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OPTIMIZATION OF ROASTING TEMPERATURE AND TIME DURING OIL EXTRACTION FROM ORANGE (*Citrus sinensis*) SEEDS: A RESPONSE SURFACE METHODOLOGY APPROACH

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ABSTRACT

Nutritionally, oils obtained from oilseeds provide the calories, vitamins and essential fatty acids in the human diet in an easily digested form. The rate of vegetable oil consumption is increasing compared with animal fat due to its low sterol. In addition to being nutritious, edible vegetable oils also have industrial uses. Separation of oil from oil seeds is an important processing operation because it affects the quality and quantity of oil obtained from the oil seeds. Literature on oil extraction from some cultivars of citrus seeds showed good potential, therefore, focus on optimization of oil extraction could enhance economic status of the seed. In this study, response surface modeling approach was employed to optimize oil extraction from orange (*Citrus sinensis*) seed. Each sample was roasted for 10, 20, 30, 40 and 50 minutes at temperatures of 110, 120, 130, 150, and 170 ^{o}C. The parameters analysed included oil yield, free fatty acid, color, refractive index, specific gravity and pH. The treatments resulted in oil yield ranging from 32.0 ± 2.7 to 56.0 ± 6.5 %, free fatty acid (0.3 ± 0.0 to 3.01± 1.7%), colour (3.45 ± 1.9 to 20.5 ± 1.8 abs), refractive index (1.4 ± 0.1 to 1.46 ± 0.1), specific gravity (0.87 ± 0.1 to 0.94 ± 0.0) and pH (4.05 ± 1.0 to 5.66 ± 1.1). Maximum oil yield of 56.0 ± 6.5 % was obtained after roasting citrus seed at 170 ^{o}C for 30 min. Roasting temperature and duration showed significant ($p < 0.05$) effect on oil yield, free fatty acid, colour and specific gravity of the oil. However, non-significant ($p > 0.05$) effect was recorded on refractive index and pH of the extracted oil. The computer software package (Design-Expert) used for optimization gave four possible optimum conditions with desirability ranging from 0.50 to 0.68. The best desirability (0.68) was achieved at roasting temperature and duration of 150^{o}C and 20 min., respectively. At these conditions oil yield was 52.6 ± 0.1%; free fatty acid, 1.4 ± 0.0%; colour, 4.7 ± 0.0 abs; specific gravity, 0.92 ± 0.0, and pH, 5.4 ± 0.1. The quantity, free fatty acid, colour and specific gravity of extracted oil from orange seed significantly depend on temperature at which the seed is roasted and duration of roasting.

Key words: Orange, Seed, Oil, Extraction, Yield

INTRODUCTION

Oil content of vegetable oil bearing seed, nut, kernel or fruit varies between 3% and 70% of the total weight [1]. Vegetable oils are chemically similar to animal fats, consisting of glycerol combined with fatty acid, but are liquid at room temperature. They are insoluble in water and hence are able to serve as a food reserve for the plant. The largest sources of vegetable oil are annual plants, which include soybean, corn, cottonseed, groundnut, sunflower, rapeseed, melon and sesame seed [2]. Other sources are oil bearing perennial plants such as olive, coconut, shea, cashew and palm. Several other oilseeds including canola, citrus seed and avocado have been identified [3].

Nutritionally, oils obtained from oilseeds provide the calories, vitamins and essential fatty acids in the human diet in an easily digested form. The rate of vegetable oil consumption is increasing compared with animal fat due to its low sterol [4]. Either than its nutritional use, edible vegetable oils often have industrial uses. The relatively oil-free residue of extracted seed is a valuable by product with many uses, including livestock feed, fertilizer and the manufacture of adhesives. Separation of oil from oil seeds is an important processing operation. The process employed has a direct effect on the quality and quantity of protein and oil obtained from the oil seeds [5].

Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques useful for the modelling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response. It differs from the procedure that involves the isolation of test variables and changing one variable at a time [6]. The RSM is important in designing, formulating, developing, and analyzing new scientific studies and products. The most common applications of RSM are in industrial, biological, clinical, social, food, physical and engineering sciences. It is also efficient in the improvement of existing studies and products. Response Surface Methodology tests several variables at a time, uses special experimental designs to cut costs and measures several effects by objective tests. The most important difference is that a computer takes the experimental results and calculates models, using Taylor second order equations, which define relationships between variables and responses [7]. The relationships are quantitative, cover the entire experimental range tested, and include interactions if present. The models can then be used to calculate all combinations of variables and their effects within the test range. Some reported applications of response surface methodology in food processing include optimization of protein extraction from fish waste [8] and enzymatic hydrolysis of defatted sesame flour [9].

