



Effects of roasting on physicochemical properties and fatty acids composition of okra seed oil

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ABSTRACT

Okra is a high-yielding annual crop whose seed oil potential has yet to gather much attention compared to its seedling and regeneration purposes. This study aimed to evaluate the effects of roasting temperature (120 – 200 °C) and roasting duration (10 – 40 mins) on the physicochemical properties and fatty acids of the oil extracted from okra seed. Morphological studies of grounded unroasted and roasted okra seed samples were also examined using scanning electron microscopy. Standard methods were used in determining the yield, free fatty acid (FFA), saponification value (SV), colour, and specific gravity (SG) of the extracted oil. The oil yield ranged between 22.13 and 64.27%, FFA (3.45 and 7.47), SV (174.38 and 184.80), colour (13.09 and 21.83), and SG (0.93 and 0.98), respectively. The okra seed oil from both roasted and unroasted seed showed the presence of linoleic acid (25.57 – 31.03%) and oleic acid (16.18 – 27.92%) as the primary polyunsaturated fatty acid and monounsaturated fatty acids respectively. Palmitic (6.85 – 19.83%) and stearic acid (3.00 – 5.31%) are the main saturated fatty acids in the okra seed oil. The surface of unroasted okra seed was smooth and compact, while roasting caused cell rupture of roasted okra seeds, leading to an increase in oil yield. This study provided valuable information on okra seed oil which would be of significant use for potential oil producers.

1. Introduction

Vegetables play an important role in human life and diet, so the demand for them has markedly increased due to rising global demand, thereby changing the dietary habits of the worldwide population [1]. Okra (*Abelmoschus esculentus*) is an annual vegetable native plant in Africa that belongs to the Malvaceae family. It is also notably cultivated in the tropical and subtropical regions of Asia, Europe, and America [2]. Okra seeds are a rich source of oil and protein and are also nutritious in terms of antioxidant compounds such as; quercetin, hydroxycinnamic, flavonoids, and catechins [3]. In addition, okra seeds are useful in confectionery and the production of coffee, a caffeine-free substitute [4]. Extraction, which is a significant unit operation in the processing of oils from its seed, is crucial since it specifies the quality and amount of oil extracted. The amount of oil in the grain decides the processing and extraction methods used for the different oil seeds. It is the most important step in the oil processing operation, and it is determined by the part of the kernel, seed, or pulp that contains the oil. In industries such as food and pharmaceuticals, vast quantities of solvents (water, n-hexane, ethanol, etc) are used to separate bioactive compounds of interest. In the extraction of seeds using solvent extraction, the bean seeds are flaked

and cooked, which in turn denatures the cell tissues to enhance easy penetration of the flakes by the solvent used. The solvent then flows through the fragments for oil to be extracted. Roasting of oilseeds which is a process that involves the application of heat, is aimed at improving oil yield during extraction, reducing moisture, and inactivating lipase and other enzymes that can trigger fatty acid oxidation [5]. A couple of parameters, such as the Okra seed variety, the extraction conditions, and the solvent used for extraction, determine the quantity of oil obtainable. Many factors influence the solvent extraction method, so screening the most significant factors in the investigated responses is critical. Response surface methodology (RSM), as well as the design such as central composite rotatable design (CCRD), are suitable for determining the most crucial factor in an experiment, and its optimization strategy helps to ascertain the optimum conditions [6]. Response surface methodology (RSM) is an assemblage of statistical and mathematical methods used to effectively calculate the effects of multiple variables and optimize processes [6]. The key benefit of RSM was that it cut down on the number of experimental trials needed to assess multiple variables and their interactions [7]. Several researchers have attempted to work on oil extraction from okra seeds [8–12]. However, literature is sparse on the influence of the temperature of roasting and its duration on the physicochemi-

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Table 1

Central Composite Design for the effect of roasting temperature and roasting duration on Okra seed oil.

Independent variable	Code	Levels				
		-1.414	-1	0	+1	+1.414
Roasting temperature (°C)	RT	120	140	160	180	200
Roasting duration (min)	RD	10	17.5	25	32.5	40

cal properties and fatty acids content of okra seed oil. In addition, the oil content of okra seed has yet to gather much attention compared to its seedling, regeneration, and fortification purposes. Understanding the impact of roasting temperature and roasting duration on okra seed oil extraction would provide valuable information about the oil-producing potential of okra seed. Therefore, this study aimed to extract oil from a new hybrid of okra seed of a variety “NHAe47-4” using the soxhlet extraction method and evaluate the effects of temperature and duration of roasting on the physicochemical properties and fatty acids composition of the okra seed oil using response surface methodology.

2. Materials and methods

Dry okra seeds (*Abelmoschus esculentus*) of a variety “NHAe47-4” were purchased at the National Horticultural Research Institute (NIHORT), and the experiment was conducted at the Processing Laboratory of the Department of Food Technology at the University of Ibadan from May 2021–August 2021.

2.1. Experimental design

Response Surface Methodology (RSM) was used to examine the effect of roasting temperature and duration on okra oil yield, free fatty acid, saponification value, specific gravity, colour, fatty acid contents, and morphological structure of okra seed. The predictor variables of roasting temperature and roasting duration ranged between 120–200 °C and 10–40 mins, as shown in Table 1. The dried Okra seed was grounded using a disc mill (Model 2A Sukhsa, India), and the grounded okra seed was then roasted at different temperatures and times. Soxhlet extraction apparatus (Model LTSW-5, India) was used for the extraction process. The experiment was performed in triplicate, with the mean values reported as the collected data. The data was evaluated using Design Expert – Version 13 (Stat-Ease Minneapolis, USA) software package and Duncan multiple tests of ANOVA in SPSS. A confidence level of 95% was used as the significant standard for the analysis of variance.

