

Research Article

Optimization of oil extraction from locust bean using response surface methodology

Rahman Akinoso and Akeem Olayemi Raji

Department of Food Technology, Faculty of Technology, University of Ibadan, Nigeria

Optimization of oil extraction from locust beans (*Parkia biglobosa*) using central composite rotatable design of RSM was carried out. Independent variables were roasting temperature (90, 100, 110, 120, 130°C) and roasting duration (5, 10, 15, 20, 25 min), while the responses were oil yield (OY), free fatty acid (FFA), color (CO), stability, anisidine value (AV), and specific gravity (SG). Data obtained from this study were analyzed using ANOVA and regression analysis. OY, FFA, CO, oil stability, AV, and SG of the oil ranged between (19.0–22.5%), (0.65–3.1%), (37.9–199.9 mg/L), (3.6–6.4%), (11.4–59.9 mg/L), (0.7–0.9), respectively. Roasting conditions significantly influenced all dependent variables at $p < 0.05$. Coefficients of determination (R^2) of the generated models ranged from 0.49 to 0.98. Optimum roasting condition was 108°C for 10 min. This gave 22.3% OY, 1.7% FFA, 54.9 mg/L CO, 4.1% stability, 16.5 mg/L AV, and 0.9 SG. Desirability of 0.8 was obtained for optimum conditions.

Practical applications: Generally, African locust bean is fermented to give condiment. It has not been used for commercial oil production despite its richness in oil, but soybean with a similar oil content of about 18–20% has been used both for condiment and commercial oil production. Research into the potential of locust bean as a source of edible oil is desirable. Roasting is among pre-treatment methods employed in vegetable oil industry. Information on degree of influence of these parameters on quantity and quality of oil recovered from African locust benefits both entrepreneur and researchers. Also, the developed mathematical expression for OY, FFA, CO, oil stability, AV, and SG, as influenced by roasting temperature and duration is an effective tool in predicting these parameters. The research output has both immediate and potential application.

Keywords: Locust beans / Oil extraction / Optimization / Predictive models / Roasting

Received: May 18, 2010 / Revised: August 6, 2010 / Accepted: September 13, 2010

DOI: 10.1002/ejlt.201000354

1 Introduction

Oil is an important component of food plant, and found along with other components such as protein, carbohydrate (cellulose, hemicellulose, starch) in plant cell [1]. The oil content of various seeds varies and this serves as a basis for the classification of seeds into oilseeds and non oilseeds. Seeds with oil content greater than 17% are classified as oilseeds (www.attar.org/attr -

pub/PDF/oilseed PDF/ revised May 2004) [2]. Nutritionally, oils obtained from oilseeds provide the calories, vitamins, and essential fatty acid in human diet in an easily digested form and at a relatively low cost.

Separation of oil involves three basic methods which are extraction method, mechanical oil expression, and combination of the two methods. In extraction method, the extraction agent (solvent, aqueous, supercritical CO₂) when brought in contact with the oilseeds dissolves the oil present in the seed. The mixture is separated by evaporation to recover clear oil. The method is most popular in North America, it is highly efficient over 98% oil recovery and a single extractor can handle very large capacity up to 4000 tones *per day* [3].

Pretreatments are conventional methods of preparing oilseeds for oil extraction. These include operations such as grinding, roasting, dehulling, flaking, cooking, or steaming.

Correspondence: Dr. Rahman Akinoso, Department of Food Technology, Faculty of Technology, University of Ibadan, Nigeria

E-mail: akinoso2002@yahoo.com

Fax: +234 802 388 5622

Abbreviations: AV, anisidine value; CO, color; FFA, free fatty acid; FFA_s, oil stability; SG, specific gravity

It is usually carried out to fractionate oil intact bodies in order to enhance the release of oil during extraction [4]. Most oil seeds and nut are heat-treated by roasting to liquefy the oil in the plant cells and facilitate its release during extraction [5].

Locust beans (*Parkia biglobosa*) belong to the leguminous group used in many food dishes as condiment in West Africa [6]. Nutritionally, the seed composed of 17.7% oil, 31.0% crude protein, 35.0%, carbohydrate, and 11.7% crude fiber [7]. This crop has not been used for commercial oil production despite its richness in oil [8]. Therefore, research into the potential of locust bean as a source for commercial oil production is desirable. The objective of this work is to determine the effect of roasting temperature and duration on the yield and quality of locust bean oil using RSM. This methodology reduces the number of experimental runs needed to provide sufficient information for experimentally acceptable result [9].

2 Materials and methods

2.1 Determination of moisture content

Locust beans obtained from a local market (Bodija, Ibadan Nigeria) were manually cleaned and milled into granules. Moisture content of the granules was determined using AOAC [10] method. About 2 g of the granules was placed in Petri dish and heated in an oven at 105°C for 2 h after which it was removed, cooled in glass jar containing silica gel desiccant for about 15 min. Weight of the Petri dish containing the cooled samples was measured using digital weight balance (ED2201-CW, Sartorius, Berlin, Germany). The sample was further dried for 30 min cooled, and reweighed. This procedure was repeated until a constant weight was observed. The experiment was duplicated for accuracy. Moisture content was calculated using Eq. 1.

