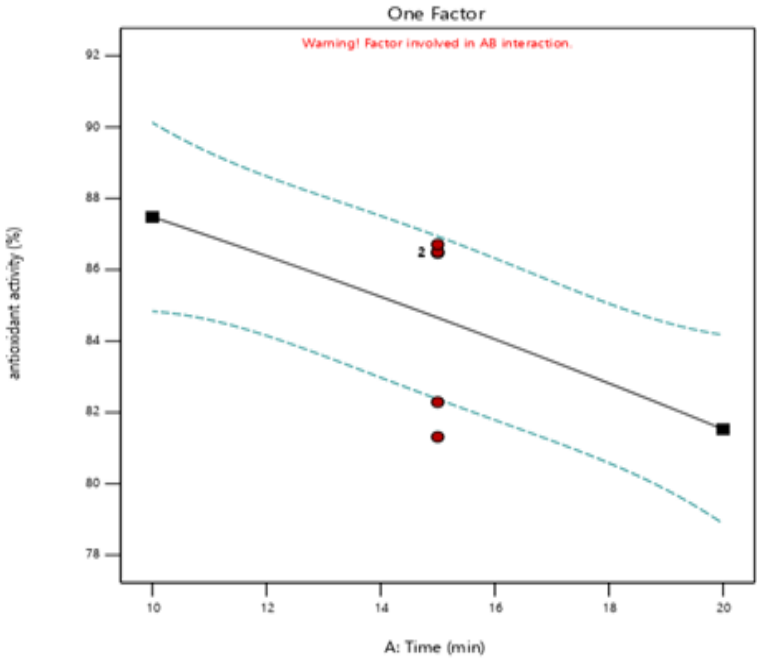


Figure 3. *Response surface of polyphenol content as a function of time and temperature.*

3.4. Evolution of Antioxidant Activity

A decrease in antioxidant activity is observed as time and temperature increase (Figure 3). Time and temperature have a significant effect on antioxidant activity. In this study, antioxidant activity was highest at 190 ℃ for 10 min (91.305%). According to *Bobková et al* [29], the intensity of roasting has an influence on antioxidant activity. Their study shows that light roasting gives a higher antioxidant activity than strong roasting. A similar result was obtained with the roasting of Robusta and Arabica coffees [30]. *Sunarharum et al* [30] found that antioxidant activity decreased with temperature. A roast at 95 ℃ for 15 minutes had a lower IC50 value than roasts at 125 ℃ and 165 ℃ for the same duration. This low IC50 value reflects a higher antioxidant power. Moreover, roasting can generate compounds (melanoidins) that can increase antioxidant activity [31, 32]. However, additional heating or the use of a higher temperature can affect antioxidant power due to degradation of the phenolic compounds [30, 33]. In addition, the binding of phenolic compounds to proteins inhibits their ability to react with free radicals, resulting in a lower percentage of DPPH inhibition [33]. This study reveals the correlation between polyphenols and antioxidant power in the sense that the degradation of polyphenols with temperature favours a reduction in antioxidant activity (Y3). The prediction of antioxidant activity (Y3) as a function of time (A) and temperature (B) is given by equation (6):

$$Y3 = +225.76892 - 1.566 \times A - 1.019 \times B + 0.0058 \times A \times B - 0.006 \times A^2 + 0.002 \times B^2 \quad (6)$$