2.2. Pretreatment of okra seed by roasting

Experiments were conducted using Akinoso and Adeyanju [13] method to examine the effect of temperature and duration of roasting on oil extraction. The values range was decided comparatively from a consideration of applicable literature but primarily from preliminary studies. Size reduction of okra seed was achieved using a disc mill (Model 2A Sukhsa, India). The samples were roasted by evenly spreading them on a tray in an oven (Model: PA0054, US) at the set temperature based on the experimental design. 150 g of each sample was roasted in the oven at different roasting temperatures and duration combinations. A stopwatch was used to monitor the roasting duration for accuracy. Plate 1 shows the pictorial view of the extracted oil from roasted okra seeds.

2.3. Oil Extraction

The extraction of okra seed oil was done using the Soxhlet extraction apparatus (Model LTSW-5, India). 150 g of roasted okra seed was loaded into the thimble that connects to a 500 ml round bottom flask. After extraction, a rotary vacuum evaporator (EYELA N-1001S-W, Japan) was

used to remove the n-hexane under reduced pressure at 50 °C. Experiments were repeated thrice, and the oil samples were thereafter stored in the dark for further analysis. The total of extracted oil was then computed gravimetrically.

2.4. Physicochemical properties

2.4.1. Determination of oil yield

Eq. (1) was used to measure the oil yield by dividing the weight of extracted oil by the weight of the sample according to [14].

$$OY = \frac{WEO}{WS} \times 100\% \quad (1)$$

where OY is the oil yield, WEO is the weight of extracted oil and WS is the weight of the samples

2.4.2. Determination of saponification value

1 g of oil sample was dissolved in 25 ml of 0.5 Methanolic potassium hydroxide solution using a 250 ml quick fit flask [15]. The flask was heated for 30 mins in a steam bath with intermittent swirling. The resultant solution was then heated with 0.5 M HCl using a phenolphthalein indicator. Under the same circumstances, a blank determination was performed. The difference between the two titre values equals the amount of HCl acid required to neutralize the alkali after saponification in milliliters. The saponification value was estimated using Eq. (2).

$$\text{Saponification value, SV (mg KOH)} = \frac{56.1 \times M \times (B - V)}{W} \quad (2)$$

where M represents the molarity of standard HCl (0.5 M), B represents the volume of HCl in ml used in the blank titration, V denotes the volume of HCl in ml used for oil and biodiesel titration respectively, and the molar mass of potassium hydroxide is 56.1, W represents weight in a gram of the oil sample.

2.4.3. Determination of free fatty acid (FFA)

In a neutral mixture of 25 mL, 1 g of extracted okra seed oil samples was dissolved (the same volume of diethyl ether and absolute ethanol) according to the method of Raji and Akinoso [16]. Titrated with 0.1M potassium hydroxide solution and three drops of phenolphthalein indicator. The titration was carried out until the desired result was obtained. The presence of a permanent pink colouration was defined as its endpoint. The free fatty acid was indicated with reference to oleic acid and determined in Eq. (3).

$$\text{FFA (\%)} = \frac{TV \times 0.0282 \times 100}{W} \quad (3)$$

where TV represents the titre value 0.0282 is constant (weight of oleic acid that is neutralized by 1 mg of KOH). W is the weight in a gram of the oil sample.

2.4.4. Determination of specific gravity

A clean 25 mL specific gravity bottle was measured and reweighed after being filled with water. The oil sample was transferred into each bottle after draining the bottle, and the weights were registered. The experiment was carried out at the same temperature in the shortest possible time (room temperature) according to the method of [17]. The specific gravity of the oil sample (i.e., okra seed oil) was calculated using Eq. (4).

$$\text{Specific gravity, SG} = \frac{\text{weight of sample}}{\text{Weight of equal volume of water}} \quad (4)$$