Citrus species are grown principally for the juices of their fruits. Citrus fruit processing produces many by-products which could be used for the production of many other food products, pectin, seed oil and dietary fibers [10]. The essential oil extracted from the peel, primarily terpenes, is used in flowering, perfumery, pharmaceutical products and soap making industry. The dried citrus peel is used as cattle feed and for the production of molasses. Citric acid may be extracted from

lemon juice. The molasses can be fermented to prepare alcohol. An oil resembling olive oil can be extracted from citrus seed.

Literature on oil extraction from some cultivars of citrus seed showed good potential [11]. Focus on optimization of oil extraction from citrus seed will enhance economic status of the seed. The objective of the research was to optimize oil recovery from orange seed using response surface methodology. Pearson brown variety of orange (*Citrus sinensis)* seed was used for the study. This cultivar of citrus is widely grown in Nigeria.

MATERIALS AND METHODS

Experimental design

A central rotatable design for two variables was employed [6]. The independent variables were roasting temperature and duration while oil yield, free fatty acid, color, refractive index, specific gravity and pH of the oil were the dependent variables. Nine experimental combinations were generated, and last treatment repeated four times. The variables levels are as shown in Table 1. Factors considered in this study and their levels were based on information from literature and preliminary laboratory investigations. The experimental procedures were replicated three times; mean values were recorded as obtained data. Data were analysed using Design Expert Version 6.0.10 (Stat Ease Minneapolis, USA) software packaged to generate regression equations and Analysis of Variance (ANOVA) was which determined at 5% level of significance. Suitability of the models was determined by values coefficients of determination (R^2) and lack of fit test.

Preparation of materials

Oranges sourced from local market and classified in the Herbarium of Department of Botany, University of Ibadan, Nigeria. The juice was extracted manually after peeling and filtered to get seeds. Moisture content of the seed was determined using standard method [12]. Roasting temperatures were achieved by reported method [4]. The product's initial temperatures were raised to equilibrium with roasting temperature. This was achieved by wrapping them in polythene bags and placed in oven at desired roasting temperature level. For each treatment combination, 50 g of grounded sample were thinly spread in a petri-dish and placed in a preset oven at different temperatures (110, 120, 130, 150, 170^{o}C) and time (10, 20, 30, 40, 50.min) combinations. All chemicals used in the experiment were of analytical grade and were products of BDH Chemicals Ltd, Poole, England. The chemicals were obtained from Show Crown Laboratory, Iwo –road, Ibadan, Oyo – State, Nigeria.

Characterization of the oil

Sample of the extracted oil (un-treated) was fractionated by Thin-Layer Chromatographic (TLC model QIG-38, Quark Enterprises Inc. Vineland, NJ, USA) using hexane-ether-acetic acid (80:20:1) as developing agent. The spots were detected with 50% sulphuric acid and identified by comparison with standards. The relative percentage of each spot was measured on a scanning densitometer (Transidyne Model 2955, Transidyn General Corp. Ann. Arbor, MI, USA).

Fatty acid composition of the oil was determined by AOCS Ce 1-62 reported method [13]. The fatty acids were converted to their respective methyl esters prior to analysis. The oil sample (50µL) was methylated in 4ml KOH (1M) for one hour at room temperature. The resultant fatty acid methyl esters (FAME) were extracted with High Performance Liquid Chromatography (HPLC, model LC-2010, Shimadzo, Tokyo, Japan) grade hexane and analyzed by Gas Chromatograph (model GC-2010, Shimadzu, Tokyo, Japan) immediately using a fused capillary column (WCOT fused silica 30 m x 0.25 mm coating, CPWAX 52CBDF = 0.25 µM, CP8713), a flame ionization detector (FID) and nitrogen gas as carrier (3.5 ml/min). Gas Chromatograph split ratio was 100%. Injector and detector temperatures were 260^{o}C and column oven temperature was 222^{o}C for 7.5 min. The fatty acid methyl esters peaks were identified by comparing their retention time with those of standards.