% moisture content (wet basis)

$$= \left(\frac{\text{weight of water}}{\text{weight of wet product}} \right) \times 100\% \quad (1)$$

2.2 Characterization of the oil

Oil was extracted from un-treated sample of locust bean by soxlet extraction method at 70°C using n-hexane as solvent. Sample of the extracted oil was fractionated by thin-layer chromatographic (TLC model QIG-38, Quark Enterprises Inc. Vineland, NJ) using hexane–ether–acetic acid (80:20:1) as developing agent. The spots were detected with 50% sulfuric acid and identified by comparison with standards. The relative percentage of each spot was measured on a scanning densitometer (Transidyne Model 2955, Transidyne General Corp. Ann. Arbor, Michigan.).

Fatty acid composition of the oil was determined by the method reported by Tahir *et al.* [11]. The fatty acids were converted to their respective methyl esters prior analysis. The oil sample (50 µL) was methylated in 4 mL KOH (1 M) for 1 h at RT. The resultant acid methyl esters (FAME) were extracted with HPLC (model LC-2010, Shimadzu Tokyo, Japan) grade hexane and analyzed by gas chromatograph (model GC-2010, Shimadzu, Japan) immediately using a fused capillary column (WCOT fused silica 30 m × 0.25 mm coating CPWAX 52CBDF = 0.25 µM, CP8713), a FID and nitrogen gas as carrier (3.5 mL/min). Gas Chromatograph split ratio was 100%. Injector and detector temperatures were 260°C and column oven temperature was 222°C for 7.5 min. The FAME peaks were identified by comparing their retention time with those of standards.

2.3 Experimental design

The experimental design employed was central composite rotatable of RSM for a two-variable case as described by Montgomery [12]. Roasting temperature (X_1 : 90, 100, 110, 120, and 130°C) and roasting duration (X_2 : 5, 10, 15, 20, and 25 min) were the independent variables (Table 1), while the responses were oil yield (OY) and oil quality (free fatty acid (FFA), color (CO), oil stability, and anisidine value (AV), and specific gravity (SG)). The choice of levels was influenced by results of experimental trials and literature [13]. Design-expert version 6.0.10 (Stat Ease Minneapolis, MN) software was used for ANOVA, mathematical modeling, regression analysis, and optimization. Optimized conditions were obtained by keeping color in range, minimizing FFA, AV, maximizing stability and OY.

2.4 Heat treatment

Roasting of the seed was done in an oven (model CS-01b, Classic Scientific, Mumbai, India). Temperature stability was achieved by Akinoso [13] method. The granule initial temperature was raised to equilibrium with roasting temperature. This was achieved by wrapping it in polythene bag and placing it in oven at desired roasting temperature level. This sample was later heated by spreading thinly on a heat conductor tray in the oven at a preset temperature for required duration. Stopwatch was used to monitor the time.

2.5 Oil extraction

Each treated sample (100 g) was separately soaked in solvent (n-hexane) at RT ($29 \pm 2^\circ\text{C}$) for 48 h (Table 1). Solvent granules ratio of 2:1 v/w was used as recommended by Ismail and Yee [14]. Oil–solvent solution was separated by evaporation in water bath heated at 70°C. The OY was calculated as the ratio of the weight of the extracted oil to the weight of the raw sample.