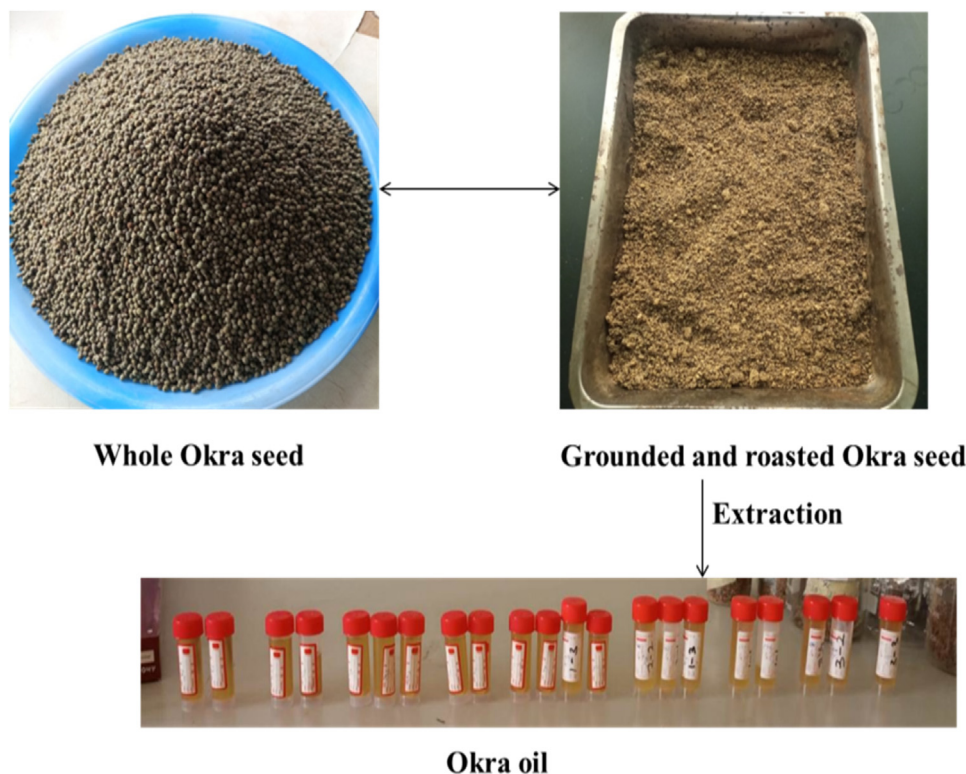


Plate 1. The pictorial view of the extracted oil from roasted okra seeds.

2.4.5. Colour determination

A Colorimeter was used to determine the colour of okra oil samples (Minolta chromameter CR400; Konica Minolta, Japan) based on the CIE system in terms of the L^* representing the lightness of colour from 0 (black) to 100 (white) in the tristimulus colour coordinate system, while a^* ranges from negative to positive (green to red), and b^* varies from negative to positive (blue to yellow) according to the method of [18]. Multiple measurements of L^* , a^* , and b^* parameters were carried out on the okra oil samples using the colorimeter. From the data collected, colour change (ΔC) was calculated using Eq. (5) as described by Falade and Kolawole [19].

$$\Delta C = (\Delta a^2 + \Delta b^2)^{0.5} \quad (5)$$

2.5. Determination of free fatty acids compounds using GC-MS

This test was performed on a gas chromatograph-mass spectrometer (GC-MS) of varian 3800/4000 gas coupled with an Agilent as well as a capillary column HP-5MS (bonded and cross-linked 5% phenyl-methyl-polysiloxane, 30 mm - 0.25 mm, coating thickness 0.25 μm) capillary column (Restek, Bellefonte, PA). At a constant flow rate of 1.0ml/min, nitrogen (carrier gas) with 99.99% purity was utilized. One μL of the sample was measured and injected using an injector temperature of 290 °C in 1:50 split mode according to the method of [20]. An initial column temperature of 80 °C preceded two stages of heating: 10 °C min^{-1} at about 150 °C and 6 °C min^{-1} at about 230 °C, with the temperature remaining constant through the process, and the duration of analysis was 50 min. The start and end of the m/z ratio are 40 and 800 respectively, with the mass detector and interface temperature being 250 °C. Comparing the mass spectrum with the already known standards in the software library (Mass Spectral Database NIST/EPA/NIH) formed the basis of the fatty acids profile characterization. Based on the entire area values of the peaks identified, the percentage of fatty esters was evaluated in terms of the respective area of each peak. The comparison of the retention times with those of real compounds and that of the spectral data obtained from the data library of the matching compounds aided the identification of

other compounds. The number of compounds present is recorded as the relative area percentages obtained from the integrator. The database of the National Institute Standard coupled with the Technology MS library (NIST- MS library comparing the spectrum obtained through GC-MS compounds in the samples were identified), which in turn helped in the identification of the free fatty acids.

2.6. Granule morphology of ground roasted okra seed

The morphology of the unroasted and roasted okra seed granules was examined by digital capture from a scanning electron microscope (PRO:X Phenom-World, MVE01570775, Thermo Fisher Scientific, USA) using the method described by Hazra et al. [21]. The samples were dried at a temperature of 40 °C and time of 12 hours, which was mounted on a scanning electron microscope stub with conductive double-sided adhesive and was subsequently treated with a gold spray before being observed. Each sample was measured and scanned in five different magnifications.

3. Results and discussion

3.1. Oil yield

Table 2 shows the roasting temperature and duration's effect on oil yield. It was observed that there were significant differences in the oil yield of okra seed oil. The oil yield from unroasted okra seed was 20.9%, while the roasted seed ranged between 22.13 and 64.27%. The highest oil yield of 64.27% was attained at 160 °C roasting temperature and 25 min roasting duration. The least oil yield was 22.13% at 120 °C roasting temperature and 10 min roasting duration. The oil yield is in agreement with Chirinos et al. [22] findings that oil content for roasted *P. huayllabambana* seed ranged between 54.2 and 62.4%. Perren and Escher [23] stated that dehydration due to the application of heat damages the indigenous microstructure of a plant cell which in turn increases their permeability and the intracellular distribution of the oil and the compounds in the oil. As shown in Fig. 1, there was a variation in oil

Table 2
Effect of roasting temperature and roasting duration on physicochemical properties of Okra seed oil.