Determination of oil yield

Oil extraction was done using AOAC 920.39C method [14]. Fifty grams of roasted sample was packed in a Whatman's filter paper and inserted into the Soxhlet extractor. Petroleum ether was used as the extracting solvent. After six continuous hours of extraction, solvent was recovered by simple distillation and the residual oil was oven-dried at 65 ± 2°C for one hour. The sample was cooled in desiccator's before being weighed. Drying, cooling and weighing processes were repeated until a constant dry weight was obtained. Oil yield in percentage was calculated using Eq. 1.

$$percentage\ oil\ yield = \frac{weight\ of\ extracted\ oil}{weight\ of\ seed\ samples}\ X\ 100 \qquad (1)$$

Determination of free fatty acid (FFA) content of the oil

Free fatty acid (FFA) was calculated using the AOCS method Ca5a – 40 [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 0.5N NaOH, vigorously shook until a permanent faint pink colour appeared and persisted for 15 sec. The percentage of FFA in the sample was calculated as stated below (Equation 2)

$$\%\ FFA = \frac{titration\ (ml) * 0.141 * 100}{wt\ of\ sample\ used} \qquad (2)$$

Determination of oil color

The color of the oil was determined according to AOCS Cc 13c -50 standard methods [15] with the aid of a spectrophotometer (UVIKON XL, North Star Scientific, Leeds, UK).

Determination of refractive index

This was determined using the Abbe refractometer. The refractometer was first standardized to 1.3333 using distilled water at a temperature of 25 ^{o}C. This water was cleaned off with tissue paper and replaced with about 0.5 g of oil sample. The dark

and light regions of the refractometer were adjusted to meet at an intercept of a crossbar before the readings were taken.

Determination of specific gravity

An empty pycnometer bottle was weighed, filled with water and reweighed. The oil was poured into the cleaned, dried bottle and the weight noted. The specific gravity was calculated using Equation 3.

$$specific\ gravity = \frac{wt\ of\ bottle\ and\ oil\ sample - wt\ of\ empty\ bottle}{wt\ of\ bottle\ and\ water - wt\ of\ empty\ bottle} \quad (3)$$

Determination of pH

The pH meter was used at 27^{o}C. Ten grams of each oil sample were homogenized in 50 ml of distilled water. The resulting suspension was decanted and their pH determined. The pH meter was standardized using a standard buffer of pH 4.0 and sterilized water.

Optimization

The combinations of roasting temperature and duration that produce best results were obtained using a commercial statistical package (Design-Expert, Stat ease Inc., Minneapolis, USA). Oil yield was maximized; the free fatty acid content of the oil was minimized while pH, specific gravity and oil color were kept at acceptable recommended range by FAO/WHO Food Standard [16].

RESULTS

Chemical composition of the oil

Moisture content of orange seed used for the study was 13.30 ± 1.05% wb. The principal components of orange seed oil were triglycerides (78.62 ± 3.71%), free fatty acid (4.86 ± 0.91%), sterols (3.01 ± 0.50%), sterol esters (2.51 ± 0.73%), hydrocarbon (3.04 ± 0.11%), diglycerides (2.95 ± 0.13%), monoglycerides (2.37 ± 0.08%) and alcohol (2.08 ± 0.00%). Oleic, linoleic, palmitic and stearic in percentage proportion of 43.03 ± 1.13, 24.11 ±1.66, 10.60 ± 0.74 and 7.90 ± 0.90, respectively, were the main fatty acids contents. Minor fatty acids in the oil include lauric (2.96 ± 0.20%), linolenic (4.3±0.00 %), myristic (0.89 ±0.01 %) and eicosenoic (0.67 ±0.00%).

Oil yield

From Table 2, maximum oil yield extracted from 50 g of the orange seed was 28.0 g, which is equivalent to 56.0 ± 6.5 % of the raw material. This was achieved at 170 ^{o}C roasting temperature and 30 min. roasting duration. Minimum oil yield extracted from 50 g of orange seed was 16.0 g, which is equivalent to 32.0 ± 2.7% of the raw material. This was achieved at 110 ^{o}C roasting temperature after roasting for 30 min. Analysis of variance of the data showed significant effect ($p<0.05$) of treatment on response. This indicates variation of roasting temperature and duration affects oil yield. Response surface plot of the interaction is shown as Fig. 1.

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Where roast dura is roasting duration and roast temp is roasting temperature

