



Optimization of Roasting Assisted Oil Extraction from Tiger Nut Using Response Surface Methodology

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Abstract

Purpose Tiger nut is a lesser known oilseed which possesses a golden colour and a nutty aroma oil with good oxidative stability. However, literature is sparse on its oil extraction enhancement using adaptable roasting technique.

Methods Tiger nuts (*Cyperus esculentus*) were subjected to different roasting conditions prior to solvent oil extraction, with the objective of determining the optimal roasting condition by applying response surface methodology (RSM). The roasting temperature (120–160 °C) and roasting duration (20–60 min) were the independent variables, while the oil-yield, free fatty acid, specific gravity, iodine value, oxidative stability, peroxide value, para-anisidine value and colour were the responses. Data obtained were analyzed using ANOVA.

Results The responses ranged as follow: oil-yield (18.56–23.80%), free fatty acid (0.06–0.16%), specific gravity (0.84–0.89 g/cm³), iodine value (0.51–1.54 i.v/wijs), oxidative stability (2.47– 6.13%), para-anisidine (0.74 -1.62 mg/L), peroxide value (1.23–3.07 meq/kg) and colour (3.44–24.04 mg/I). The responses were influenced at $p < 0.05$ by the roasting conditions. The generated models' coefficients of determination (R^2) ranged from 0.52–0.95.

Conclusions The overlay plots of the eight responses indicated that roasting at 130 °C for 53 min would produce optimum oil-yield (23.09%) and acceptable quality characteristics (FFA; 0.10%, specific gravity; 0.89 g/cm³, iodine value; 0.77 i.v/wijs, oxidative stability; 3.58%, Para-anisidine; 1.00 mg/l, Peroxide value; 1.33 meq/kg and colour; 17.16 mg/I).

Keywords Tiger nut · Roasting · Oil extraction · Optimization · Response surface methodology

Abbreviations

Y	The response variables,
β	The independent variables
M_o	Mass of oil in gram
M_g	Mass of dry sample
Y_{yield}	Oil yield in percentage
FFA	Free fatty acid
PCI	Photometric colour index
A	Absorbance
PAV	Para-anisidine value
W_1	Weight of the empty bottle
W_2	Weight of the bottle and sample
W_3	Weight of the bottle and water
X_1	Roasting temperature

X_2	Roasting duration
PV	Peroxide value

1 Background

An important constituent of food plant is oil and can exist along with other constituents such as carbohydrate and protein in plant cell [1]. Seeds oil contents vary and this is serving as a basis for regarding some seeds as oilseeds and non-oilseeds. Seeds having oil content greater than 17% are regarded as oilseeds [2].

Oilseeds are part of the most important components of modern agriculture. Nutritionally, they provide calories, vitamins and essential fatty acids in the human diet, while cake obtained after oil extraction is a good source of protein for animal feeds [3]. Oils extracted from some seeds may contain poisons and unpleasant flavors, hence such oils are inedible [4]. However, edible oils are obtained from plants and animal and they are free from poisons and unpleasant flavors [5]. Oils extracted from plants are regarded as

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vegetable oils, and can be largely obtained from soybeans, corn, cottonseed, groundnut, sunflower, rapeseed, melon, sesame seed olive, coconut, shear, cashew and palm [6, 7].

Tiger nut (*Cyperus esculentus*) is an emergent grass-like plant that is commonly grown in the tropical region [8], which possesses high content of soluble glucose and oleic acid, along with high energy content (starch, fats, sugars and proteins), it is rich in phosphorous, potassium, calcium, magnesium, iron, vitamins E and C [9, 10]. Its natural vitamin E is more than 56% [11]. It has high oleic acid, low polyunsaturated fatty acid and low acidity which made it suitable for the nourishment of the body [12].

Tiger nut oil has been reported to possess a golden colour and a nutty aroma, which make it an ideal oil for different uses in cosmetic and domestic applications [13]. Its exceptional resistant to chemical decomposition at high temperature and low absorption than other frying oils makes it a good candidate for deep frying [14]. Also, its good oxidative stability makes it to compete favourably with olive oil, corn oil, soybean oil and cottonseed oil and can thus serve their substitute especially in time of scarcity [15].

Pretreatments are conventional methods which are necessary for preparing oil bearing seeds for extraction of oil [16, 17]. They are usually carried out for oil intact bodies fractionation, thereby promoting the release of oil from oilseeds during extraction [16]. However, several works had been carried out on enhancement of oil extraction from tiger nut. Ezech et al. [18] reported on enzymatic pretreatment effect on tiger nut oil extraction, Lasekan and Abdulkarim [19] worked on super critical CO₂ enhancement of oil extraction from tiger nut, Koubaa et al. [20] researched on gas assisted extraction of oil from tiger nut. Worthily, literature is sparse on roasting assisted oil extraction from tiger nut, despite its affordability and adaptability. Therefore research into roasting assisted oil extraction of tiger nut is desirable.