Treatment	Independent Variables		Response Variables			
	Roasting Temperature (°C) RT	Roasting Duration (min) RD	Y ₁ (%)	Y ₂ (%)	Y ₃	Y ₄
1	120	10	22.13 ^a	6.50 ^e	174.38 ^a	0.93 ^a
2	200	10	25.07 ^b	7.47 ^b	184.8 ^b	0.94 ^a
3	120	40	41.60 ^c	3.45 ^g	178.22 ^c	0.98 ^a
4	200	40	29.87 ^d	6.63 ^d	180.94 ^d	0.94 ^a
5	103.43	25	32.27 ^e	7.12 ^b	180.72 ^e	0.96 ^a
6	216.57	25	22.80 ^f	6.48 ^e	179.78 ^f	0.94 ^a
7	160	3.79	29.07 ^g	6.91 ^c	179.48 ^g	0.94 ^a
8	160	46.21	51.87 ^h	5.64 ^f	182.66 ^h	0.94 ^a
9	160	25	64.27 ⁱ	6.49 ^e	182.26 ⁱ	0.94 ^a
10	160	25	64.27 ⁱ	6.49 ^e	182.26 ^j	0.94 ^a
11	160	25	64.27 ⁱ	6.49 ^e	182.26 ^j	0.94 ^a
12	160	25	64.27 ⁱ	6.49 ^e	182.26 ^j	0.94 ^a
13	160	25	64.27 ⁱ	6.49 ^e	182.26 ^j	0.94 ^a

where Y₁ - oil yield, Y₂ - free fatty acid, Y₃ - saponification value, Y₄ - specific gravity of okra seed oil
Mean value with different superscript are significantly different at p<0.05.

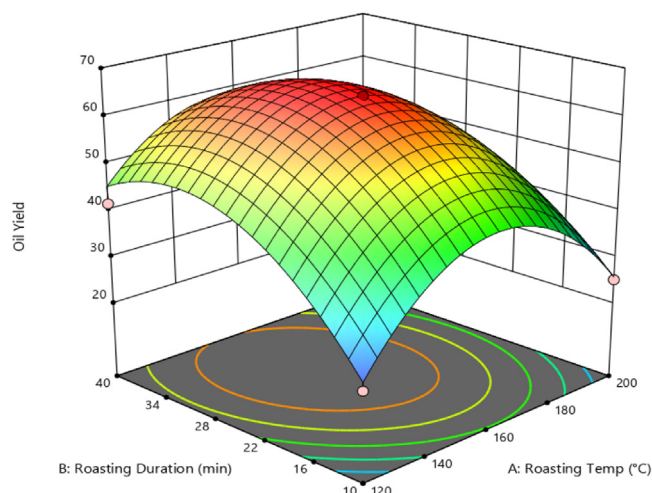


Fig. 1. Effect of roasting temperature and roasting duration on oil yield of okra oil seed.

yield according to the difference in roasting temperature and roasting duration. Okra seed oil increased at different roasting s with an increasing roasting duration. However, there was a visible decrease in oil yield after the optimum roasting temperature of 160 °C and a roasting duration of 25 min was attained. The variation in oil yield and treatment parameters may be due to the optimum level for the relevant physicochemical changes in the Okra seed.

3.2. Free fatty acid

Table 2 shows the effect of roasting temperature and duration on free fatty acid composition in roasted okra seed oil. It was observed that the free fatty acid ranged from 3.45 to 7.47%. The highest free fatty acid from okra seed oil was 7.47% at 200 °C roasting temperature and 10 min roasting duration. According to Fig. 2, the free fatty acid decreases as the roasting duration increases. However, at a roasting temperature of 120 °C and a time of 40 min, the free fatty acid value of 3.45% was observed to be minimum. This means the enzyme lipase that begins the hydrolytic deterioration process in oil has been rendered inactive almost completely. Also, there is a visible decrease in free fatty acid value at each roasting temperature and different roasting duration. This means that the free fatty content reduces at constant roasting temperature and

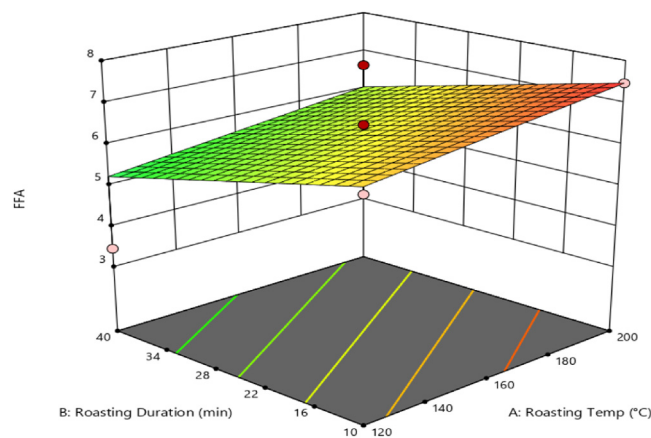


Fig. 2. Effect of roasting temperature and roasting duration on free fatty acid (FFA) of okra oil seed.

a proportionate increase in roasting duration. These changes agree with Al-Amrousi et al. [24] that changes in free fatty acid content depend on the temperature of the heating oil seeds alongside other factors.