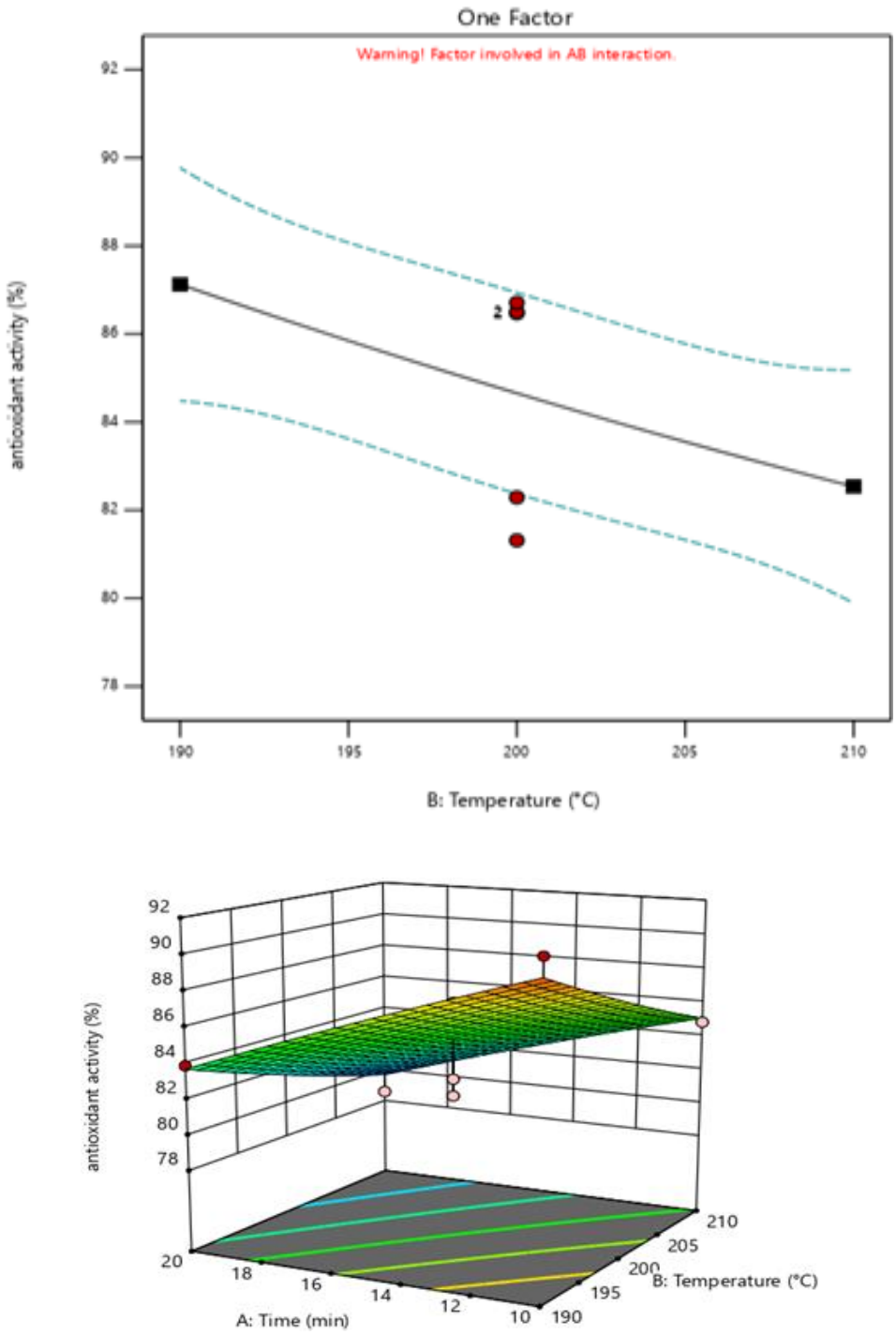


Figure 4. *Antioxidant activity response surface as a function of time and temperature.*

3.5. Optimal Roasting Conditions

In order to produce a high-quality coffee substitute, the following criteria were imposed on the Design Expert software. The production of African locust bean coffee would be optimal provided that the colour difference, polyphenol content and antioxidant activity reached maximum values. Thus, the optimum roasting parameters are 202.544 °C ≈ 203 °C for 11.5373 ≈ 12 minutes. Under these conditions the predicted colour difference, polyphenol content and antioxidant activity would be equal to 49.1899, 73.9493 mg/g and 86.0209% respectively (Figure 4). The predicted values are almost similar to the experimental values for the African locust bean substitute produced at a temperature of 203 ℃ for 12 minutes (colour difference =47.7630, polyphenol content =73.7297 mg/g and antioxidant activity =86.5891%).