2 Materials and Methods

2.1 Material

2.1.1 Collection of Sample

Tiger nuts were purchased from Oja Oba market in Ilorin, Kwara state, Nigeria.

2.1.2 Preparation of Sample

Tiger nuts obtained were sorted and winnowed to remove dirt and stones. The dirt-free tiger nuts were dried for two hours and roasted at different roasting regimes described in

Table 1 Roasting temperature and duration level combinations for tiger nut oil extraction

Treatment	Coded X ₁	Coded X ₂	Actual X ₁	Actual X ₂
1	− 1	− 1	130	30
2	1	− 1	150	30
3	− 1	1	130	50
4	1	1	150	50
5	0	2	140	60
6	0	− 2	140	20
7	2	0	160	40
8	− 2	0	120	40
9	0	0	140	40

Table 1 (roasting temperature and time combinations), after which they were milled into finely divided granules.

2.2 Methods

2.2.1 Design of Experiment

The experimental design that was employed was response surface methodology using the central composite rotatable design techniques, as it emphasizes on the optimization of a process or a system [21, 22]. Response surface methodology is advantageous as it reduces the number of experimental runs needed to obtain sufficient information for experimentally acceptable result [23].

The roasting temperature (X₁: 100–160 °C) and roasting duration (X₂: 20–60 min) as shown in Table 1 were the independent variables, while oil-yield and oil quality (specific gravity, free fatty acid, colour, oxidation stability, para anisidine peroxide value, iodine value) were the response variables. However, the mathematical model equation described below represented the independent variables and the response variables:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{22} X_2^2 + \beta_{12} X_1^2 + \beta_{12} X_1 X_2 \quad (1)$$

where Y = the response variables, β = the independent variables.

Furthermore, the software that was used for statistical analysis (ANOVA), regression constants and graphical optimization was design expert version 6.0.10 (stat Ease Minneapolis, Minn). Also, the coefficient of determination (R²) was used to establish the fitness of the models.

2.3 Moisture Content Determination

The tiger nut granules moisture content was determined using AOAC [24] method.

2.4 Roasting of Samples

Exactly 180 g of each finely divided tiger nut was subjected to roasting at different roasting temperature and duration level as described in Table 1,

2.5 Solvent Extraction

Oil extraction from roasted tiger nut samples was carried out using direct cold hexane extraction method, following Ismael and Yee [25] procedure and modified as follows:

After roasting, each milled sample was soaked immediately in 360 ml hexane. It was vigorously stirred for 15 min to facilitate oil extraction and thereafter it was allowed to stand for 48 h. The oil extracted was collected and 180 ml of fresh n-hexane was used to wash the cake. Whitman filter paper no 4 was used to filter both the extract and washing into a beaker before evaporating the solvent in a solvent extractor at 70 °C. After evaporation, the beaker was weighed so as to evaluate the percentage of oil present in the sample.

2.6 Oil Yield

The oil yield from the roasted tiger nut sample was evaluated as the ratio of the weight of the extracted oil to the weight of the milled sample.

$$Y_{\text{yield}} = \frac{M_o(\text{g}) \times 100}{M_g(\text{g})} \quad (2)$$

M_o = mass of oil in gram

M_g = mass of dry sample

Y_{yield} = oil yield in percentage

2.7 Oil Quality

The oil quality was established by determining the parameters described below.

2.7.1 Determination of Free Fatty Acid Content

The free fatty acid (FFA) was carried out using the alkaline titration method, following Pike [26] procedure. A milliliter of the sample was mixed with 50mls of neutral solvent containing 1:1 (v/v) mixture of ethanol and di-ethylether. A few drops of phenolphthalein indicator solution was introduced into the mixture and it was titrated against 0.1N Sodium Hydroxide (NaOH) solution. Titration was stopped when a pink end point colour which persisted for more than 15 seconds occurred. FFA was expressed as shown below:

$$\% \text{ FFA} = \frac{\text{Titration (ml)} \times 0.141 \times 100}{\text{Weight of sample used}} \quad (3)$$

2.7.2 Determination of Photometric Colour Index

The photometric colour index (pci) was calculated following the method described by Pike [26]. Exactly 1 ml of oil was dissolved in 20 ml of hexane. The absorbance at the following wavelengths: 400, 550, 620 and 670 nm was read using a spectrophotometer (T80 +, PG Instruments, England). The blank was the solvent. Photometric colour index was expressed as shown in Eq. 4.

$$\text{Pci} = 1.29 \times (A_{400}) + 69.70 \times (A_{500}) + 41.20 \times (A_{620}) - 56.41 \times (A_{670}) \quad (4)$$

where, A is the absorbance.