3.3. Saponification value

Saponification is a good indicator for the detection of adulteration [25]. The saponification value of the oil ranged between 184.80 and 174.38 mgKOH/g, with the highest saponification value, as shown in Table 2, being 184 mgKOH/g at a roasting temperature of 200 °C and roasting duration of 10 mins. The lowest saponification value was 174.38mgKOH/g at a roasting temperature of 120 °C and a duration of 10 mins. The saponification values obtained are within specification as reported by Ekpe et al. 2018 [26], whose saponification value for Irvingia gabonensis seed oil was 181.9±0.21 mgKOH/g. Anwar et al. [27] reported a saponification value in the range of 180.3-185.8mgKOH/g for okra seeds oil, Ogungbenle and Omosola [28] in their assessment of dry Nigerian okra oil reported a saponification value of 182.20 mgKOH/g. All these are similar to the findings of this work. The effect of roasting temperature and duration on the saponification value of okra oilseed is evident, as seen in Fig. 3, with a visible increase in the saponification value with increasing temperature and time of roasting. However, a peak was reached at a roasting temperature of 200 °C and a duration

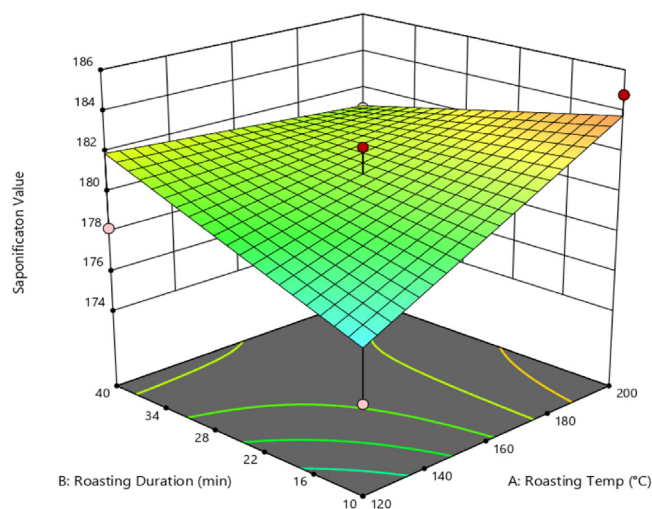


Fig. 3. Effect of roasting temperature and roasting duration on free fatty acid (FFA) of okra oil seed.

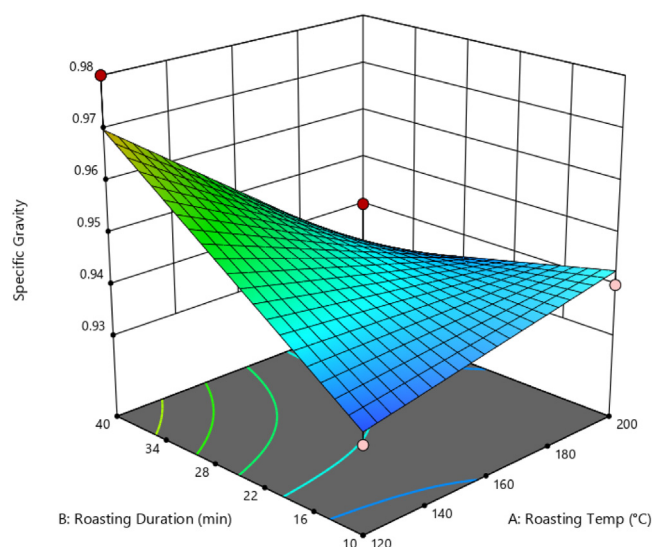


Fig. 4. Effect of roasting temperature and roasting duration on free fatty acid (FFA) of okra oil seed.

of 10 min, after which there was a decrease in the oil's saponification value.

3.4. Specific gravity

Table 2 shows no significant difference in the specific gravity of the okra oil. There is a direct relationship between oil's specific gravity and the relative density, and it is very pivotal in establishing the oil quality and the effectiveness of extraction methods [29]. The specific gravity of the oil extracted ranged between 0.93 and 0.98. The minimum specific gravity of 0.93 obtained was higher than 0.917 reported by [28]. The extracted oil obtained in this study is in agreement with the findings of Akinoso and Oni [30] on melon seed oil with a range of 0.9 to 1.0 and the work of Bamgboye and Adejumo [31] with a specific gravity of 0.96 for Roselle seed oil. The maximum specific gravity was observed at roasting temperature and duration of 120 °C and 40 min respectively, while the minimum specific gravity value was achieved at 120 °C and 10 min. Fig. 4 shows that an increase in roasting duration and a decrease in its corresponding temperature increases the specific gravity of the oil. In

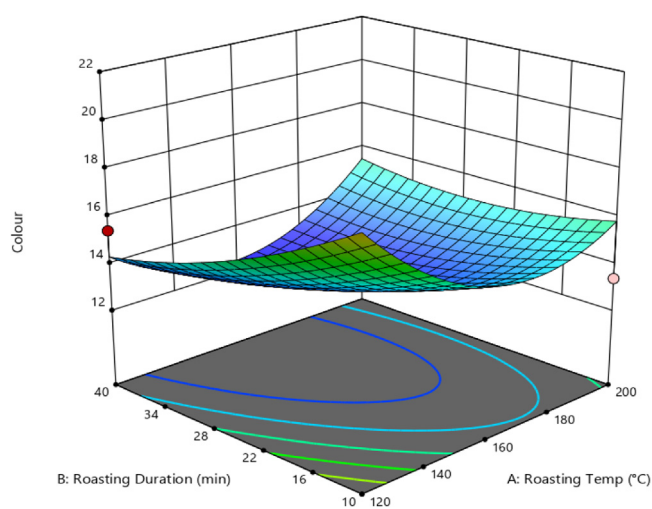


Fig. 5. Effect of roasting temperature and roasting duration on change in colour of okra oil seed.

contrast, an increase in roasting temperature and a decrease in duration leads to increased specific gravity.