Table 1. The experimental design and obtained values of the responses

S/N	Coded		Actual		^{a)} OY (%)	^{a)} SG	^{a)} FFA (%)	^{a)} CO (mg/L)	^{a)} FFA ₅ (%)	^{a)} AV (mg/L)
	X_1	X_2	X_1	X_2						
1	−1.0	−1.0	100.0	10.0	19.5 ± 1.2	0.9 ± 0.1	1.7 ± 1.0	64.3 ± 11.9	3.6 ± 1.3	19.3 ± 3.4
2	1.0	−1.0	120.0	10.0	20.0 ± 2.2	0.8 ± 0.4	0.6 ± 0.1	89.4 ± 21.5	3.7 ± 1.1	26.8 ± 1.2
3	−1.0	1.0	100.0	20.0	20.0 ± 1.13	0.8 ± 0.7	3.1 ± 1.2	45.9 ± 12.7	6.5 ± 2.6	13.8 ± 5.4
4	1.0	1.0	120.0	20.0	20.5 ± 4.0	0.9 ± 0.2	2.5 ± 1.7	199.9 ± 39.4	5.5 ± 1.5	59.9 ± 11.1
5	0.0	1.4	110.0	25.0	21.5 ± 1.1	0.9 ± 0.2	2.3 ± 1.9	199.9 ± 31.9	5.5 ± 3.6	59.9 ± 7.1
6	0.0	−1.4	110.0	5.0	22.5 ± 5.2	0.9 ± 0.1	2.0 ± 0.0	79.0 ± 15.9	3.7 ± 1.7	23.7 ± 7.4
7	1.4	0.0	130.0	15.0	20.5 ± 2.2	0.7 ± 0.1	3.1 ± 1.7	199.9 ± 28.9	5.5 ± 2.7	59.9 ± 15.4
8	−1.4	0.0	90.0	15.0	19.0 ± 3.4	0.9 ± 0.6	1.1 ± 1.1	37.9 ± 21.9	3.8 ± 2.4	11.4 ± 5.1
9	0.0	0.0	110.0	15.0	22.5 ± 1.2	0.9 ± 0.3	2.0 ± 1.5	79.0 ± 17.6	3.7 ± 1.9	23.7 ± 5.4
10	0.0	0.0	110.0	15.0	21.6 ± 1.3	0.9 ± 0.1	1.9 ± 1.7	79.1 ± 21.1	3.0 ± 1.7	23.1 ± 8.6
11	0.0	0.0	110.0	15.0	22.1 ± 1.1	0.9 ± 0.3	1.9 ± 1.0	79.6 ± 16.9	3.4 ± 2.6	23.6 ± 5.3
12	0.0	0.0	110.0	15.0	20.9 ± 2.3	0.8 ± 0.1	2.0 ± 1.3	79.9 ± 22.9	3.7 ± 1.2	22.9 ± 7.4
13	0.0	0.0	110.0	15.0	22.8 ± 3.2	0.9 ± 0.2	1.9 ± 1.2	77.7 ± 14.9	3.6 ± 1.4	23.7 ± 3.7

^{a)} Mean of three replicates.

2.6 Determination of free fatty acid (FFA) content

FFA content was calculated using AOCS method Ca5a – 40 AOCS [15]. Mixture of 1.0 g of oil, 25 mL of diethyl ether, 25 mL of alcohol, and 1 mL of phenolphthalein solution was prepared. The mixture was titrated with aqueous 0.5 N NaOH, vigorously shook until a permanent faint pink color appeared and persisted for 15 s. The percentage of FFA in the sample was calculated as stated below (Eq. 2)

$$\% \text{ FFA} = \frac{\text{Titration(ml)} \times 0.141 \times 100}{\text{Wt of sample used}} \quad (2)$$

2.7 Determination of color (CO)

The CO of the oil was determined using spectrophotometric color method AOCS method Cc 13c – 50 [15]. Mixture of oil and n-hexane was prepared in ratio 1 to 9 mL. This mixture was shaken vigorously, and the absorbance was read at 420 nm on UVIKON XL spectrophotometers (North Star Scientific, Leeds, UK).

2.8 Determination of oil stability (FFA₅)

The stability of the oil was determined using schaal oven test as described by Brien [16]. This method employs heat and aeration to accelerate rancidity of oil and shortens the time required to reach the end point [16]. The oil samples were stored at 70°C for a week in a forced air oven. After a week of storage, FFA analysis was conducted on the samples using AOCS method Ca 5a – 40 [15] as described above. The result obtained was compared with FFA of fresh samples, as it provide index of stability of the oil under use conditions.

2.9 Determination of anisidine value (AV)

The AV of locust bean oil was determined using AOCS method Cd 12-57 [15]. The oil (2 mL) was diluted with 25 mL. n-hexane and absorbance of the solution (Z) was measured as A_1 . About 5 mL of solution (Z) was diluted with 1 mL of p-anisidine solution (2.5 g in glacial acetic acid containing less than 0.1% moisture), its absorbance was recorded as A_2 . AV of the oil was determined using Eq. 3.

$$\text{AV} = 25 \times (1.2A_1 - A_2) \quad (3)$$

2.10 Determination of specific gravity (SG)

This was carried out as described by Pomeranz and Meloan [17]. An empty pycnometer bottle (Q_1), filled with water (Q_2), and oil (Q_3) were weighed separately. The SG of the oil was calculated using mathematical relationship (Eq. 4).

$$\text{SG} = \frac{Q_2 - Q_1}{Q_3 - Q_1} \quad (4)$$

3 Results

3.1 Moisture content

The moisture content of un-treated locust bean granules was determined to be 5.7% wet basis.