2.7.3 Determination of Oxidative Stability

The oxidative stability of oil was calculated using schaal oven test as described by O'Brien [27]. The heat and aeration method was employed to accelerate rancidity of oil and shortened the time required to reach the end point. Each oil sample was stored at 70 °C for a week in a forced air oven. Thereafter, free fatty acid analysis was carried out on the sample as described above. The storage stability index of the oil under use conditions was determined by comparing the result obtained with the free fatty acid of fresh samples.

2.7.4 Determination of Para-Anisidine

Para-anisidine values (PAV) of the oil samples was determined following AOCS [28] method. Five milliliter of oil sample was mixed with 25 mL iso-octane. The solution's (Ab) absorbance at 350 nm was measured using iso-octane as the reagent blank. Five milliliter from the above solution and 5 mL of iso-octane were kept in separate test tubes which were further mixed with 1 mL of p-anisidine reagent (2.5% w/v in acetic acid). The absorbance of the sample solution (As) against the blank was measured after 10 min at 350 nm using a UV-VIS spectrophotometer (UV-1800 Shimadzu, Kyoto Japan). The p-anisidine values for the oil samples were calculated following the equation stated below:

Calculation

$$\text{P.A.V} = \frac{25 \times (1.2A_1 - A_2)}{\text{MI}} \quad (5)$$

2.7.5 Determination of Specific Gravity

The specific gravity was carried out following Pomerai and Meleon [29] method. A weighed pycnometer bottle was filled with water and reweighed. Also, oil was poured into a clean bottle and weighed. The specific gravity was expressed as:

$$\text{Specific gravity} = \frac{W_2 - W_1}{W_3 - W_1} \quad (6)$$

where W_1 = weight of the empty bottle
 W_2 = weight of the bottle and sample
 W_3 = weight of the bottle and water

2.7.6 Determination of Iodine Value

The Wiji's titrimetric method as described by Pike [26] was used. Exactly 5 ml of the sample was mixed with 10mls of carbon tetrachloride (CCl_4) in a conical flask. Twenty millimeters (20 mls) of Wiji's Iodine solution was added to it and it vigorously mixed. The solution was allowed to stand in a dark cupboard at room temperature for 30 min. Thereafter, 20mls of 10% potassium iodide solution was introduced into it followed by 100mls of distilled water. About 2mls of 1% starch indicator was also added before it was titrated against 0.1 M sodium thiosulphate solution until the characteristic iodine colour disappears. Meanwhile, a reagent blank was prepared with 10mls of the carbon tetrachloride above and titrated as well.

2.7.7 Determination of Peroxide Value

The peroxide value was determined by thiosulphate titration method as described by Onwuka [30]. One milliliter of the sample (oil) was introduced into a mixed solvent containing Chloroform and Acetic Acid in 2:1 ratio (v/v). The mixture was heated under reflux for 60 s and 20 millimeters of 5% Potassium iodide solution was added followed by 50 mls of distilled water. The mixture was titrated against 0.002 N Sodium thiosulphate solution using 2 mls of 1% starch solution as indicator, until a clear colour of the mixture was observed. The peroxide value (PV) was calculated.

3 Results and Discussion

3.1 Results

The moisture content of the unroasted tiger nut was established to be 5.23% wet basis.

The oil yield obtained varied from 18.56 to 23.80% (Table 2), with a mean value of $22.08 \pm 0.50\%$.

From the response surface plot in Fig. 1, it could be deduced that the oil yield increased when the roasting temperature was kept at 130 °C for 30–50 min. However, the ANOVA for oil yield response surface model was tested for its adequacy using lack of fit test at 95% confidence level. The linear effect was insignificant, but significant at the quadratic term (Eq. 7). Higher value of the coefficient of determination ($R^2 = 0.95$) indicated that the model had a good fit.

