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Random Surface Methodology: Process Optimization for Peanut Oil Extraction in A Mechanical Oil Expeller

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ABSTRACT

The extraction process of peanut oil has been a major concern for local processors due to the difficult task it constitutes during processing. The use of oil expellers has been found to reduce the difficulty in this task yet different processing factors tend to affect the efficiency of those oil expellers. In this study, the optimum peanut oil processing factors and their interaction were investigated using Response Surface Methodology (RSM) with fractional factorial design (3^3) model of Central Composite Design (CCD). Processing factors such as Moisture Content (10, 12, and 14% db), Peanut Temperature (50, 65, and 80°C), and Water Quantity added during extraction (12, 14, and 16 ml). This aimed at providing the optimum parameter needed to obtain the optimum oil yield using a peanut oil expeller. From this study, it was observed that all three factors considered affecting the oil yield of peanuts during extraction. Only water quantity added during extraction is statistically different. The optimum condition of the oil extraction processing parameter was observed at 50°C, 10 db, and 120 ml. The correlation coefficient (R-squared) of the model analysis was found to be 0.8901.

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Introduction

Peanuts have become common for their economic importance and nutritional value on a global scale. Peanut plants produce flowers directly above the ground level while the pod husk grows underneath the ground. The oil from the seed is nutritious having a high content of fat, protein, and carbohydrate.

In peanut processing, oil extraction is a well-established industrial activity in several developing countries. This is because, since the early 1950s, most oil seeds growing countries had favored indigenous oil extraction in preference to the export of oilseeds (Curt Beckmann and Chriswaterguy, 2008). The oil extracting machine is a device that employs an attrition force and compressional force to the oilseed thereby rubbing and compressing it on the internal surface of a pipe.

Although some existing oil-extracting machines had been developed for the extraction of the oil from peanuts, some of these machines present little extracted oil due to the effect of the processing parameters. For this research, Response surface methodology (RSM) will be used in optimizing the processing factors to know the optimum oil yield during extraction in an oil expeller.

RSM is an effective-technique 3D-graphical-experimental strategy used for investigating optimum processing parameters for multivariable systems. Central composite design (CCD) allows sequential experimentation with a reasonably reduced number of design points for understanding complex processes and the detailed mechanisms of which are not known (Damirel and Kayan, 2012).

Rezzoug et al. (2005) optimize rosemary oil extraction using response surface methodology from which it was discovered that processing pressure and time were the most significant parameters for the global extraction yield and the yield of the various oil investigated. Samira et. al. (2017) employed RSM to study the ultrasonic-assisted enzymatic extraction of peanut oil. The results showed that enzyme additive amount, hydrolysis time, hydrolysis temperature, materials to water rate, pH, and total protein extraction rate were the major parameters that influenced oil extraction.

This study optimizes some processing parameters for peanut oil extraction in a mechanical oil expeller using the random surface methodology. The effect of processing conditions and their interactions on peanut oil extraction yield were also investigated.

Methodology

Materials

A 45 kg bag of peanuts was purchased from a local market in Ogbomosho, Oyo State. The mechanical peanut oil expeller developed by Ogundahunsi et al., (2021) in Ladoke Akintola University of Technology was used to extract oil from the peanut.

Methods

Sample Preparation

Olaomi (2008) and Ajao et al. (2010) stated that peanut expresses their optimum oil only when the peanut is pretreated. The peanut used for the investigation was pre-treated using open-pan roasting method for 25 minutes at 100ºC (Adeeko et al., 1990; Ogunsina 2010, and Olatunde et al. (2014). About 1 kg of the pretreated peanut was then introduced into the machine and the oil yield of extracted oil. The test was repeated thrice and the mean value was recorded (Aluko et al., 2020).

$$\text{Oil Yield (\%)}=\left(\frac{\text{Practical oil yield ()}}{\text{Theoretical oil yield}}\times 100\right)\% \qquad (1)$$

Practical oil yield = Quantity of oil extracted (ml)

$$\text{TOY} = \text{SOP} \times \text{WP} \qquad (2)$$

Where
TOY: Theoretical oil yield
SOP: Standard oil percent (or Max. oil content)
WP: Weight of peanut
Peanut oil density = 0.9 g/ml (Jack et al., 2012)

$$\text{MOE} = \text{DO} \times \text{WOE} \qquad (3)$$

Where
MOE: Mass of oil extracted(g)
DO: Density of the oil(g/ml)
WOE: Volume of oil extracted(ml)

The maximum oil content of a peanut seed is between 30-45% (FAO, 1998), and 30% oil content is adopted for this work.

Experimental Design of the Extraction Process

The oil extraction process from peanuts was optimized using RSM with fractional factorial design (3^3) model of CCD which gives 15 experimental runs as shown in Table 1. The extraction processing parameters are Peanut Heating Temperature (50, 65, and 80); Moisture Content (10, 12, and 14); and Water Quantity Added (12, 14, and 16). A second-degree polynomial equation was fitted in each response to investigate the effect of variables and to explain the process using mathematical expression. To examine how each variable affects the extraction process and to explain the process mathematically, a second degree polynomial equation was fitted into each of the responses.