3.2 Chemical composition of the oil

The principal components of locust bean oil as determined were triglycerides (68.31%), free sterols (14.76%), sterol esters (11.21%), FFA (2.74%) diglycerides (0.31%), monoglycerides

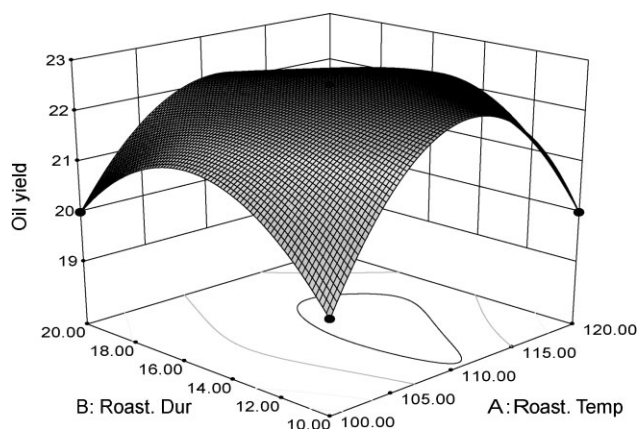


Figure 1. Plot of oil yield against roasting temperature and duration.

(0.30%), tocopherol (0.07). Oleic, linoleic, and palmitic in percentage proportion of 43.14, 17.49, and 15.5 were the main fatty acids contents. Minor fatty acids in the oil include lino-
lenic acid (0.24%), palmitoleic (1.36%), steric (0.16%), capric (0.41%), myristic (0.03%), and arachidi (0.02%).

3.3 Effect of roasting conditions on oil yield (OY)

OY ranged from 19.00 to 22.50% (Table 1), with a mean value of $20.58 \pm 0.95\%$. Responses surface plot of the relationship is shown as Fig. 1. The graph showed a quadratic relationship with peak point at 110°C and 14 min roasting temperature and duration respectively. Equation 5, expressed functional relationship between OY and the independent variables. Roasting temperature ($^{\circ}\text{C}$) and duration (min) were represented by X_1 and X_2 respectively. Lack of fit test for the model was non significant at $p < 0.05$ (Table 2). All the model terms were significant ($p < 0.05$).

$$\text{OY} = 22.50 + 0.38X_1 - 0.31X_2 - 0.69X_1^2 - 0.19X_2^2 + 0.38X_1^2X_2 - 0.13X_1X_2^2 - 1.63X_1^2X_2^2 \quad (5)$$

3.4 Effect of roasting conditions on free fatty acid (FFA)

Recorded FFA ranged from 0.56 to 3.10% (Table. 1) with a mean value of $2.35 \pm 0.67\%$. From the response surface plot

(Fig. 2), it could be seen that the FFA content of the oil increased with increase in roasting temperature and duration. A linear model was used to represent the relationship (Eq. 6). The model satisfied lack of fit test at $p < 0.05$. Roasting temperature was the only significant model term ($p < 0.05$). Coefficient of determination R^2 is 0.49

$$\text{FFA} = -2.83 + 0.04X_1 + 0.06X_2 \quad (6)$$

3.5 Effect of roasting conditions on color (CO)

The intensity of color obtained ranged from 37.90 to 199.90 mg/L (Table 1) with a mean value of 135.34 ± 73.83 mg/L. Response surface plot was shown as Fig. 3. Color intensity increased with both treatments. A linear model (Eq. 7) best described the relationship between color of oil as affected by heat treatment of locust of locust bean. All the model terms were significant, and the model satisfied lack of fit test at $p < 0.05$.

$$\text{CO} = 1835.21 - 26.50X_1 - 76.86X_2 + 0.64X_1X_2 + 0.09X_1^2 + 0.42X_2^2 \quad (7)$$

3.6 Effect of roasting conditions on oil stability (FFA₅)

Mean value of stability test was $4.92 \pm 0.92\%$. Stability of the oil decreased with increase in the roasting temperature and duration (Fig. 4). Locust oil with high stability was obtained at 105°C for 14 min. ANOVA (ANOVA) revealed a significant effect ($p < 0.05$) in linear relationship (Table 2). Coefficient of determination R^2 of the model was 0.61 (Eq. 8). Lack of fit test at 95% confidence level for the predictive model was non-significant.

$$\text{FFA}_5 = +0.82 + 0.02X_1 + 0.14X_2 \quad (8)$$

3.7 Effect of roasting conditions on anisidines Value (AV)

AVs obtained ranged from 11.37 to 59.97 mg/L with a mean value of 40.60 ± 22.15 mg/L. From Fig. 5, it could be seen

Table 2. Summary of Analysis of Variance for response surface models

Parameter	Sum of square	df	Mean square	F value	p-value
OY (%)	10.92	12	81.37	6.36×10^7	0.0001
FFA (%)	4.27	12	2.13	4.80	0.0345
CO (mg/L)	64673.91	12	12934.70	121.75	0.0001
FFA ₅ (%)	6.27	12	3.14	7.96	0.0086
AV (mg/L)	5819.74	12	1163.95	122.03	0.0010
SG	0.07	12	0.01	20.88	0.0040