Table 2 Properties of extracted roasted tiger nut oil samples

Roasting temperature (°C)	Duration (min)	Oil yield (%)	Iodine value (i.v/wijs)	Free fatty acid (%)	Oxidative stability (%)	Peroxide value (meq/kg)	Specific gravity (g/cm ³)	Colour (mg/l)	Para-anisidine value (mg/L)
160.00	40.00	18.51 ^e ± 0.16	1.54 ^a ± 0.24	0.08 ^{de} ± 0.00	3.80 ^{cd} ± 0.00	1.90 ^{cd} ± 0.00	0.85 ^e ± 0.00	8.66 ^e ± 0.51	1.04 ^d ± 0.00
140.00	60.00	20.40 ^{cde} ± 0.25	1.06 ^b ± 0.73	0.06 ^e ± 0.00	4.37 ^{bcd} ± 0.12	2.18 ^{bcd} ± 0.06	0.85 ^e ± 0.00	19.83 ^b ± 0.42	1.18 ^c ± 0.01
140.00	20.00	21.53 ^{bcd} ± 1.33	1.02 ^{bc} ± 0.13	0.08 ^{de} ± 0.00	4.63 ^{bc} ± 0.29	2.32 ^{bc} ± 0.14	0.89 ^a ± 0.00	24.04 ^a ± 0.67	1.30 ^b ± 0.02
120.00	40.00	21.50 ^{bcd} ± 0.50	0.91 ^{bc} ± 0.97	0.09 ^{cd} ± 0.01	4.73 ^{bc} ± 0.21	2.37 ^{bc} ± 0.10	0.89 ^a ± 0.00	3.72 ^f ± 0.30	1.32 ^b ± 0.02
150.00	50.00	19.60 ^{de} ± 0.50	0.89 ^{bc} ± 0.13	0.13 ^{abc} ± 0.01	4.83 ^{bc} ± 0.076	2.42 ^{bc} ± 0.29	0.83 ^g ± 0.00	3.44 ^f ± 0.22	1.32 ^b ± 0.16
140.00	40.00	23.50 ^{ab} ± 1.00	0.76 ^{cd} ± 0.12	0.16 ^a ± 0.02	2.47 ^e ± 0.58	1.23 ^e ± 0.29	0.88 ^b ± 0.00	15.36 ^{cd} ± 0.68	0.74 ^e ± 0.05
130.00	30.00	22.43 ^{abc} ± 0.51	0.55 ^{de} ± 0.73	0.12 ^{bcd} ± 0.01	5.47 ^{ab} ± 0.58	2.73 ^{ab} ± 0.29	0.86 ^d ± 0.00	13.98 ^d ± 0.52	1.56 ^a ± 0.05
130.00	50.00	23.80 ^a ± 0.20	0.51 ^{de} ± 0.13	0.13 ^{ab} ± 0.02	3.47 ^{de} ± 0.58	1.73 ^{de} ± 0.29	0.87 ^c ± 0.00	14.65 ^d ± 0.66	1.01 ^d ± 0.05
150.00	30.00	22.10 ^{abc} ± 1.31	0.37 ^e ± 0.12	0.10 ^{bcd} ± 0.02	6.13 ^a ± 0.58	3.07 ^a ± 0.29	0.84 ^f ± 0.00	16.33 ^c ± 0.89	1.61 ^a ± 0.05

Average means scores with the same alphabet in the same column are not significantly different, $p = 0.05$

Oil Yield
X = A: Roasting Temperature
Y = B: Roasting Duration

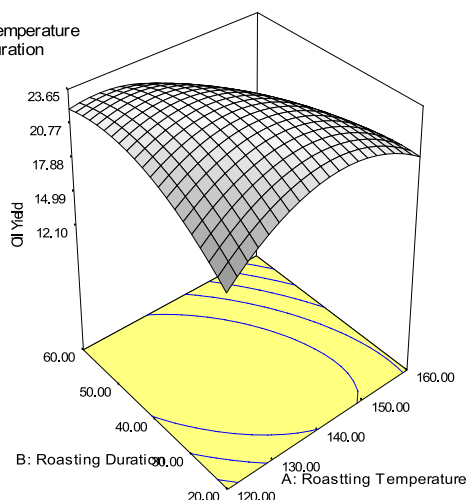


Fig. 1 Variation in oil yield values of tiger nut oil with roasting temperature and duration

$$\begin{aligned} \text{Oil yield} = & -185.85868 + 2.66309X_1 + 1.49910X_2 \\ & - 8.73664 \times 10^3 X_1^2 - 5.56164 \times 10^3 X_2^2 \\ & - 7.75000 \times 10^3 X_1 X_2 \end{aligned} \quad (7)$$

X_1 = Roasting Temperature X_2 = Roasting Duration.

The free fatty acid values obtained ranged from 0.06 to 0.16% (Table 2), with a mean value of $0.12 \pm 0.010\%$. Tiger nut oil with the highest free fatty acid content was obtained at 140°C for 40 min, while tiger nut with the lowest free fatty acid content was observed at 140°C for 60 min (Fig. 2). The linear quadratic model was the best to establish