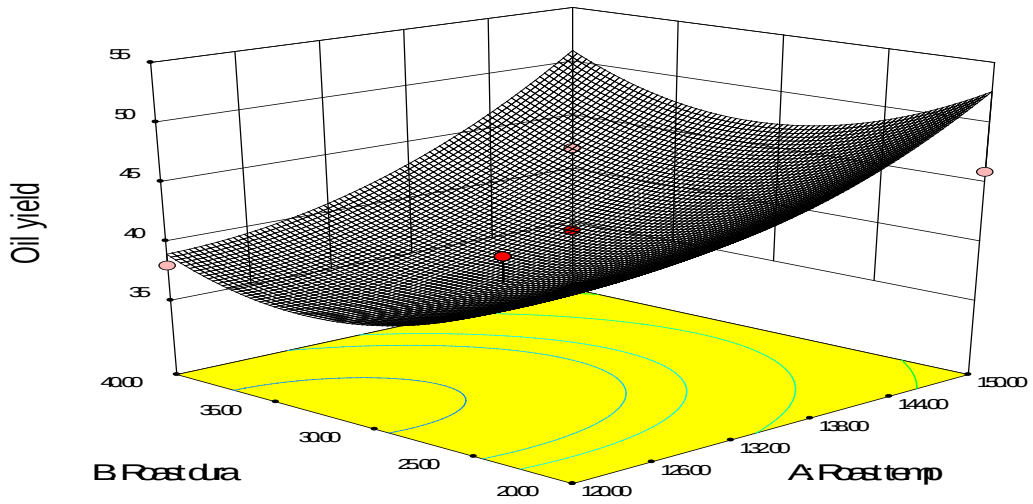

Figure 1: Plot of roasting temperature and duration against oil yield

Free fatty acid (FFA)

The maximum value of free fatty acid content of the oil was 3.1 ± 1.7% recorded at 170 ^{o}C roasting temperature and 30 min roasting duration while the minimum free fatty acid was 0.3 ± 0.0% oleic recorded at 150 ^{o}C roasting temperature and 40 min roasting duration (Table 2). Effect of both roasting temperature and duration was significant ($p<0.05$). Visual illustration of the relationship is shown as Fig. 2. Decrease in FFA was observed with increase in roasting temperature and duration.

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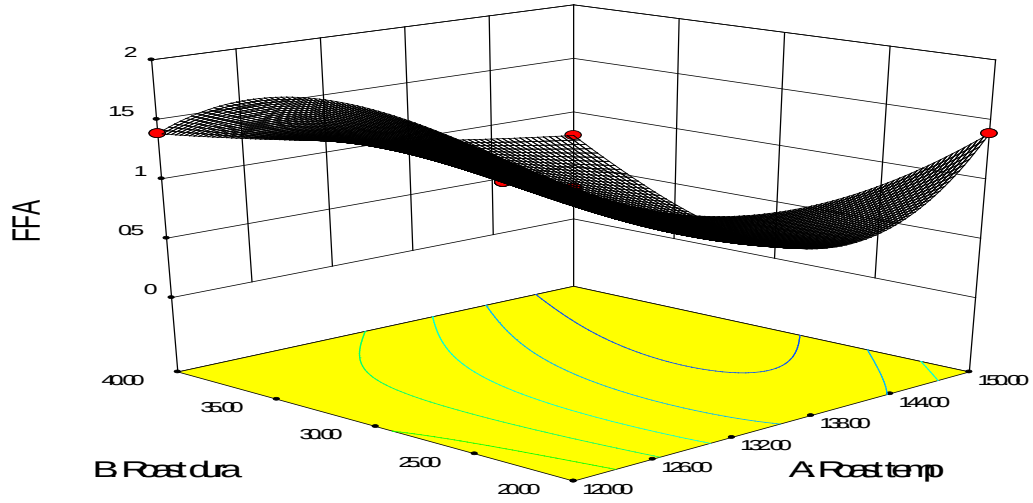

Figure 2: Response plot of roasting temperature and duration against free fatty acid

Colour

Colour intensity of the oils ranged from 3.4 ± 1.9 to 20.5 ± 1.8 abs. The oil color was significantly ($p<0.05$) dependent on heat treatments. Increase in both roasting temperature and duration increased colour intensity of the extracted oil (Fig. 3). The response plot revealed polynomial.

Where roast dura is roasting duration and roast temp is roasting temperature

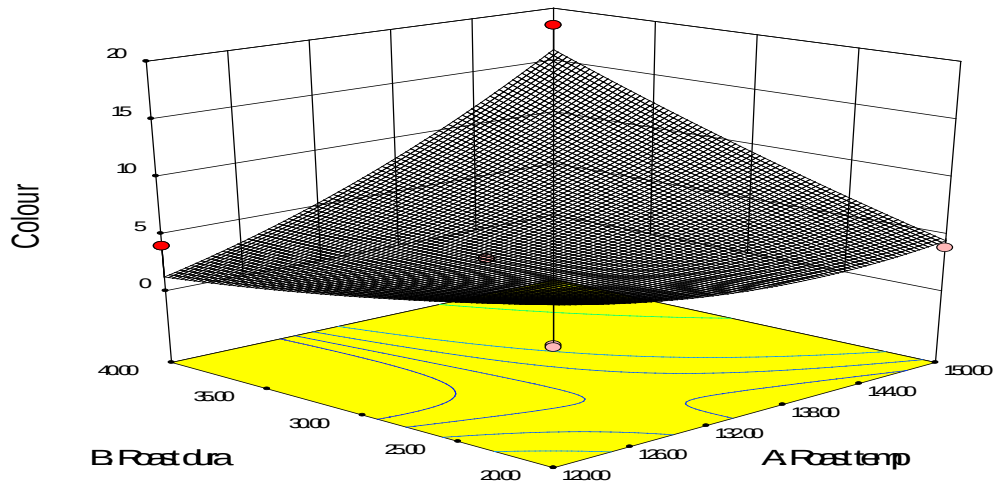

Figure 3: Response surface plot of roasting temperature and duration against colour