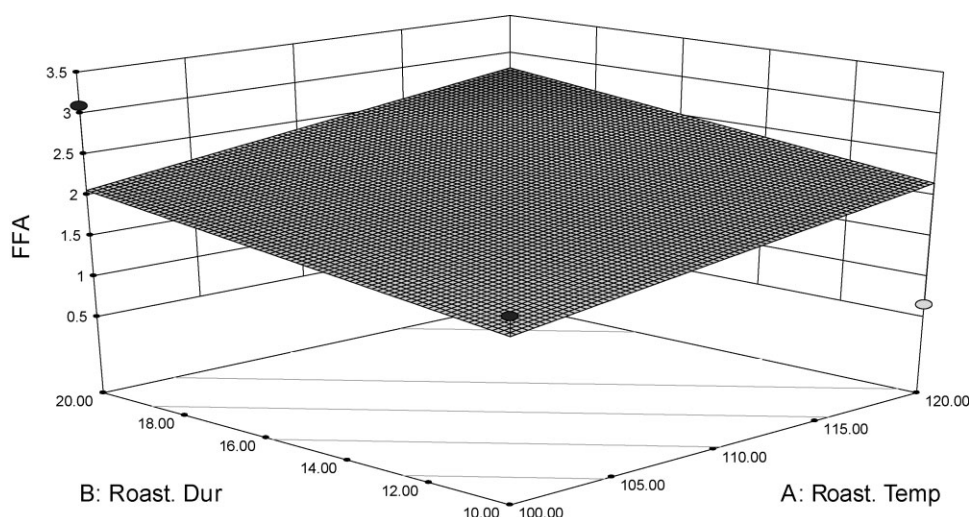


Figure 2. Plot of oil FFA against roasting temperature and duration.

that AV of the oil increased with both roasting temperature and duration. Quadratic model was found appropriate to express the relationship (Eq. 9). The model has high coefficient of determination R^2 (0.98) and satisfied lack of fit test at $p < 0.05$.

$$\begin{aligned} \text{AV} = & 550.34 - 7.95X_1 - 23.05X_2 + 0.19X_1X_2 \\ & + 0.03X_1^2 + 0.13X_2^2 \end{aligned} \quad (9)$$

found to be significant at 5% level of significance (Table 2). From Fig. 6, the SG showed a quadratic effect with 18 min roasting duration and 115°C roasting temperature as saddle points. Further increase in roasting temperature and duration resulted in lower values. A quadratic model for the relationship is Eq. 10. Coefficient of determination R^2 is 0.93.

$$\begin{aligned} \text{SG} = & -0.22 + 0.07X_1 - 0.10X_2 + 8.5 \\ & \times 10^{-4}X_1^2 - 2.35 \times 10^{-4}X_1^2 + 5.13 \times 10^{-5}X_2^2 \end{aligned} \quad (10)$$

3.8 Effect of roasting condition on specific gravity (SG)

The SG of oil is directly related to the relative density and it is very important in determining the quality of oil and efficiency of the extraction procedures. Recorded SG ranged from 0.71 to 0.90 with a mean value of 0.86 ± 0.08 . Treatment effect was

4 Discussion

4.1 Moisture content

The moisture content of the seed is within the recommended moisture content range (2.9–6.2% wet basis) for obtaining

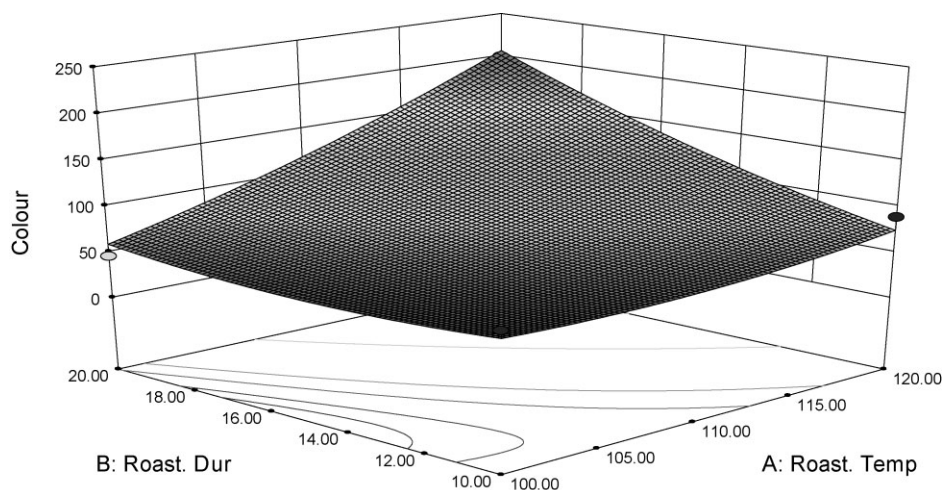


Figure 3. Plot of oil color against roasting temperature and duration.