Free Fatty Acid
X = A: Roasting Temperature
Y = B: Roasting Duration

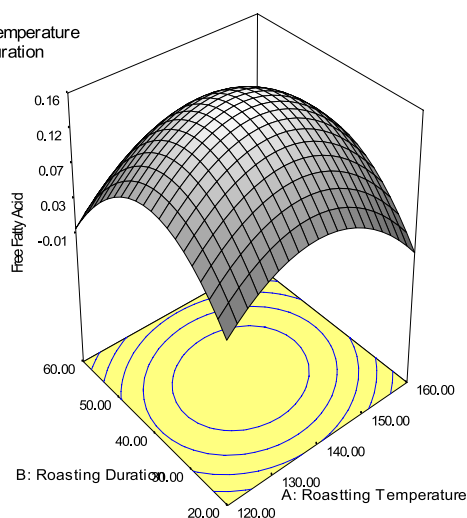


Fig. 2 Variation in free fatty acid values of tiger nut oil with roasting temperature and duration

the relationship between the tiger nut roasting conditions and FFA (Eq. 8), and it had a good fit ($R^2 = 95\%$).

$$\begin{aligned} \text{Free Fatty Acid} = & -3.47 + 0.05X_1 + 0.01X_2 - 1.76 \times 10^4 X_1^2 \\ & - 2.23 \times 10^4 X_2^2 + 2.35 \times 10^5 X_1 X_2 \end{aligned} \quad (8)$$

The intensity of colour reported varied from 3.44–24.04 mg/L (Table 2) with a mean value of 13.96 ± 2.96 mg/L. Lowest value was observed in a sample that was roasted at 150°C for 50 min, while highest value was obtained from a sample that was roasted at 140°C for 20 min (Fig. 3). However, the ANOVA for response surface model for colour was reportedly tested for its adequacy using lack of fit test at 95% confidence level. The linear effect was not significant, but significant at the quadratic term ($P \leq 0.05$). Higher value of the coefficient of determination ($R^2 = 0.8451$) indicated that the model had a good fit. The predictive equation stated below expressed the influence of roasting conditions on the colour.

$$\text{Colour} = -601.69 + 7.90X_1 + 3.30X_2 - 0.023X_1^2 + 0.02X_2^2 \quad (9)$$

The oxidative stability of oil samples reported in this study ranged from 2.47–6.13% with a mean value of $3.83 \pm 1.17\%$ (Table 2). However, the stability of the oil increased with increase in the roasting temperature and duration (Fig. 4). The linear effect was significant and it was also the best to describe the relationship between the roasting condition and the oxidative stability ($P \leq 0.05$). The value of the coefficient of the determination ($R^2 = 0.52$) indicated that the model was moderately fit. Predictive model equation

Colour
X = A: Roasting Temperature
Y = B: Roasting Duration

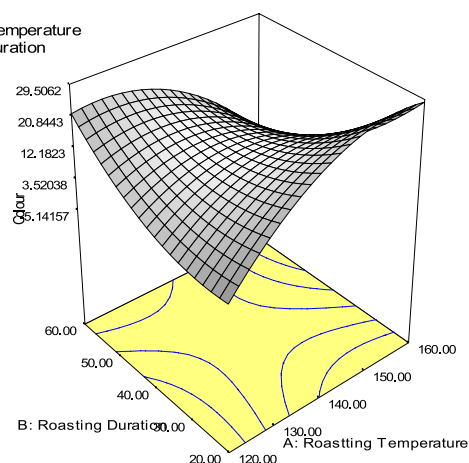


Fig. 3 Variation in colour values of tiger nut oil with roasting temperature and duration

Oxidative Stability
X = A: Roasting Temperature
Y = B: Roasting Duration

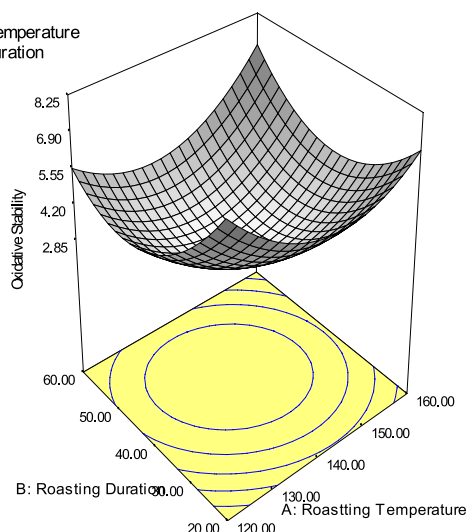


Fig. 4 Variation in oxidation stability values of tiger nut oil with roasting temperature and duration

described below established the relationship between the oxidative stability and the independent variables.

$$\text{Oxidative Stability} = 115.78 - 1.40X_1 - 0.70X_2 + 4.77 \times 10^3 X_1^2 + 5.35 \times 10^3 X_2^2 + 1.75 \times 10^3 X_1 X_2 \quad (10)$$

The para-anisidine values varied from 0.74–1.62 mg/L with a mean value of 1.08 ± 0.30 mg/L (Table 2). Interestingly, tiger nut oil with the highest para-anisidine content

