

Effects of Process Parameters on the Yield of Oil from Coconut Fruit

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Abstract—Analysis of the properties of coconut (*Cocos nucifera*) and its oil was evaluated in this work using standard analytical techniques. The analyses carried out include proximate composition of the fruit, extraction of oil from the fruit using different process parameters and physicochemical analysis of the extracted oil. The results showed the percentage (%) moisture, crude lipid, crude protein, ash and carbohydrate content of the coconut as 7.59, 55.15, 5.65, 7.35 and 19.51 respectively. The oil from the coconut fruit was odourless and yellowish liquid at room temperature (30°C). The treatment combinations used (leaching time, leaching temperature and solute: solvent ratio) showed significant differences ($P < 0.05$) in the yield of oil from coconut flour. The oil yield ranged between 36.25%-49.83%. Lipid indices of the coconut oil indicated the acid value (AV) as 10.05NaOH/g of oil, free fatty acid (FFA) as 5.03%, saponification values (SV) as 183.26mgKOH⁻¹g of oil, iodine value (IV) as 81.00 I₂/g of oil, peroxide value (PV) as 5.00 ml/ g of oil and viscosity (V) as 0.002. A standard statistical package minitab version 16.0 program was used in the regression analysis and analysis of variance (ANOVA). The statistical software mentioned above was also used to generate various plots such as single effect plot, interactions effect plot and contour plot. The response or yield of oil from the coconut flour was used to develop a mathematical model that correlates the yield to the process variables studied. The maximum conditions obtained that gave the highest yield of coconut oil were leaching time of 2hrs, leaching temperature of 50°C and solute/solvent ratio of 0.05g/ml.

Keywords—Coconut, oil-extraction, optimization, physicochemical, proximate.

I. INTRODUCTION

SEED oils have been rated as the second most valuable commodity in the world trade today [1]. Coconut is the fruit of *Cocos nucifera* L., a palm which grows within the tropics, generally on the littoral, an alluvial soil, with high temperature, high rainfall and sunshine being preferred. It is one of the most extensively grown and used nuts in the world and is rated as one of the most important of all palms [2], [3]. World production in 1969 was estimated to be 3296500 tonnes of copra and 29765 million nuts [4]. As a smallholders' crop, the palm provides building materials (palm fronds and tree trunks), fibre goods from the husk (coconut matting, ropes and packing), fuel (shell and shell charcoal), food (protein and oil

from flesh) and drink (the 'water' from inside the kernel). The nuts are available throughout the year and enter international trade as copra, oil, nuts and desiccated coconut. Many countries depend on exports of one of these as a major source of export earnings.

In plantation, trees may be planted at about 10m intervals and annual yields of 60 nuts per tree can be expected, though yields of 120 are common in well-run plantations: smallholders may get only 20 to 30 nuts. Fodder and foods crops may be grown under the palms and the grazing of cattle is beneficial.

The coconut has been a traditional food in practically all the countries where it is grown and the quantity of fresh coconuts consumed locally varies from over 90% of the total production, for example in Thailand, to less than 2% of the total production in the Philippines. Coconut enters into the diet of the people in many ways; in the form of tender nuts used for their water, mature nuts for cooking and the preparation of sweetmeats, and oil for home consumption [5]. Probably the best-known product is coconut milk, the oil/protein/water emulsion obtained when the grated fresh coconut meat (endosperm) is squeezed through a muslin cloth. Coconut can also be used to produce desired texture in cookies, candles, cakes, pies, salads and desserts. Coconut is commercially viable because of its rich nutritive values [6], [7]. While the proximate analyses to estimate the food values of the fruit preceded the main which is parameters effect on the yield of oil from the flour and the physicochemical analysis of the extracted oil were also carried out. Many researchers in the past have worked in this area of the effects of process conditions on the yield of oil from local seeds [8]. However, their efforts were centred more on one-factor effect. Definitely, this type of treatment does not address the true position of the system where many other factors are at play simultaneously. It is based on this fact that a factorial design technique is applied in order to consider the interactive effects of the key parameters on the yield of oil. This provides the statistical power and framework for a more realistic analysis of the problem [9]. Extraction of oil from crushed seeds/fruits is by leaching process which is mainly affected by the following: leaching time, leaching temperature and solute-to-solvent ratio. Analysis of variance (ANOVA) will be applied to the results of the experimental design in the statistical analysis.

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II. MATERIALS AND METHODS

A. Collection and Processing of Sample

The coconut fruits were bought from a shop at New market, Enugu, Enugu State, Nigeria. The fruits were taken to Food Science and Technology laboratory of the Institute of Management and Technology (IMT) Enugu. Standard methods for sample processing, preparation and analytical procedures were used.