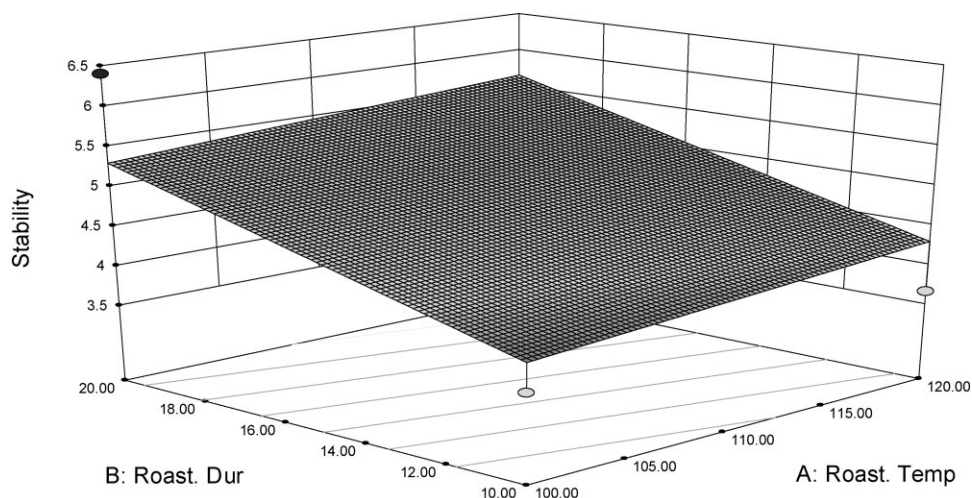


Figure 4. Plot of oil stability against roasting temperature and duration.

high yield and good quality oil from oil seeds [13]. Therefore, results of this experiment are not likely to be badly influenced by moisture content of the raw material.

4.2 Fatty acid composition

The key to understand the chemical and physical characteristics of a fat is the understanding of the component of fatty acids that comprise the triglyceride. High proportion oleic and linoleic in locust bean oil is indication of high level of unsaturation. That is fatty acids of the oil are likely to be chemically reactive. It should be noted that fatty acid compositions of oils is affected by species, genetics, variety, growing conditions, locality, climatic conditions, and post harvest treatment [18].

4.3 Effect of roasting conditions on OY (OY)

The treatment boost oil recovered by 1.3–4.8% in comparison with 17.7% oil content of un-roasted locust beans reported by Omafuvbe *et al.* [7]. Similar observation was reported by Kumar *et al.* [4] for pulsed IR roasting of groundnut under different roasting temperature and duration. They started that roasting enhanced the release of groundnut oil by 0.83–8.09%, depending on the roasting temperature (160–200°C) and duration (5.2–12.0 min) level combinations. Increase in oil recovered can be attributed to fractionating of intact oil bodies and rupturing of cellular structure as a result of heating.

Case hardening noticed at higher roasting temperature and duration during the experiment might hindered oil flow,

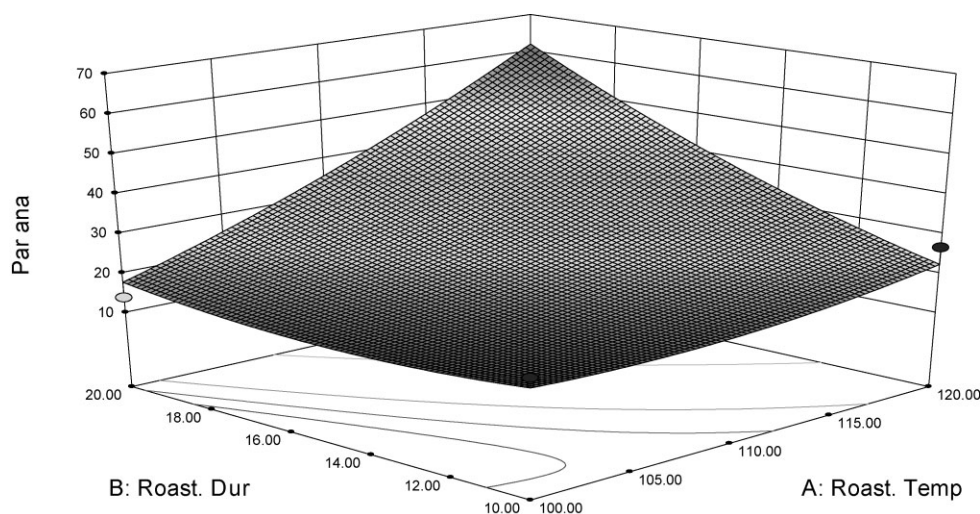


Figure 5. Plot of oil anisidine value against roasting temperature and duration.