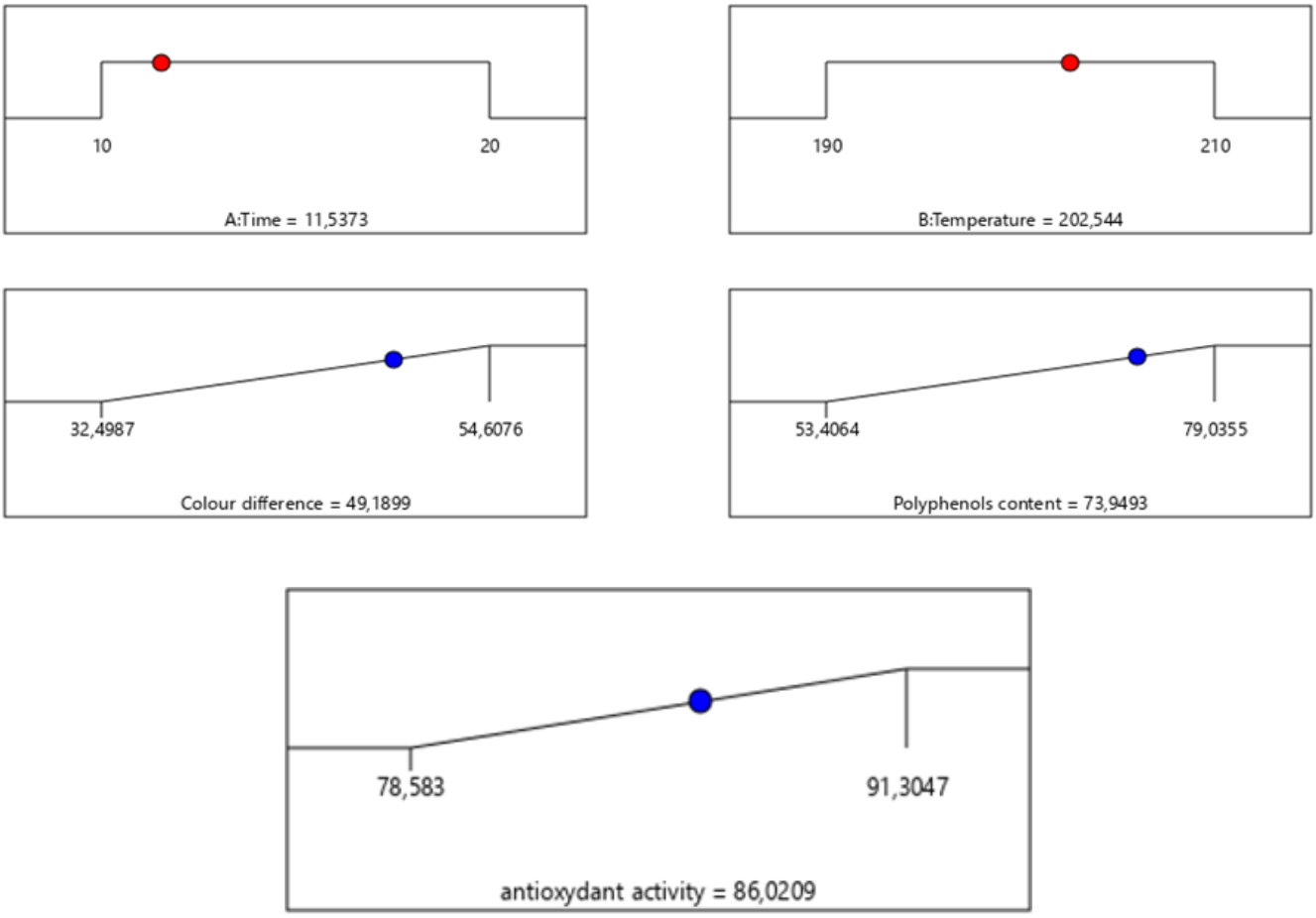


Figure 5. *Prediction of response parameter values for optimum roasting time and temperature.*

4. Conclusion

The aim of this study was to investigate the optimum conditions for roasting *Parkia biglobosa* oilcake for processing into coffee substitutes. The study revealed that time and temperature had a significant effect on colour difference (increase), polyphenol content and antioxidant activity (decrease). The roasting treatment (203 ℃/12 min) was found to produce a superior quality substitute with maximum colour difference, phenolic compound content and DPPH inhibition percentage. In the future, it would be interesting to carry out a sensory analysis, particularly the hedonic test, to assess the degree of appreciation of African locust bean coffee. In addition, determination of the aromatic profile would be necessary for the study aimed at combining African locust bean coffee with another substitute.

Abbreviations

DPPH	2,2-diphenyl 1-pycrilhydrazyl
ANOVA	Analysis of Variance

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Author Contributions

Omar Touré: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Resources, Software, Writing – original draft

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Médoune Gaye Sarr: Data curation, Funding acquisition, Project administration, Resources, Visualization

Edmond Antoine Badock: Data curation, Formal Analysis, Software, Visualization, Writing – original draft

Nicolas Cyrille Ayessou: Supervision, Validation, Visualization, Writing – review & editing

Mady Cissé: Supervision, Validation, Visualization, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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