The coconut fruit passed through various processing steps in the course of its preparation for extraction. Healthy coconuts were husked manually with knife and the inner hard shells removed. It was then carefully broken and the fruit collected and sun-dried after cutting to small sizes to reduced the moisture content thereafter, it was milled manually using milling machine, wrapped in polythene bag and kept in a desiccator until needed.

B. Proximate and Lipid Indices Analysis

Proximate analysis tells the food value and nutritional composition of the food. Proximate analysis was carried out on the coconut flour to determine the percentage moisture, crude fat, ash, protein and carbohydrate contents using standard method of analysis. The moisture content of the processed sample was determined by the gravimetric method of AOAC. The crude fat content of the minced sample was extracted by soxhlet apparatus method as described by [10], [11]. The crude protein was determined by the Kjeldahl method, the protein was calculated using the general factor 6.25 [12]. The percentage ash content of the sample was determined gravimetrically by the method of AOAC, while the percentage carbohydrate content was estimated as the nitrogen free extract (NFE) as outlined in [12]. The results of the proximate analyses are presented in Table II.

C. Physicochemical Analyses of Oil

A standard procedure of American oil chemist society was used for the lipid indices values, acid and peroxide values were determined as outlined by [12]. The indicator method was used in determining the saponification value as outlined by Pearson [13]. The iodine value was determined by Wij's method as described by [10], [11]. The refractive index of the oil sample was determined using a refractometer according to [7]. The specific gravity of the castor oil sample was described using pycnometric method as described by [14], while the viscosity was determined using a viscometer according to the method outlined by [12]. The results are shown in Table III.

D. Oil Extraction

The extraction of oil from the processed flour was done using solid-liquid extraction otherwise known as leaching.

The Treatment Combination: The treatment combinations variables are: leaching time (x_1), leaching temperature (x_2) and concentration (x_3). The weighed flour sample was dispersed in the given volume of solvent and subjected to the heating temperature and time in a water bath. At the end of the process, the supernatant (oil solvent mixture) was decanted out and centrifuged at 900rpm for 5minutes. The clear transparent

liquid obtained after centrifuge was then evaporated completely in a hot air oven and the oil was cooled, weighed and the yield calculated. The % oil yield was calculated thus:

$$\% \text{oilyield} = \frac{\text{weight of extracted oil}}{\text{wt. of sample}} \times \frac{100}{1} \quad (1)$$

III. EXPERIMENTAL DESIGN

The experiment was designed using Minitab software version 16.0 to determine the influence of leaching time, leaching temperature and solute/solvent ratio as parameters in extraction of oil from the coconut. The three parameters were investigated at two levels (low and high). Eight experiments were obtained and the detailed experimental design is presented in Table I.

TABLE I
EXPERIMENTAL DESIGN SHOWING THE TREATMENTS GIVEN TO COCONUT FLOUR (COF)

S/No	Code	X_1	X_2	X_3
1	COF ₁	1	40	2:40
2	COF ₂	2	50	2:40
3	COF ₃	2	40	2:30
4	COF ₄	2	40	2:40
5	COF ₅	1	40	2:30
6	COF ₆	2	50	2:30
7	COF ₇	1	50	2:40
8	COF ₈	1	40	2:30

COF = Coconut Flour; X_1 = Leaching Time (hr); X_2 = Leaching Temperature ($^{\circ}\text{C}$); X_3 = Solute; Solvent ratio (g/ml).

The mathematical model equation that correlates the yield to the process variables is given by:

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_{12} + b_{13}x_{13} + b_{23}x_{23} \quad (2)$$

where Y is the predicted response, a, the value of the fixed response or intercept; b_1 , b_2 , b_3 are the linear coefficients for the input factors x_1 , x_2 , and x_3 ; b_{12} , b_{13} , b_{23} are the interaction effect coefficients and regression terms, respectively; x_{12} , x_{13} , x_{23} , ... are the levels of independent variables. The yield/result of the two-level three-factor experiment is shown in Table IV.

IV. RESULTS AND DISCUSSION

TABLE II
PROXIMATE COMPOSITION OF THE COCONUT FRUIT

Components	Coconut %*
Moisture	7.590±0.014
Fat	55.150±1.202
Protein	5.650±0.212
Ash	7.350±0.354
Carbohydrate	19.510±1.146

*Data are means of duplicate determination ± SD

Table II shows the proximate composition of the coconut fruit. The proximate composition being the nutrient compositions showed high values of fat and carbohydrate content in the fruit. The high fat content in coconut suggests it as a good source of edible oil which when ingested metabolizes to give energy and other fat soluble vitamins. The good source of energy is also confirmed by the relatively high

carbohydrate content of the fruit. The percentage protein content of the fruit (5.7) is however lower than what is obtainable in beans which ranged between 7.5%-40% [15]. According to [10], food plants that provide more than 12% of its calorific values from protein is considered good source of protein, therefore coconut with 5.7% calorific value did not meet this requirement and as such not rich source of protein.