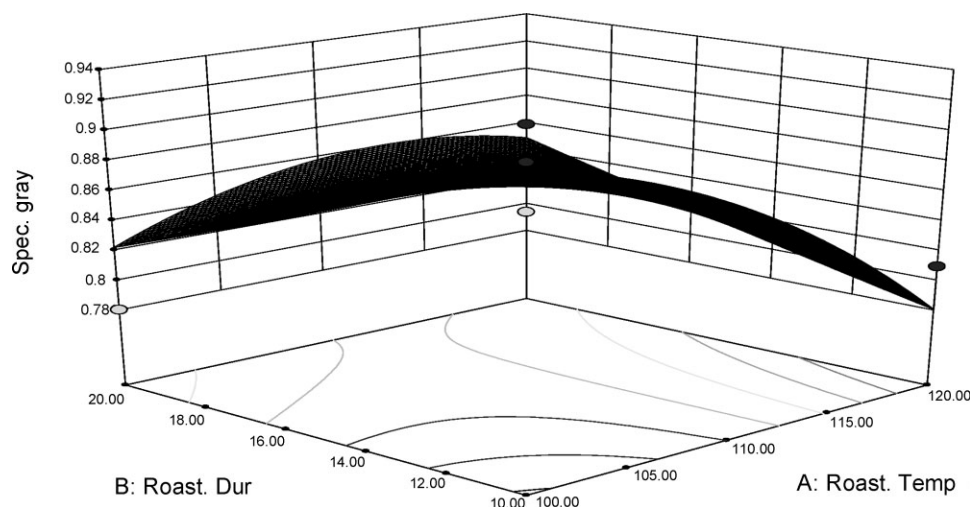


Figure 6. Plot of oil specific gravity against roasting temperature and duration.

thus the shape of plot. High coefficient of determination R^2 (0.98) of the model is an indication of good fit. Therefore, it can be applied to predict OY as affected by roasting temperature and duration with minimum error.

4.4 Effect of roasting conditions on free fatty acid (FFA)

FFA is formed due to the hydrolysis of triglycerides and is responsible for off flavor development during storage. In appropriate conditions such as high temperature, moisture, and presence of active lipase are responsible for the formation of FFA in fat containing raw materials or oils [4]. Moisture content and lipase activity in the oilseed could be controlled by thermal process such as roasting [3]. Increase in FFA content of the oil with increase in roasting temperature and duration may be due thermal oxidative decomposition of oil during roasting.

4.5 Effect of roasting conditions on color (CO)

The spectrophotometer used to determine oil CO, measured the CO of the oil samples by relating the intensity to the amount of radiation absorbed by the oil samples. This was possible, because there was a direct relationship between the CO intensity and absorbance using Beer's law [19]. Thus, the color intensity may be an indicator for the presence of carotenoids.

Response surface plot is shown in Fig. 3. CO intensity increased with both treatments. Hafez *et al.* [20] also reported increase in CO intensity of roasted soybeans similar to Fig. 3. The increase in absorbance with an increase in roasting temperature and duration could be attributed to color formation by both non enzymic browning reaction and phospholipids degradation during roasting process [21]. Akinoso *et al.* [3] also traced increase in absorbance

of thermally treated oils to the formation of conjugated dienes and trienes which transform into polymer compounds with increase in roasting temperature. High coefficient of determination R^2 (0.99) indicated that the model had a good fit.

4.6 Effect of roasting conditions on oil stability (FFA₅)

Recorded mean FFA after 5 days storage is an increment of 96.3% on initial FFA. Low stability could be attributed to thermal oxidative decomposition. At 95% confidence level, the non significance of lack of fit test was an indication that the model could be applied with little error.

4.7 Effect of roasting conditions on anisidines value (AV)

The AV measures the secondary oxidation or the past history of an oil, and therefore useful in determining the quality of crude oil and efficiency of process procedures [16]. Trend of the plot (Fig. 5) might due to thermal oxidative transformation of free radicals, which initiated the degradation of unsaturated fat producing volatile compound [22].

4.8 Effect of roasting condition on specific gravity (SG)

The SG of oil is directly related to the relative density and it is very important in determining the quality of oil and efficiency of the extraction procedures. The SG recorded in this study is within the range of some edible oils such rapeseed oil, 0.906–0.914 and sunflower oil, 0.894–0.899 [23]. The physical characteristics of fat or oil are dependent upon the degree of unsaturation, the carbon chain length, the isometric fatty acid forms, and the molecular configuration [16]. Significant influence of treatments on the oil SG may be traced to

thermal decomposition of fatty acid bond. Structural variations affect chemical and physical properties of a fatty acid and the resulting triglyceride [24]. Coefficient of determination R^2 (0.93) suggests that the model is adequate to navigate the design space.

5 Conclusions

The results obtained in this study revealed that locust bean is a potential source of vegetable oil. Roasting duration and temperature combinations influenced both OY and quality significantly at 95% confidence level. Predictive models were developed for locust bean OY, FFA, CO, oil stability, AV, and SG, as influenced by roasting temperature and duration. The models had good fits. Three possible optimum solutions were found with desirability ranging from 0.787 to 0.783. The best of the three conditions was roasting at 108.12°C for 10 min which gave 22.29% OY, 1.74% FFA, 54.96 mg/L CO, 4.10% stability, 16.49 mg/L AV, and 0.89 SG. This treatment has desirability of 0.79, a close value to 1. The optimum condition produced a relatively high OY with acceptable color and good storage stability.

The authors have declared no conflict of interest.