3.5. Colour

Table 3 shows the extracted okra seed oil's L^* , a^* , and b^* values. The L^* ranged between 68.94 and 67.81, a^* (-8.35 and -6.61), and b^* (21.25 and 12.36), respectively. Values of coordinates L^* and b^* agree with what Ofori et al. [32] reported in their work on dried okra seed flour samples of two different genotypes. They also suggested that the L^* colour brightness can be further improved by subjecting the okra seeds to a solution of ascorbic acid or a percentage of sodium metabisulfite solution before drying to later prevent enzymatic browning. From Table 3, the colour change showed that the highest value (21.83) was obtained at a roasting temperature of 216.57 °C and 25 mins roasting duration. In contrast, at 200 °C roasting temperature and duration of 40 mins, the colour change was lowest at 13.09. Fig. 5 shows that increased roasting temperature and duration increase the colour change. According to Anwar et al. [27], this intensity is due to seed pigment extraction. Chandrasekara and Shahidi [33] also stated that the formation of colour in oil may have been influenced by roasting temperature as the increase in the intensity of oil's colour with a proportionate increasing roasting temperature may be due to Maillard reaction at increasing roasting temperatures.

3.6. Composition of fatty acids in okra oil

The fatty acid composition in an oil sample can be a measure of its physical characteristics, nutritive value, and stability [33]. Table 4 shows the results of the fatty acid profile of Okra seed oil which was measured by gas chromatography-mass spectrometry. The compositions are represented in percentage chromatographic area. Seventeen fatty acids were identified in the oil sample from unroasted okra seed and each sample of the roasted Okra seeds, with the primary monounsaturated fatty acid found in the oil of both roasted and unroasted seeds being Oleic acid (C18:1n-9). They were found to be between 16.18 to 27.92%, while Linoleic acid (C18:2n-6) was the highest polyunsaturated fatty acid in the oil, and it was between 25.57 and 31.03% (Table 4). The oil analysis showed that the okra seed oil contains a high degree of unsaturation which is evident in the amount of linoleic acid that is the main constituent in the oil. This further buttresses the nutritional desirability of Okra seed oil as it is oxidatively stable and can also be

Table 3

Effect of roasting temperature and roasting duration on colour properties of Okra seed oil.

Treatment	Independent Variables		L*	Response Variables		
	Roasting Temperature (°C) RT	Roasting Duration (min) RD		a*	b*	ΔC
Control	0	0	68.8 ^b	-7.39 ^c	16.12 ⁱ	16.77 ^h
1	120	10	68.45 ^c	-6.96 ^b	14.68 ^e	15.43 ^e
2	200	10	67.81 ^f	-7.4 ^c	16.23 ^d	16.87 ^d
3	120	40	68.82 ^b	-6.69 ^a	12.64 ^f	13.35 ^f
4	200	40	68.7 ^c	-6.61 ^a	12.36 ^g	13.09 ^g
5	103.43	25	68.94 ^a	-6.69 ^a	12.57 ^f	13.31 ^f
6	216.57	25	68.83 ^b	-8.35 ^g	21.25 ^a	21.83 ^a
7	160	3.79	68.58 ^d	-8.08 ^e	19.96 ^b	20.24 ^b
8	160	46.21	68.38 ^e	-7.96 ^f	19.00 ^c	19.62 ^c
9	160	25	68.54 ^d	-7.49 ^d	16.23 ^d	16.92 ^b
10	160	25	68.54 ^d	-7.49 ^d	16.23 ^d	16.92 ^b
11	160	25	68.54 ^d	-7.49 ^d	16.23 ^d	16.92 ^b
12	160	25	68.54 ^d	-7.49 ^d	16.23 ^d	16.92 ^b
13	160	25	68.54 ^d	-7.49 ^d	16.23 ^d	16.92 ^b

Mean values with different superscript are significantly different at $p < 0.05$.**Table 4**

Effect of roasting temperature and roasting duration on the composition of fatty acid in okra seed oil.