TABLE III
PHYSICO-CHEMICAL COMPOSITION OF THE EXTRACTED OIL

Parameters	Coconut oil*
V	0.002±0.000
R/I (30-40°C)	1.361±0.170
AV (mg NaOHg ⁻¹ of oil)	10.050±0.071
SG	0.900±0.004
PV (mlg ⁻¹ of oil)	5.000±0.000
IV (12g 100g ⁻¹ of oil)	81.000±1.414
SV (mgKOHg ⁻¹ of oil)	183.260±0.085
FFA (%)	0.550±0.014

*Data are means of duplicate determination ±SD

V = viscosity, RI = Refractive index AV = Acid value, SG = Specific gravity, PV = Peroxide value, FFA=Free Fatty Acid.

Table III shows the physicochemical composition of the coconut fruit oil. The oil exhibited low viscosity (0.002cP) and thus may be suitable as penetration fluid (lubricant). The peroxide value of the coconut oil (5.00 mlg⁻¹ of oil) compared favorably with the range (0.39-7.4) reported for non-conventional seed oils in Nigeria and Congo Brazzaville [16]-[18]. Fresh oils have peroxide values less than 10meq/kg [10], [19]. The low peroxide value of this oil is indicative of low level of oxidative rancidity of the oil and suggests the presence of high level of antioxidant.

The saponification value of the oil (183.2mgKOHg⁻¹ of oil) is lower than the values reported by numerous authors for some plant seeds and most conventional oils sold in the Nigerian market. A relative high saponification value of oil indicates that the oil has potential for use in the industries especially in soap manufacturing industries [7], thus coconut oil may not be recommended for this. Acid value is used as an indicator for edibility of oil and stability for use in the paint industry. The acid value of the oil studied fell within allowable limits for edible oils [19], therefore the oil is edible.

TABLE IV
YIELD OF OIL FROM THE COCONUT FLOUR

S/No	Sample treatment			Coconut*
	(x ₁)	(x ₂)	(x ₃)	%
1	1	40	40	44.12±0.19 ^a
2	2	50	40	49.50±0.71 ^b
3	2	40	30	48.30±0.28 ^c
4	2	40	40	49.83±0.39 ^b
5	1	50	30	36.25±0.35 ^d
6	2	50	30	46.03±0.11 ^e
7	1	50	40	47.5±0.07 ^f
8	1	40	30	45.96±0.23 ^c

*Data are means of duplicate determination ± SD

Data bearing different superscripts in the column differed significantly (P≤0.05). For instance, the oil yield of flour for samples 1 and 2 differed significantly hence the super scripts "a" and "b" respectively. This could be attributed by variation in the parameters.

x₁ = Leaching time (hr); x₂ = Leaching temperature (°C); x₃ = Vol. of solvent used to extract oil from 2g of flour sample.

Table IV shows the result of percentage oil yield from coconut flour. From the table, the treatment given to the flour in order to obtain oil yield have significant differences on the sample. The treatments given to samples 2 and 4 have no significant difference in their oil yield and likewise samples 6 and 8 but the treatment given to samples 3, 5 and 7 differed significantly. The percentage oil yield for coconut ranged between 36.25%- 49.83% and the highest yield was seen in sample 4 (49.83%).

V. STATISTICAL ANALYSIS OF FACTORS AFFECTING OIL YIELD

All extractions and analyses were performed in duplicate. Results were expressed as mean ± standard Deviation (SD). The design of experiment selected for this study was two level- three factor factorial design and the response measured was the yield of oil from coconut flour. The three parameters studied were leaching time, leaching temperature and solute/solvent concentration. Fishers least significant difference (LSD) was used to identify significant differences among treatment means at p ≤ 0.05 using a statistical package (SPSS version 17.0). Minitab version 16.0 program was used in the regression analysis and analysis of variance (ANOVA). The statistical software mentioned above was also used to generate single effect plots, interaction plots and contour plots shown below. The response or yield of oil extracted from the coconut flour was used to develop a mathematical model that correlates the yield of oil to the process variables studied.