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Refractive index

Recorded mean value for refractive index was 1.42 ± 0.06. The treatments did not influence the oil refractive index significantly ($p > 0.05$). From Fig. 4, decrease in refractive index of the oil was observed with increase in both roasting temperature and duration.

Where roast dura is roasting duration and roast temp is roasting temperature

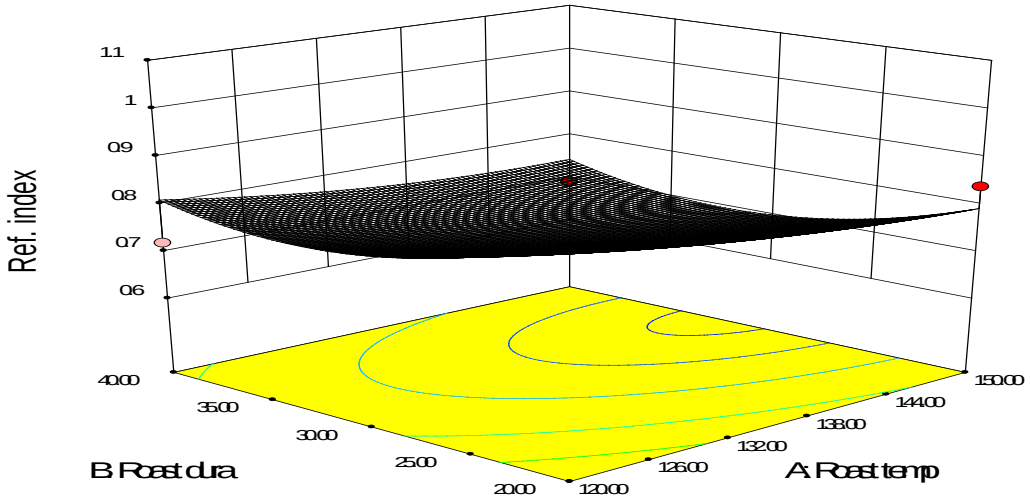

Figure 4: Response surface plot of roasting temperature and duration against refractive index

Specific gravity

The maximum specific gravity of the oil (0.94 ± 0.00) was achieved at 150 ^{o}C roasting temperature and 20 min roasting duration while the minimum specific gravity of 0.87 ± 0.10 was achieved at 170 ^{o}C roasting temperature and 30 min roasting duration (Table 2). A difference of 0.07 was obtained between the maximum and minimum value. The mean value of 0.91 ± 0.06 was recorded. Statistical analysis of the data showed significant effect of roasting temperature and duration on specific gravity at 5% level of significance. Graphical illustration of the relationship showed a polynomial effect (Fig. 5).

Where roast dura is roasting duration and roast temp is roasting temperature

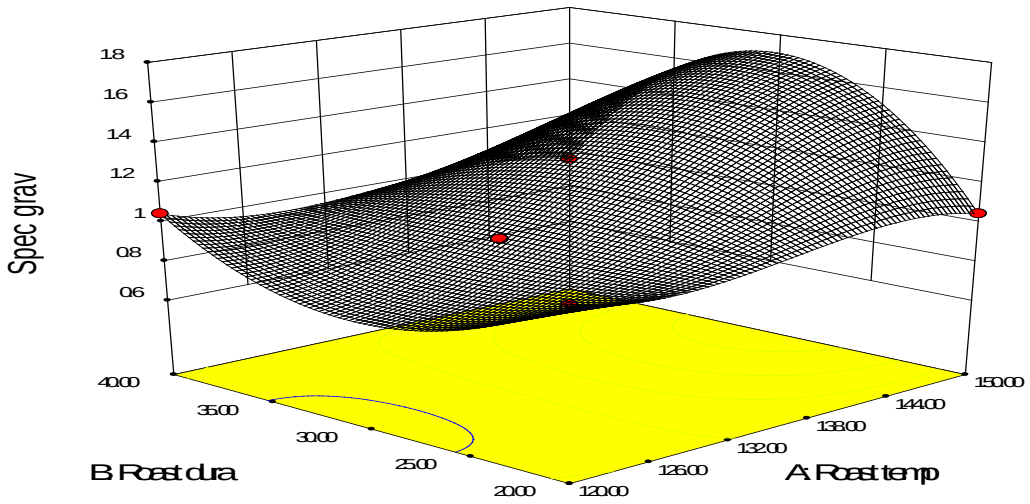

Figure 5: Response surface plot of roasting temperature and duration against specific gravity