Fatty Acid Components	X ₀	X ₁	X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	X ₈	X ₉
1, 3-trans, 5-cis-Octatriene (C ₈ H ₁₂)	0.72	1.03	2	1.96	2.15	2.11	2.1	2.92	2.95	2.37
Trans-Linalool oxide (C ₁₀ H ₁₈ O ₂)	2.06	2.73	2.86	1.05	1	2.02	2.02	2.07	1.88	1.55
Caryophyllene (C ₁₅ H ₂₄)	2	2.87	2.94	1.54	1.59	1.86	1.9	1.95	1.96	1.97
Hexadecanoic acid, methyl ester (Methyl Palmitate) (C17H34O2)	12.01	6.83	3.9	2.79	2.31	4.8	4.78	4.85	4.86	4.86
n-Hexadecanoic acid (C ₁₆ H ₃₂ O ₂) - Palmitic acid	17.05	17.24	6.85	18.13	15.52	19.61	19.75	13.63	15.17	19.83
Dodecanoic acid, methyl ester (Methyl laurate) (C13H26O2)	2	2.51	2.92	2.92	1.98	2.59	2.52	2.19	2.4	2.52
Palmitoleic (C ₁₆ H ₃₀ O ₂)	1.18	3.55	2.55	1.85	2.96	2.93	2.97	2.02	2.99	3.99
Tetradecanoic acid (Myristic acid) (C ₁₄ H ₂₈ O ₂)	2.29	2.86	3.83	2.88	2.8	2.94	2.96	3.27	3.16	3.18
Geranyl isovalerate (C ₁₅ H ₂₆ O ₂)	0.98	1.82	3.14	1.72	1.41	1.96	1.99	2.09	2	1.99
Nonadecanoic acid (C ₁₉ H ₃₈ O ₂)	0.84	0.8	0.9	0.38	0.32	0.87	0.87	1.93	1.05	0.87
n- Nonadecanol-1 (C ₁₉ H ₄₀ O ₂)	0.62	0.52	1.96	0.98	0.37	1.83	1.74	1.84	1.96	1.86
9, 12-Octadecadienoic acid (Z, Z) -(Linoleic Acid) (C18H32O2)	27.74	27.33	30.56	31.03	25.57	27.42	27	26.16	26.79	25.75
Benzeneethanamine, 3, 4-demethoxy- (C ₁₃ H ₂₂ O ₃)	2.82	4.1	3.62	1.97	1.74	3.91	3.91	3.91	3.96	3.99
Oleic Acid (C ₁₈ H ₃₄ O ₂)	23	20.63	25.17	27.92	24.67	20.17	16.88	23.75	23.86	18.34
Octadecanoic acid (C ₁₈ H ₃₆ O ₂) - Stearic Acid	5.31	3	4.37	5.04	5	3	5.31	3.05	3.95	5
Eicosanoic acid (Arachidic acid) (C ₂₀ H ₄₀ O ₂)	0.75	0.81	0.94	0.26	0.24	0.2	0.2	0.2	0.2	0.2
Squalene (C ₂₂ H ₄₂ O ₂)	0.49	0.6	5.66	0.14	0.11	0.11	0.11	0.1	0.1	0.11

X₀ is control(unroasted okra seed), Okra seed oil of with roasting temperature and duration of (X₁: 103.43 °C – 25 min) (X₂: 120 °C – 10 min) (X₃: 120 °C – 40 min) (X₄: 160 °C – 3.79 min) (X₅: 160 °C – 25 min) (X₆: 160 °C – 46.21 min) (X₇: 200 °C – 10 min) (X₈: 200 °C – 40 min) (X₉: 216.57 °C – 25 min).

an excellent source of essential fatty acids. It is, therefore, suitable for cooking and has also been found applicable in margarine production. According to Awolu et al. [34], oils with high linoleic acid can be considered a healthy alternative to slightly hydrogenated vegetable oils. The result of the analysis also showed small quantities of Palmitoleic acid. Palmitic acid and Stearic acid were the major saturated fatty acid in the oil at 6.85 to 19.83% and 3.00 to 5.31%, respectively. The presence of Linoleic, Oleic and Palmitic acid was also confirmed in the reports published by Anwar et al. [4]. The fatty acid profile of okra seed oil found, as seen in Table 4, is comparable to reports by Anwar et al. [27], Awolu et al. [34], and Omoniyi et al. [35]. They also reported similar fatty acid compositions. The slight variations in the reported fatty acid may result from the differences in cultivar, biological origin, seed maturation, roasting temperature, roasting duration, type of solvent, method of extracting the oil, equipment, and method used for the analysis of the oil. However, there is not much difference in the fatty acid profile of the unroasted and roasted okra seed oil analyzed, which agrees with erstwhile studies like Chandrasekara and Shahidi [33] and Awolu et al. [34], who both reported no significant differences

in the fatty acid profiles of roasted cashew nut oil and okra seed oil respectively.

3.7. Granule morphology of ground roasted and unroasted okra seed

Fig. 6 shows the granule morphology of okra seed samples at the control and under different roasting temperatures and roasting duration. The grounded unroasted okra seed particle surface in samples a₁ and a₂ showed a smooth and compact cell with a network of intertwined tiny tissue fibers. However, there were gradual changes in the cell morphology, evident in samples c₁ and c₂; this showed that roasting at an increasing temperature significantly affected okra seed cells. The roasting temperature broke down and opened up the indigenous microstructure of the okra seed cells, which increased the permeability and subsequent increase in oil yield. Complete cell destruction in samples g₁ and g₂, which had the highest roasting duration, showed that a long duration of roasting could significantly impair the cell of okra seed. Also, cavities and intercellular apertures are evident in the micrographs of grounded roasted okra seeds, which according to Chen et al. [36], may be the