TABLE V
ANALYSIS OF VARIANCE (ANOVA)

Source	df	Adj. S S	Adj. MS	F-value	P. value
Time	1	49.154	49.154	4.10	0.113
Temperature	1	9.968	9.968	0.83	0.413
Solute/Solvent Ratio	1	25.956	25.956	2.17	0.215
Error	4	47.948	11.987		
Total	7	133.026			
R-sq		63.967			
R-sq (Adj.)		36.92%			
R-sq (pred.)		0.00%			

$$Y_{(\text{coconut})} = 45.936 + 2.479x_1 - 1.116x_2 + 1.801x_3 + 0.466x_1x_2 - 0.551x_1x_3 + 1.879x_2x_3 - 1.39x_1x_2x_3 \quad (3)$$

A. Single Factor Effect

The single effect of treatment combination x₁, x₂, and x₃ on the percentage oil yield is shown in Fig. 1. The single (one) factor effect shows the interaction of the three process variables studied independently on the yield of oil from the coconut flour. The effect of leaching time and solute/solvent ratio influenced the yield of oil from coconut positively while leaching temperature showed a decline in the yield of coconut oil as the temperature increased from low to high.

B. Effect of Interaction between Process Variables

The interaction of the factors X₁, X₂ and X₃ were assessed at two levels each (low and high). The black line depicts low level while the red line shows high level. The interaction of any of the two factors with two levels each will give 2x2 = 4 means.

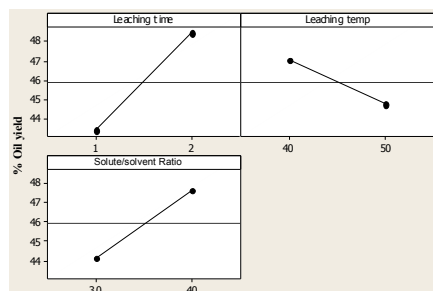


Fig. 1 Single Effect Plot for Coconut

For instance the interaction of leaching time by leaching temperature is shown in the table below

TABLE VI
RESPONSE VALUES FOR INTERACTION OF LEACHING TIME BY LEACHING TEMPERATURE

Leaching Time	Leaching Temperature	
	40	50
1	45	49
2	42	47

Here leaching time (factor 1) by leaching temperature (factor 2) plotting can be summarized as follows:

Black represents leaching time level 1. Minitab plots the response means (45.0, 42.0) at each level of leaching temperature and connects them with a solid line. This line has a negative slope showing that the response decreases as leaching temperature increases.

Red represents leaching time level 2. Minitab plots the response means (49.0, 47.0) at each level of leaching temperature and connects them with a dashed line. This line also has a negative slope showing that the response equally decreases as leaching temperature increases. Because the change in response differs across the levels of leaching temperature, the two factors appear to interact.

Interaction of leaching time by solute/solvent ratio:

Here leaching time (factor 1) by solute/solvent ratio (factor 2) is plotted and can be summarized as follows:

Black represents leaching time level 1. Minitab plots the response means (41.0, 46.0) at each level of solute/solvent ratio and connects them with a solid line. This line goes up as solute/solvent ratio increases indicating that the response increases as solute/solvent ratio increases.

Red represents leaching time level 2. Minitab plots the response means (47.0, 49.0) at each level of solute/solvent ratio and connects it with a dashed line. This line also goes up as solute/solvent ratio increases indicating that the response also increases as solute/solvent ratio increases.

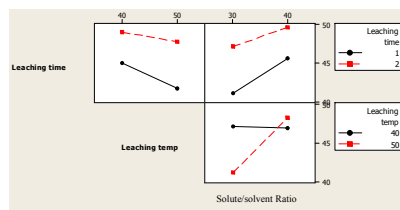
Interaction of leaching temperature by solute/solvent ratio:

Here leaching temperature (factor 1) by solute/solvent ratio (factor 2) is plotted and can be summarized as follows:

Black represents leaching temperature level 40. Minitab plots the response means (47.0, 47.0) at each level of solute/solvent ratio and connects them with a solid line. This line is horizontal indicating that the response is the same for the two levels of solute/solvent ratio.

Red represents leaching temperature level 50. Minitab plots

the response means (41.0, 48.0) at each level of solute/solvent ratio and connects them with a dashed line. The line goes up as solute/solvent ratio increases. Thus when temperature is 40°, the response is the same for all levels of solute/solvent ratio whereas when temperature is 50° the response significantly increases as solute/solvent ratio increases. Because the change in response differs across the levels of solute/solvent ratio depending on the level of temperature, the two factors interact.

Fig. 2 Interaction Effect of x_1 , x_2 and x_3 on Oil Yield of Coconut

C. Optimization of the Process

The contour plot shows the optimization parameters for leaching of oil from coconut.