Oil pH

The highest pH value of 5.66 ± 1.1 was recorded at 120^{o}C and 20 min. roasting temperature and duration respectively. While roasting temperature of 150 ^{o}C and 40 min. roasting duration gave least value of 4.05 ±1.0 (Table 2). The response surface plot for the effect of roasting temperature and duration on pH of orange seed oil (Fig 6) showed marginal decrease in acidity level of the oil with increase in both roasting temperature and duration. Outlook of the plot is closed to being linear with saddle point at center. Statistical analysis of the data revealed non- significance ($p>0.05$) influence of treatment on pH values of the oil.

Where roast dura is roasting duration and roast temp is roasting temperature

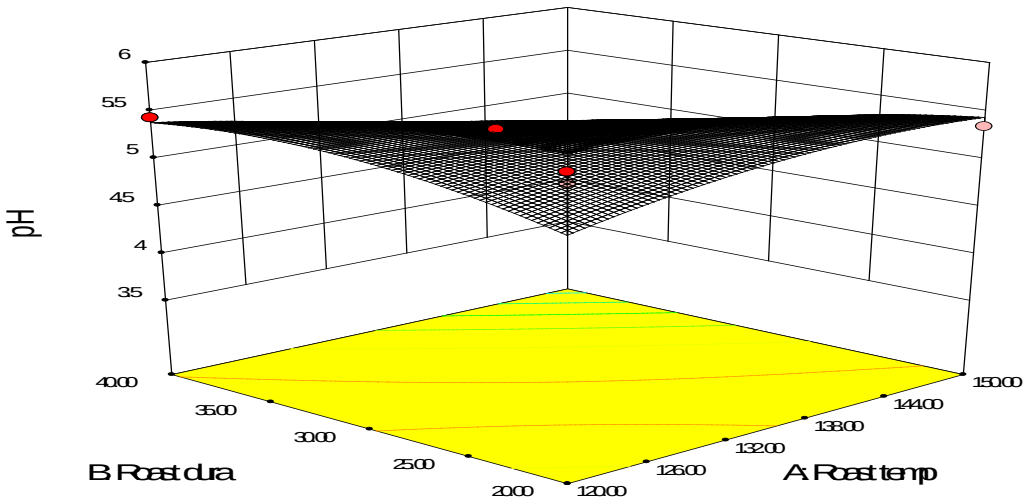

Figure 6: Response surface plot of roasting temperature and duration against pH

Models

Using the obtained empirical data, model equations to predict the effects of roasting temperature and duration on oil yield, free fatty acid, color, refractive index, specific gravity and pH of the oil generated are presented as Eqs. 4 to 9, respectively. Based on lack of fit test and coefficient of determination R^2, quadratic model was appropriate for oil yield (OY), pH, refractive index (RI), and colour (CO) while cubic model was found to be suitable to express the specific gravity (SG) and free fatty acid content (FFA) of the oil. Where X_1 is roasting temperature (^{0}C) and X_2 is roasting duration (min).

$$OY = +290.9 - 3.2X_1 - 3.7X_2 + 5.9x10^{-3}X_1X_2 + 1.2x10^{-2}X_1^2 + 4.6x10^{-2}X_2^2 \quad (4)$$
$$R^2 = 0.83, \quad P - value = 0.014$$

$$FFA = +0.79 - 0.86X_1 + 0.26X_2 - 0.13X_1X_2 + 0.22X_1^2 - 0.25X_2^2 - 0.67X_1^2X_2^2 + 0.20X_1X_2^2 + 0.25X_1^3 \quad (5)$$
$$R^2 = 0.67, \quad P - value = 0.001$$

$$CO = +215.9 - 2.5X_1 - 3.9X_2 + 0.03X_1X_2 + 6.8x10^{-3}X_1^2 + 5.0x10^{-3}X_2^2 \quad (6)$$
$$R^2 = 0.91, \quad P - value = 0.002$$

$$RI = +3.7 - 0.03X_1 - 0.05X_2 + 6.6x10^{-5}X_1X_2 + 8.6x10^{-5}X_1^2 + 7.0x10^{-4}X_2^2 \quad (7)$$
$$R^2 = 0.80, \quad P - value = 0.24$$

$$SG = +120 + 0.64X_1 - 0.03X_2 - 0.02X_1X_2 + 0.02X_1^2 - 0.19X_2^2 + 2.8x10^{-3}X_1^2X_2 - 0.5X_1X_2^2 - 0.2X_1^3 \quad (8)$$
$$R^2 = 0.91, \quad P - value = 0.001$$

$$pH = -14.9 + 0.23X_1 + 0.41X_2 - 2.4x10^{-3}X_1X_2 - 6.13x10^{-4}X_1^2 - 1.8x10^{-3}X_2^2 \quad (9)$$
$$R^2 = 0.77, \quad P - value = 0.3$$