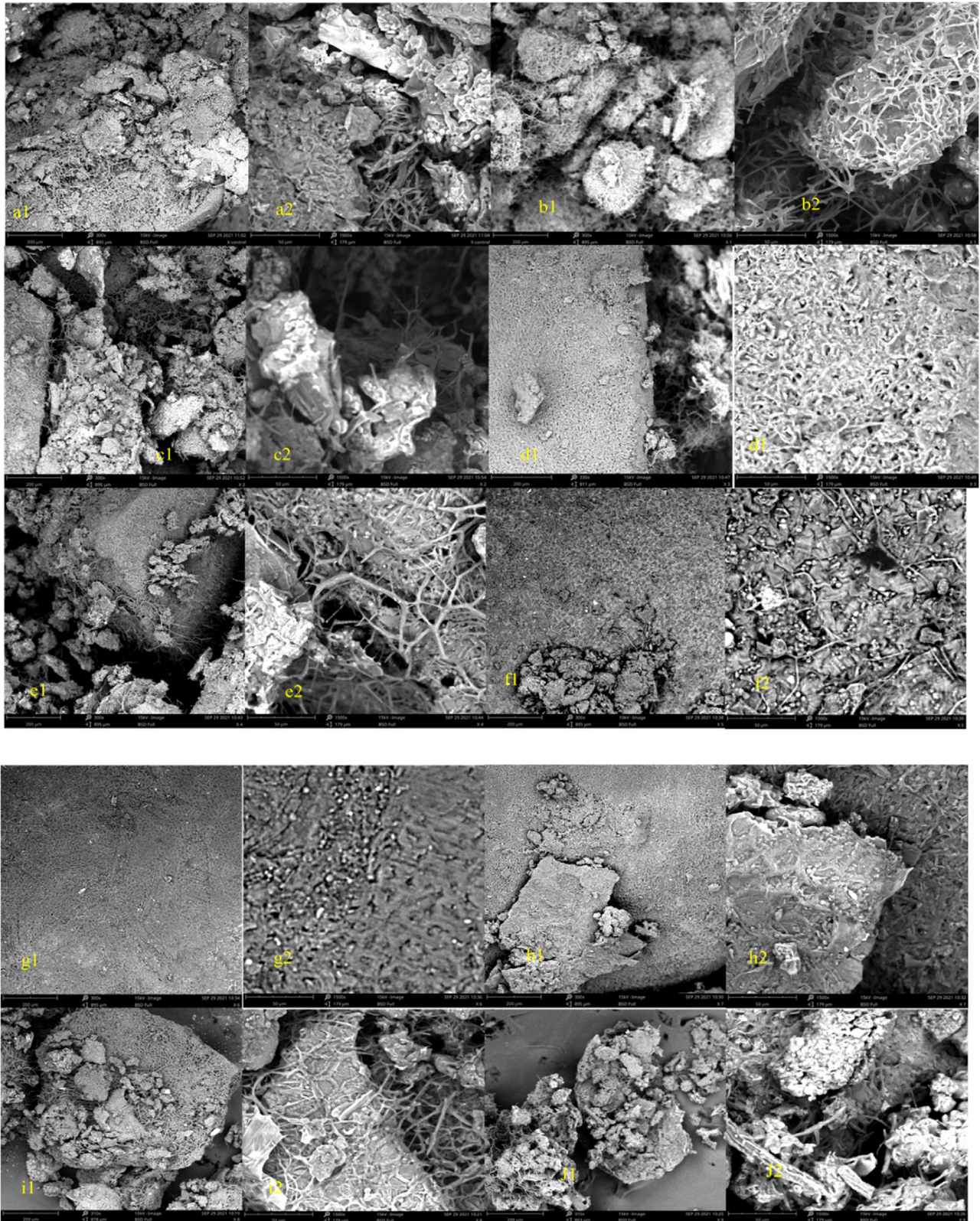


Fig. 6. Scanning electron micrograph at the same magnification and scale bar [x300 - x1500; 200 μm -50 μm]. (a1-a2) ground-unroasted okra seed; (b1-b2) okra seed roasted at 120 °C for 10 min; (c1-c2) okra seed roasted at 120 °C for 40 min; (d1-d2) okra seed roasted at 160 °C for 3.79 min; (e1-e2) okra seed roasted at 160 °C for 25 min; (f1-f2) okra seed roasted at 160 °C for 46.21 min; (g1-g2) okra seed roasted at 200 °C for 10 min; (i1-i2) okra seed roasted at 200 °C for 40 min; (j1-j2) okra seed roasted at 216.57 °C for 25 min.

result of the disintegration and destruction of cell walls. Bhavani et al. [37] also further reiterated that temperature and time are two critical factors in determining the morphology of a sample.

4. Conclusion

The oil extracted from okra seed of variety “NHAe47-4” gave an excellent oil yield and quality. The result obtained from the solvent extraction of edible oil from Okra seed showed that the optimum process parameters are 160 °C roasting temperature and 25 min roasting duration to get maximum oil yield (64.25%), moderate free fatty acids (6.49%), 16.92 for the colour change, and 0.94 for specific gravity. The study showed that roasting temperature and duration greatly influenced the extraction and quality of okra oil. From the Gas chromatography-mass spectroscopy analysis, Oleic acid is the primary monounsaturated fatty acid, with linoleic (25.57- 31.03%) being the primary polyunsaturated fatty acid. Palmitic and stearic were the major saturated fatty acids present at (6.86-19.83%) and (3.00-5.31%). The oil analysis showed that the okra seed oil contains a high degree of unsaturation, which is evident in the amount of linoleic acid that is the main constituent in the oil. This, in turn, further buttresses the nutritional desirability of Okra oil as it is oxidatively stable, and it can be inferred that the oil is rich in essential fatty acids and is a good source of edible oil.

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Declaration of Competing Interest

The authors declare that there are no conflicts of interest for the study.

CRediT authorship contribution statement

Rahman Akinoso: Conceptualization, Supervision, Funding acquisition, Data curation, Writing – original draft, Writing – review & editing. **Emmanuel Olatunde Adegoye:** Funding acquisition, Formal analysis, Writing – original draft, Data curation. **Mayowa Saheed Sanusi:** Supervision, Conceptualization, Formal analysis, Writing – review & editing.

Supplementary materials

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