Fig. 3 is the plot of yield in relation with leaching temperature versus Solute/Solvent ratio.

For the leaching data, the contour plot shows the following:

- Leaching temperature is plotted on the x-axis and Solute/Solvent ratio is plotted on the y-axis
- The contour represents constant response which corresponds to yield of 38, 40, 42, 44, 46, and 48.
- The contour with the darkest green colour (the upper right corner) indicates where the yield is highest (48).

Observe that yield increases as you move from the lower right to the upper right corner of the plot. That is yield increases as the temperature and the solute/solvent ratio increase. This plot suggests that yield can be maximized at a temperature of 48° and solute/solvent ratio of ≤ 0.051 g/ml.

Fig. 4 is the plot of yield in relation with leaching time versus solute/solvent ratio.

For the leaching data, the contour plot in Fig. 4 shows the following:

- Leaching time is plotted on the x-axis and solute/solvent ratio is plotted on the y-axis.
- The contour areas represent constant response which corresponds to yield of 38, 40, 42, 44, 46 and 48.
- The contour with the darkest green colour is the upper right corner indicates where yield is the highest (48)

Observe that yield increases from lower left to upper right corner of the plot. This means that yield increases with increase in leaching time and solute/solvent ratio. This plot suggests that yield can be maximized at a time slightly higher than 1.6hrs and a solute/solvent ratio of ≤ 0.059 g/ml.

Fig. 5 is the plot of yield in relation with leaching time versus leaching temperature.

For the leaching data, the contour plot shows the following:

- Leaching time is plotted on the x-axis and leaching temperature (leaching temp.) is plotted on the y-axis
- The contour areas represent constant response which

corresponds to yield of 38, 40, 42, 44, 46 and 48.

- The contour with the darkest green colour is the lower right corner indicates where yield is the highest (48)

Observe that yield increases as you move from the upper left to the lower right corner of the plot. That means that yield increases as you simultaneously reduce temperature and increase time. This plot suggests that yield can be maximized at a temperature slightly higher than 46° and a time less than 1.8 hrs.

D. Contour Plot of Oil Yield from Coconut

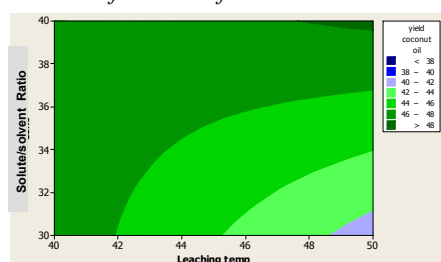


Fig. 3 Contour Plot for Oil Yield of Coconut

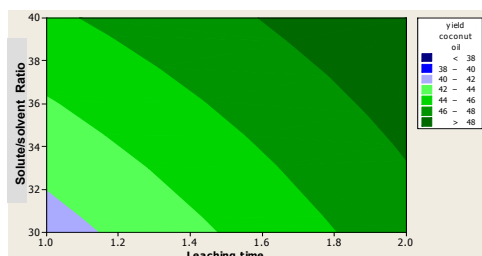


Fig. 4 Contour Plot for Oil Yield of Coconut

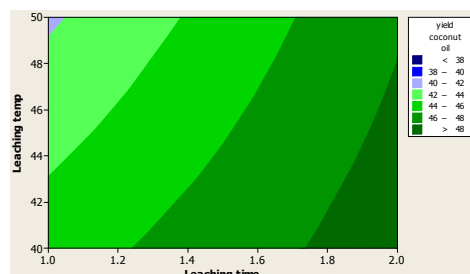


Fig. 5 Contour Plot for Oil Yield of Coconut

VI. CONCLUSION

The proximate composition of the fruit, effect of process variables on the extraction process and the physicochemical properties of the extracted oil were evaluated in this study. The results obtained showed the coconut fruit to be nutritionally potent with high level of metabolizable energy, as confirmed by the high percentage contents of carbohydrate and fat. Thus the seeds could be a good source of food supplement for human nutrition and animal feeds.

The characteristics of the coconut oil such as Iodine value, Peroxide value, Acid value, etc compared favourably with most of the conventional vegetable oil sold in Nigerian markets. The study also demonstrated the use of multilevel

factorial design using Minitab software version 16.0 in determining the conditions leading to the optimum yield of coconut oil extraction. The optimum conditions are leaching time of 2hrs, leaching temperature of 40°C and solute/solvent ratio of 0.05g/ml. This methodology could therefore be successfully employed to any process where an analysis of the effects and interaction of many experimental factors are studied.

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