References

- [1] Dominguez, H., Sineiro, J., Nunez, M. J., Lema, J. M., Enzymatic treatment of sunflower kernels before oil extraction. *Food Res. Int.* 1996, 28, 537–545.
- [2] Bachman, J., Oilseeds processing for small scale producer. NCAT Agriculture Specialist USA.
- [3] Akinoso, R., Igbeka, J. C., Olayanju, T. M. A., Predictive models for palm kernel (*Elaeis guineensis*) and Sesame (*Sesamum indicum*) oil color. *J. Appl. Sci. Eng. Technol.* 2006, 6, 34–38.
- [4] Kumar, S., Debnath, S., Hebbar, U. H., Pulsed infrared roasting of groundnuts and its quality. *Int. J. Food Eng.* 2009, 5, 1–15.
- [5] Cammerer, B., Kroh, L. W., Shelf life of linseeds and peanuts in relation to roasting. *Food Sci. Technol.* 2009, 42, 545–549.
- [6] Awogbemi, O., Ogunleye, I. O., Effect of quantity of salt and drying on the quality of locust beans. *J. Eng. Appl. Sci.* 2008, 3, 261–265.
- [7] Omafuvbe, B. O., Falade, O. S., Osuntogun, B. A., Adewusi, S. R., Chemical and biochemical changes in African locust bean (*Parkia biglobosa*) and melon (*Citrullus vulgaris*) seeds during fermentation to condiments. *Pak. J. Nutr.* 2004, 3, 140–148.
- [8] Kashyap, M. C., Agrawal, Y. C., Ghosh, P. K., Jayas, D. S., *et al.* Enzymatic hydrolysis pretreatment to solvent extraction of soybrokens for enhanced oil availability and extractability. *J. Food Proc. Eng.* 2006, 29, 664–674.
- [9] Lee, W. C., Yusuf, S., Hamid, N. S. A., Baharin, B. S., Optimizing conditions for hot water extraction of banana juice using Response Surface Methodology (RSM), *J. Food Eng.* 2006, 75, 473–479.
- [10] AOAC International. *Official Methods of Analysis*, 18th Edn. Association of Official Analytical Chemists, Gaithersburg, MD, USA 2007.
- [11] Tahira, R., Rehman, A., Butt, M. A., Characterization of rice bran oil. *J. Agric. Res.* 2007, 45, 225–230.
- [12] Montgomery, D. C., *Design and Analysis of Experiments: Response Surface Method and Designs*, John Wiley and Sons, Inc., New Jersey, USA 2005.
- [13] Akinoso, R., *Ph. D. Thesis*, University of Ibadan, Nigeria 2006.
- [14] Ismail, A., Yee, C. L., Antioxidative effect of extracts of cocoa shell, roselle seeds, and a combination of both extracts on the susceptibility of cooked beef to lipid oxidation. *J. Food Technol.* 2006, 4, 10–15.
- [15] AOCS, Official methods and recommended practices of the American Oil Chemists Society, American Oil Chemist Society (Champaign) 1997.
- [16] Brien, O. O., *Fats and Oils Formulating and Processing for Application*, Technical Publishing Company Inc, Lancaster, USA 2008, pp. 183–223.
- [17] Pomeranz, Y., Meloan, C. F., *Food Analysis: Theory and Practical*, Van Nostrand Reinhold, New York, USA 1987, pp. 424–441.
- [18] Gulfranz, M., Kasuar, R., Arshad, G., Mehmood, S., *et al.* Isolation and characterization of edible oil from wild olive. *Afr. J. Biotechnol.* 2009, 8, 3734–3738.
- [19] Ibanoglu, E., Kinetic study on color changes in wheat germ due to heat. *J. Food Eng.* 2002, 51, 209–213.
- [20] Hafez, S. Y., Mohammed, A. I., Perera, P. A., Singh, G., Hussein, A. S., Effect of microwave heating and gamma irradiation on phytate and phospholipids content of soybean (Glycine Max. L.). *J. Food Sci.* 2006, 54, 958–962.
- [21] Mohagir, A. M., Kamga, R., Kapseu, C., Abi, C. F., Optimization of some pre-treatments involved in the press extraction of Shea (*Vitellaria paradoxa* Gaertner F.) butter. *Asian J. Appl. Sci.* 2009, 2, 372–384.
- [22] Wang, J. W., Hashimoto, K., Shibamoto, T., Antioxidant activities of rosemary, sage extracts and vitamin E in a model meat system. *J. Agric. Food Chem.* 1995, 43, 2702–2712.
- [23] Salunkhe, D. K., *World Oilseeds Chemistry, Technology and Utilization*, Chapman and Hall, London, UK 1992.
- [24] Saastamoinen, M., Kumpulainen, J., Nummela, S., Häkkinen, U., Effect of temperature on oil content and fatty acid composition of oat grains. *Acta Agric. Scand.* 1990, 40, 349–356.