The result shown in Table 2 were analyzed using RSM to fit the quadratic polynomial equation generated using Design-Expert software version 11. Analysis-of-Variance (ANOVA) was used in evaluating the model fit.

Table 1. Factors and Levels for Central Composite Design

Variable	Symbol	Coded Levels		
		-1	0	1
Peanut Heating Temperature	A	50	65	80
Moisture Content	B	10	12	14
Water Quantity Added	C	12	14	16

Table 2. Full Central Composite Design for Peanut Oil Extraction

Run	F1	F2	F3
1	80	14	160
2	80	14	120
3	65	9	140
4	50	10	120
5	50	14	160
6	40	12	140
7	65	15	140
8	65	12	106
9	80	10	120
10	65	12	174
11	80	10	160
12	90	12	140
13	50	10	160
14	65	12	140
15	50	14	120

F1: Factor 1 A: Peanut Temperature (°C), F2: Factor 2 B: Moisture Content (% db), F3: Factor 3 C: Water Quantity Added (ml)

Result and Discussion

Result and Statistical Analysis of Peanut Oil Extraction

The oil yield obtained in this research ranges between 81-95% as shown in Table 3. The results from regression analysis of the developed process model and response are presented in Table 4.

The Model F-value of 4.50 suggests that F-value has 5.61% chance to occur because of noise.

$P>0.05$ showed that model terms including C^2 are significant. The model terms are insignificant since their values are higher than 0.1000. The fitness of the regression model was checked with the coefficient of determination having an R^2 value of 0.8901. The quadratic regression equation in terms of coded factors describing the peanut oil extraction process is given in Eq. (4). Table 5 shows the actual and predicted value of the oil yield.

$$\text{Oil yield} = 93.59 + 1.10A - 1.49B - 0.9053C - 0.6250AB + 1.88AC + 1.63BC - 0.1401A^2 - 0.4937B^2 - 3.68C^2 \qquad (4)$$

Figure 1 shows the plot of the predicted value of peanut oil yields against the actual yields obtained from the experiments. From the result, the data points are close to the line of fitness, signifying the experimental values of peanut oil yield are closer to the predicted values by the model. The good agreement between the predicted values and the actual value of oil yield further explains why the obtained R^2 in this study is close to unity. Therefore, the regression model adequately estimates the model response (peanut oil yield) concerning the variation in peanut heating temperature, moisture content, and water quantity added during extraction.

Table 3. Process factors and Peanut Oil yields using CCD

Run	Factor 1 A: Peanut Temperature (°C)	Factor 2 B: Moisture Content (% db)	Factor 3 C: Water Quantity Added (ml)	Yield (%)
1	80	14	160	91
2	80	14	120	85
3	65	9	140	92
4	50	10	120	95
5	50	14	160	86
6	40	12	140	89
7	65	15	140	90
8	65	12	106	83
9	80	10	120	95
10	65	12	174	81
11	80	10	160	92
12	90	12	140	95
13	50	10	160	87
14	65	12	140	94
15	50	14	120	90

Table 4. Analysis of variance (ANOVA) of oil the extraction process

Source	Sum of Squares	Df	Mean Square	F-Value	P-Value
Model	248.64	9	27.63	4.50	0.0561
A-Peanut Temperature	16.68	1	16.68	2.72	0.1602*
B-Moisture Content	30.36	1	30.36	4.95	0.0767
C-Water Quantity	11.19	1	11.19	1.82	0.2348
AB	3.12	1	3.12	0.5091	0.5074
AC	28.13	1	28.13	4.58	0.0853
BC	21.13	1	21.13	3.44	0.1227
A^2	0.1189	1	0.1189	0.0194	0.8947
B^2	1.48	1	1.48	0.2404	0.6447
C^2	81.78	1	81.78	13.32	0.0147
Residual	30.69	5	6.14		
Cor Total	279.33	14			

*Not Significant; The Sum of squares is Type III – Partial

Table 5. The actual and predicted value of the oil yield

Run Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residuals	Externally Studentized Residuals	Cook's Distance	Influence on Fitted Value DFFITS	Standard Order
1	91.00	90.86	0.1356	0.670	0.095	0.085	0.002	0.122	8
2	85.00	85.67	-0.6750	0.670	-0.474	-0.434	0.046	-0.619	4
3	92.00	94.70	-2.70	0.608	-1.742	-2.486	0.471	-3.098(1)	11
4	95.00	93.45	1.55	0.670	1.091	1.119	0.242	1.595	1
5	86.00	86.15	-0.1544	0.670	-0.109	-0.097	0.002	-0.139	7
6	89.00	91.34	-2.34	0.608	-1.506	-1.823	0.352	-2.271	9
7	90.00	89.69	0.3138	0.608	0.202	0.182	0.006	0.226	12
8	83.00	84.72	-1.72	0.608	-1.107	-1.139	0.190	-1.420	13
9	95.00	93.16	1.84	0.670	1.295	1.421	0.341	2.026	2
10	81.00	81.67	-0.6714	0.608	-0.433	-0.395	0.029	-0.492	14
11	92.00	91.85	0.1534	0.670	0.108	0.097	0.002	0.138	6
12	95.00	95.05	-0.0523	0.608	-0.034	-0.030	0.000	-0.038	10
13	87.00	84.64	2.36	0.670	1.661	2.220	0.561	3.165(1)	5
14	94.00	93.59	0.4097	0.988	1.533	1.883	19.955(1)	17.354(1)	15
15	90.00	88.46	1.54	0.670	1.079	1.102	0.237	1.571	3