Para Anisidine
X = A: Roasting Temperature
Y = B: Roasting Duration

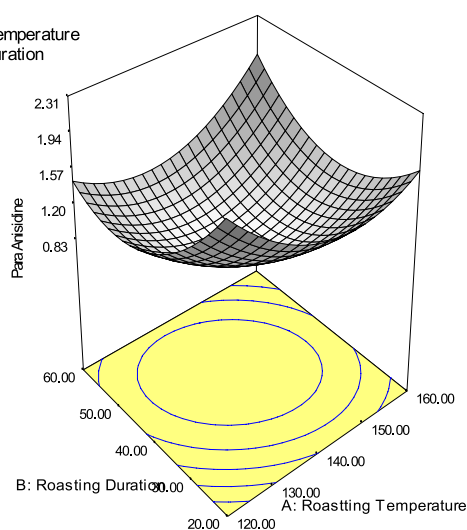


Fig. 5 Variation in para-anisidine values of tiger nut oil with temperature and duration

was obtained at 150 °C for 30 min, while lower para-anisidine value was found at 140 °C for 40 min (Fig. 5).

However, quadratic model was the most suitable to describe the relationship between the roasting conditions and the para-anisidine as established in Eq. 11. The model had a good fit. The value of the coefficient of determination ($R^2 = 0.53$) indicated that the model fitted moderately.

$$\text{Para-anisidine} = 30.16 - 0.36X_1 - 0.20X_2 + 1.18 \times 10^3 X_1^2 + 1.33 \times 10^3 X_2^2 + 6.32 \times 10^4 X_1 X_2 \quad (11)$$

The specific gravity value observed in this study varied from 0.83–0.89 g/cm³ with a mean value of 0.87 ± 0.017 g/cm³ (Table 2). The highest specific gravity was observed in oil obtained at 150 °C for 50 min (Fig. 6). The model effect was significant at the quadratic term ($P \leq 0.05$) as expressed in Eq. 12. Higher value of the coefficient of determination ($R^2 = 0.64$) indicated that the model had a good fit.

$$\text{Specific Gravity} = 0.87 - 0.04X_1 + 0.01X_2 - 0.01X_1^2 - 0.01X_2^2 - 0.02X_1 X_2 + 0.02X_1^3 - 0.02X_2^3 \quad (12)$$

The iodine value reported varied from 0.372–1.5369 i.v/wijs with a mean value of 0.82 ± 0.27 i.v/wijs. Table 2 showed that the highest iodine value content could be obtained at 160 °C for 40 min, while the lowest iodine content could be obtained at 150 °C for 30 min (Fig. 7). The model was significant at the cubic term ($P \leq 0.05$) as shown

Specific Gravity
X = A: Roasting Temperature
Y = B: Roasting Duration

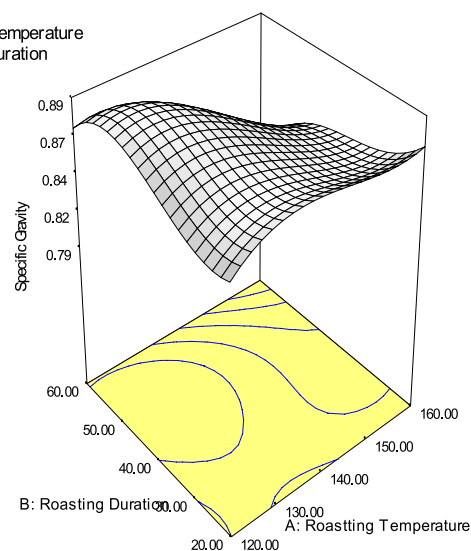


Fig. 6 Variation in specific gravity values of tiger nut oil with roasting temperature and duration

Iodine Value
X = A: Roasting Temperature
Y = B: Roasting Duration

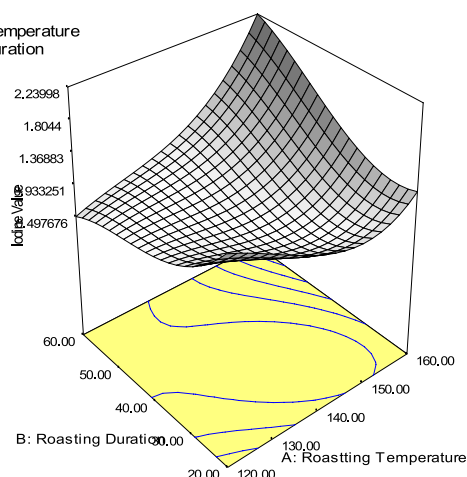


Fig. 7 Variation in Iodine values of tiger nut oil with roasting temperature and duration