Optimum parameters

The computer software package (Design Expert Version 6.0.10, Stat Ease Minneapolis, USA) used for optimization gave four possible optimum conditions with desirability ranging from 0.50 to 0.68. The best desirability (0.68) was achieved at roasting temperature and duration of 150 ^{o}C and 20 min. At these conditions, oil yield was 52.6 ± 0.1%; free fatty acid, 1.4 ± 0.0%; colour, 4.7 ± 0.0 abs; specific gravity, 0.92 ± 0.0, and pH, 5.4 ± 0.1. The optimum oil yield (52.6 ± 0.1%) is lower than the maximum oil yield (56 ± 6.5%) obtained in this study.

DISCUSSION

Chemical composition of the oil

Application of oils is a function of chemical properties. Chemical compositions of orange seed oil suggest it bears the properties of unsaturated oil. The results agreed with the previous findings that palmitic, oleic and linoleic acids are the major components in the lipid of seeds from three species of citrus namely *Citrus sinensis*, *Citrus paradise* and *Citrus aurantium* [17].

Oil yield

Maximum percentage oil recovered was higher than 36% and 36.5% reported for un-roasted *Citrus Sinesis* seed by *Nwobi et al.*[11] and *Waheed et al.* [17], respectively. Difference of 24% recorded between the maximum and minimum oil yield is an indicator of remarkable influence of heat treatment on orange seed oil yield. This concurs with findings that treatments determine the percentage of oil yield from coconut [18]. A similar finding was also reported on palm kernel [4]. Heating of oilseeds breakdown oil cells, coagulation of the protein, adjust moisture contents of the meal to optimal value for extraction and reduce oil viscosity. All these effects allow easy flow of oils [19]. Trend of the plot (Fig. 1) suggests that increase in roasting temperature beyond 150 ^{o}C might further increase the oil yield. A similar observation was reported for cramble seed [20].

Free fatty acid (FFA)

The findings agreed with earlier report that temperature affects edible oil and fats stability [21]. From Table 2, out of the 13 treatments, only two combinations

produced FFA values that were not within the acceptable permissible level as recommended by FAO/WHO [16]. The recommended maximum permissible FFA is 2.0% for virgin vegetable oil. This may be attributed to inactivation of lipase enzyme [2]. A reduction in FFA content of vegetable oil enhances the quality grade.

Colour

The colour of the food products is the first attribute that affects the decision of consumer for purchasing or consuming any food [22]. Shape of response surface plot is an indication of irregular effect of heat treatment on the appearance. Similar trend was observed on bread colour as result of variation in baking temperature and time [23]. Oil color is understood to be due to the presence of carotenoid and chlorophyll pigments. It is noteworthy that co-oxidation of carotein and fatty acid cause significant color formation during thermal process [2]. High temperature accelerates oxidation with an attendant colour rise. Since there was no oil bleaching absorbent in the treated samples, oxidation and colour fixation are prone to occur thus causing the observed dark red colour recorded at high temperature and lengthy roasting duration.

Refractive index, specific gravity and pH

The refractive index as a quality factor allows rapid sorting of oils suspected of adulteration. It is a measure of oil purity. The mean value of refractive index (1.42 ± 0.06) obtained for orange seed oil in this study is indicative of the high degree of purity of the oil. Refractive index is a function of heat treatment [3]. The range of recorded specific gravity was comparable with 0.92 from literature [24]. When considering the quality or purity of oil, specific gravity is of diagnostic value. It is used in assessing the weight of oil in bulk shipment or oil stored in large tanks, and for the design of piping and tanks for storage. Recorded pH confers a reasonable stability on the oil. Low level of acidity indicates presence of low fatty acid, and better nutritious value.