Peroxide Value
X = A: Roasting Temperature
Y = B: Roasting Duration

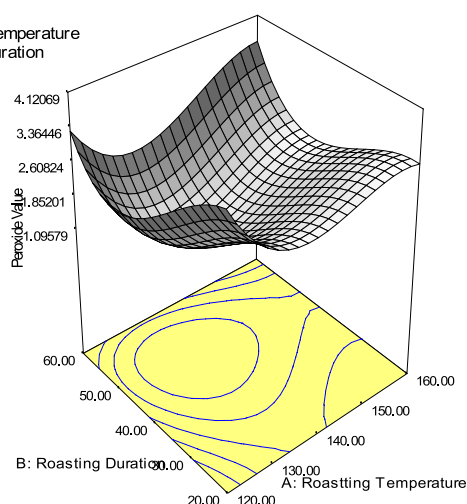


Fig. 8 Variation in peroxide values of tiger nut oil with roasting temperature and duration

in Eq. 13. Higher value of the coefficient of determination ($R^2=0.63$) showed that the model possessed a good fit

$$\text{Iodine value} = 0.66 + 0.03X_1 + 0.31X_2 + 0.44X_1^2 + 0.25X_2^2 + 0.56X_1X_2 + 0.28X_1^3X_2^3 \quad (13)$$

The peroxide value obtained varied from 1.23 to 3.06 meq/kg with a mean value of 1.91 ± 0.58 meq/kg (Table 2). The result shows that highest peroxide value was obtained at 150 °C for 30 min, while the lowest value was observed in the sample that was roasted at 140 °C for 40 min (Fig. 8). The model was insignificant at both the linear and quadratic terms, but significant at the cubic term ($P \leq 0.05$)

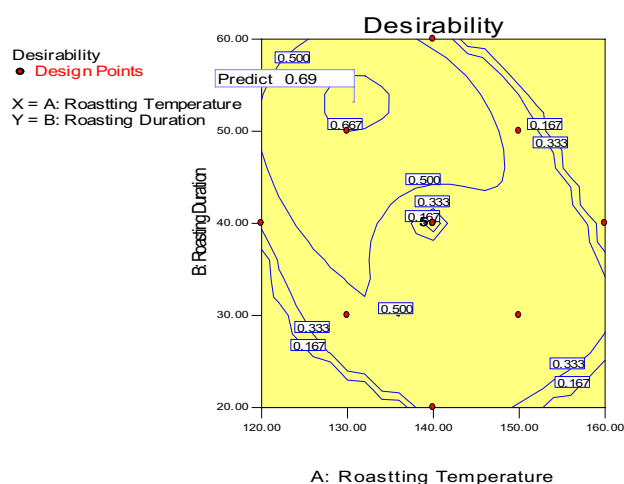


Fig. 9 Super imposition of the eight responses surface plots

as stated in Eq. 14. Higher value of the coefficient of determination ($R^2=0.67$) indicated that the model had a good fit.

$$\begin{aligned} \text{Peroxide value} = & 1.45 + 0.76X_1 - 1.08X_2 + 0.95X_1^2 + 1.07X_2^2 \\ & + 0.35X_1X_2 - 0.99X_1^3 + 1.01X_2^3 \end{aligned} \quad (14)$$

The eight response surface plots were super imposed to arrive at the optimum conditions (Fig. 9). The optimized conditions were obtained by selecting lower FFA, higher value for specific gravity, higher iodine value, lower oxidative stability, lower para-anisidine, lower peroxide value, higher value for colour and higher value for oil yield (Table 3).

3.2 Discussion

The observed moisture content in this study fell within the range (2.9–6.2%) recommended for adequate roasting to obtain good yield and quality [31]. Therefore the expected outcome for roasting at the above moisture content is likely to be favourable. Roasting enhanced the release of available oil by a significant amount of 0.26–5.5% as compared to 18.3% oil content of the unroasted tiger nut. Similar observation was reported by Kumar et al. [16] for pulsed infrared roasting of groundnut under different roasting temperature and duration whereby roasting enhanced the release of groundnut oil by 0.83–8.09%. Increase in oil extraction from the pretreated oil seed could be attributed to fractionation of intact oil bodies and rupturing of cellular structure as a result of heating [16]. Higher temperature resulted into loss of oil, as a result of partial decomposition of the samples during roasting [31]. Lower oil yield was also observed at air temperature lower than 130 °C, even at higher roasting

Table 3 Optimized processing conditions

Name	Constraint	Lower limit	Upper limit	Solutions	
				A	B (selected)
Roasting Temperature	Is in range	120.00	160.00	135.51	130.79
Roasting Duration	Is in range	20.00	60.00	29.57	53.11
Oil Yield	Maximize	18.56	23.80	23.00	23.09
Free Fatty Acid	Minimize	0.06	0.16	0.14	0.10
Specific Gravity	Maximize	0.83	0.89	0.87	0.89
Iodine Value	Maximize	0.37	1.54	0.68	0.77
Oxidative Stability	Minimize	2.47	6.13	3.98	3.58
Para-anisidine	Minimize	0.74	1.62	1.15	1.00
Peroxide Value	Minimize	1.23	1.23	2.08	1.33
Colour	Maximize	3.44	3.44	16.07	17.16
Desirability				0.50	0.69

duration. This might be as a result of the inability of the roasting temperature to adequately fractionate oil bearing bodies in the seeds.

Free fatty acid (oleic acid) establishes the suitability of the oil for edibility or industrial uses [32]. Hydrolysis of triglycerides results into formation of free fatty acid and it leads to off flavor development during storage. In appropriate conditions such as high temperature, moisture, and presence of active lipase can aid FFA development in fat containing raw materials or oils [16]. Generally, the FFA contents of oil samples observed in this study were very low, implying that they might possess good oxidative stability. Low FFA content is desirable in edible oil as it is a pointer to the stability of oil during storage [32, 33].

The presence of carotenoids in fat which are the primary sources of yellow–red colour are responsible for the oil colour [31]. Invariably, increase in roasting temperature to about 140 °C for duration of 20 min enhanced the colour to an acceptable level. The lightness of colour was further decreased by increase in roasting temperature and duration, resulting into the darkening of oil and increase in absorbance. The increase in absorbance as a result of increase in roasting temperature and roasting duration could be attributed change in colour as a result of both non enzymatic browning reaction and phospholipids degradation during roasting process [34]. Similar findings were reported by Hafez et al. [35] and Akinoso and Raji [31] who reported on the influence of roasting on oil extraction from soybeans and locust beans respectively. Also, Farmer and Sutton [36] deduced that increase in absorbance of thermally treated oils was due to the formation of conjugated dienes and trienes, which was proportional to the uptake of oxygen and formation of peroxide during the early stage of oxidation, while Mohagir et al. [34] stated that most of the dienes would transform into polymer compounds with increase in roasting temperature.

The stability of the oil increased with increase in the roasting temperature and duration (Fig. 4). Tiger nut oil with the highest oxidative stability was obtained at 150 °C for 30 min, while the tiger nut oil with the lowest stability was observed at 140 °C for 40 min. Low oxidative stability could be attributed to thermal oxidative decomposition [31]. Increase in temperature resulted in increase in the para-annisidine value of the oil, and this might be attributed to the thermal oxidative transformation of free radicals, that might cause the degradation of unsaturated fat producing volatile compound [37]. The para-annisidine value is found to be a measure of the secondary oxidation or the past history of an oil, and therefore it is very useful in determining the quality of crude oil and efficiency of process procedures [31].

The specific gravity of oil has a direct relationship with the relative density and it is very useful in determining the quality of oil and extraction procedures efficiency [31]. The result obtained correspond to 0.89 g/cm³ reported for Africa oil bean seed reported by Odoemelam [38], and also it was within the range reported by Mohammed and Hamza [39] for *Sesamum Indicum* L. seed oil. Iodine value is one of the measures of the unsaturation of the oils and it is used to measure the oil quality [40]. The peroxide value of oil is a measure of the deterioration of oil as a result of oxidation [41]. Therefore, the lower peroxide value of tiger nut oil when compared to palm kernel oil indicates that the oil can be kept for a very long period of time [41]. Peroxides are regarded as unstable compounds particularly under high temperature conditions, which decompose to form carbonyl and aldehydic compounds causing a decrease in peroxide value [42].

4 Conclusions

The result obtained in this study shows that tiger nut is a potential source of vegetable oil. Combinations of roasting temperatures and durations influenced both oil yield and oil quality significantly at 95% confidence level. Predictive models were developed for tiger nut oil yield, free fatty acid, colour, oxidative stability, para-anisidine value, specific gravity, iodine value, peroxide value as influenced by roasting temperature and duration. The models had good fits. Two possible optimum solutions were found with desirability ranging from 50 to 69%. The best of the two result was roasting at 130.79 °C for 53 min which gave 23.09% oil yield, 0.10% free fatty acid, 0.89 g/cm³ specific gravity, 0.77 i.v/wijs iodine value, 3.58% oxidative stability, 1.00 mg/L para-anisidine value, 1.33 meq/kg peroxide value, 17.16 mg/I colour. This treatment had a desirability of 0.69, a close value to 1. The optimum condition produced a relatively high oil yield with acceptable color and good storage stability.

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Availability of Data and Material All data generated and analyzed are included in the manuscript.

Declarations

Conflict of Interest There is no conflict of interest on this work.

Ethics Approval and Consent to Participate Not applicable.

Consent for Publication I humbly accept to publish my manuscript in your highly referred outlet.

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