Models and optimum parameters

A coefficient of determination of 0.0 is worst while 1.0 is best. The coefficients of determination, R^2 were OY (0.83), CO (0.91), RI (0.80) and SG (0.91), which were indications of good fitness. That is, the models can be used to navigate the design space with fewer errors at 5% level of significance. The desirability lies between 0 and 1; and it represents the closeness of a response to its ideal value. If a response falls within the unaceptable intervals the desirability is 0 and if it falls within the ideal intervals or the response reach as to ideal value, the desirability is 1. The optimum oil yield (52.6 ± 0.1%) is lower than the maximum oil yield (56 ± 6.5%) obtained in this study. This is expected because of compromises to achieve the conditions. However, the value is greater than 36% and 36.5% reported for un-roasted *Citrus Sinesis* seed *Nwobi et al.*[11] and *Waheed et al.* [17], respectively. It should also be noted that based on FAO/WHO standard [16], the optimum roasting conditions produced crude orange seed oil with acceptable quality parameters.

CONCLUSIONS

Orange (*Citrus sinensis*) seed contains high quantity of unsaturated oil and it is a potential source of vegetable oil. The quantity and some quality parameters of extracted oil from orange seed depend on the temperature at which the seed is roasted and the duration of roasting. Generated model equations can be applied to predict orange seed oil yield at 83% accuracy, free fatty acid content at 67% accuracy, colour at 91% accuracy, refractive index at 80% accuracy, specific gravity at 91% accuracy and pH at 77% accuracy of any given roasting temperature and roasting duration. Roasting temperature and duration of 150 ^{o}C and 20 min respectively, will produce high oil yield 52.6 ± 0.1%; low free fatty acid (1.4 ± 0.0%); moderate colour (4.7 ± 0.0 abs); acceptable specific gravity (0.92 ± 0.0), and pH (5.4 ± 0.1).

Table 1: Experimental design matrix

Variables		Levels				
Code		-1.414	-1	0	1	1.414
Roasting Temperature (^{o}C)	(Actual)	110	120	130	150	170
Roasting Duration (min.)	(Actual)	10	20	30	30	50

Table 2: The treatment combinations and obtained responses

RUN	RT [^{o}C]	RD [min]	OY* [%]	FFA* [%]	CO* [abs]	RI*	SG*	pH*
1	120	20	48.6 ± 3.2	1.39 ± 0.9	3.45 ± 1.9	1.41± 0.1	0.94 ± 0.2	5.66 ± 1.1
2	150	20	46.8 ± 4.9	1.41 ± 0.7	3.90 ± 2.1	1.44 ± 0.1	0.94 ± 0.1	5.35 ± 0.9
3	120	40	38.4 ± 3.7	1.41 ± 1.1	4.05 ± 1.9	1.42 ± 0.2	0.94 ± 0.0	5.44 ± 1.1
4	150	40	42.8 ± 7.2	0.30 ± 0.0	18.42 ± 3.6	1.41 ± 0.4	0.93 ± 0.1	4.05 ± 1.0
5	130	50	53.4 ± 4.6	2.25 ± 0.9	3.96 ± 2.1	1.46 ± 0.1	0.88 ± 0.1	4.70 ± 0.7
6	130	10	50.8 ± 8.1	1.41 ± 1.2	8.49 ± 1.2	1.46 ± 0.7	0.91 ± 0.3	4.65 ± 0.1
7	170	30	56.0 ± 6.5	3.10 ± 1.7	20.5 ± 1.8	1.40 ± 0.0	0.87 ± 0.1	4.38 ± 0.7
8	110	30	32.0 ± 2.7	1.69 ± 0.8	4.92 ± 1.2	1.41 ± 0.2	0.89 ± 0.0	4.88 ± 0.6
9	130	30	41.2 ± 7.3	1.12 ± 1.0	4.14 ± 0.7	1.41 ± 0.2	0.91 ± 0.5	5.44 ± 1.2
10	130	30	40.4 ± 4.0	1.12 ± 0.9	4.13 ± 0.4	1.40 ± 0.2	0.91 ± 0.1	5.42 ± 1.2
11	130	30	41.0 ± 4.1	1.12 ± 0.3	4.14 ± 2.1	1.41 ± 0.4	0.91 ± 0.3	5.41 ± 1.0
12	130	30	41.6 ± 5.3	1.10 ± 0.6	4.12 ± 1.2	1.40 ± 0.2	0.92 ± 0.0	5.42 ± 0.8
13	130	30	41.4 ± 5.2	1.12 ± 0.5	4.15 ± 1.0	1.42 ± 0.1	0.91 ± 0.3	5.44 ± 1.1

*Recorded values are mean of three determinations ± Std.
Where: RT is roasting temperature; RD is roasting duration ; OY is oil yield ; FFA is free fatty acid ; CO is oil colour ; RI is refractive index ; SG is specific gravity ; pH is acidity of the oil.

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