Best Lamba 95%; CI Low 95%; CI High 3.00

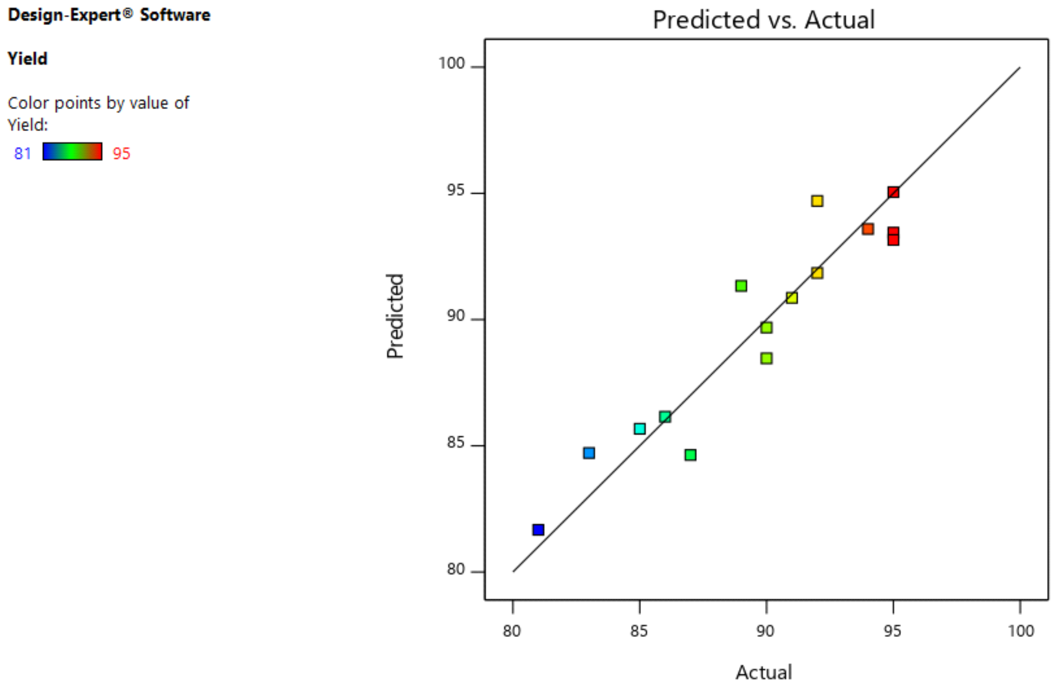

Figure 1. Plot of predicted values against the actual value of peanut oil yields.

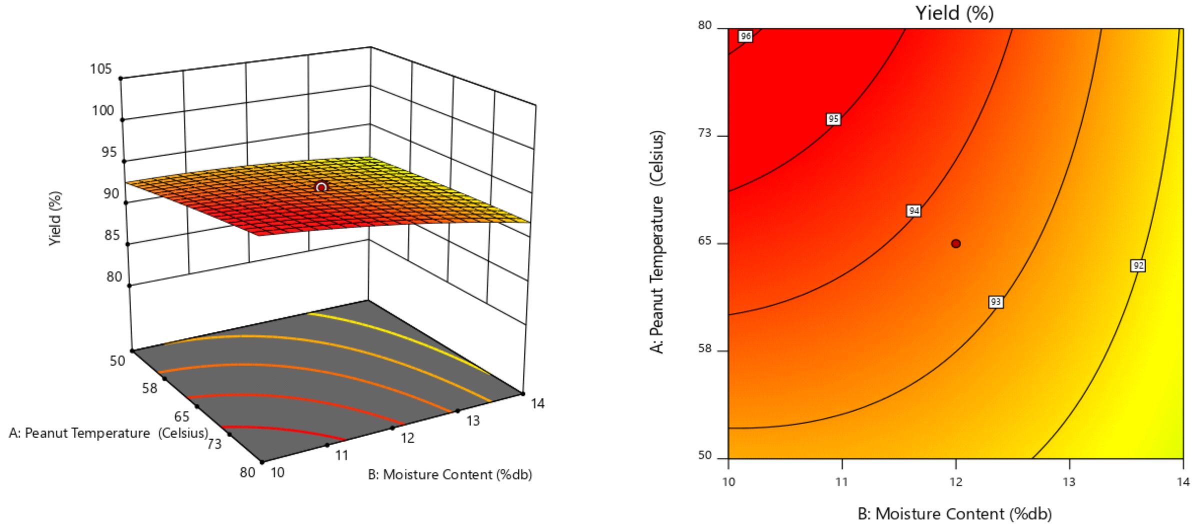

Figure 2. Contour plot and 3D surface plot of peanut temperature and moisture content interactions on oil yield.

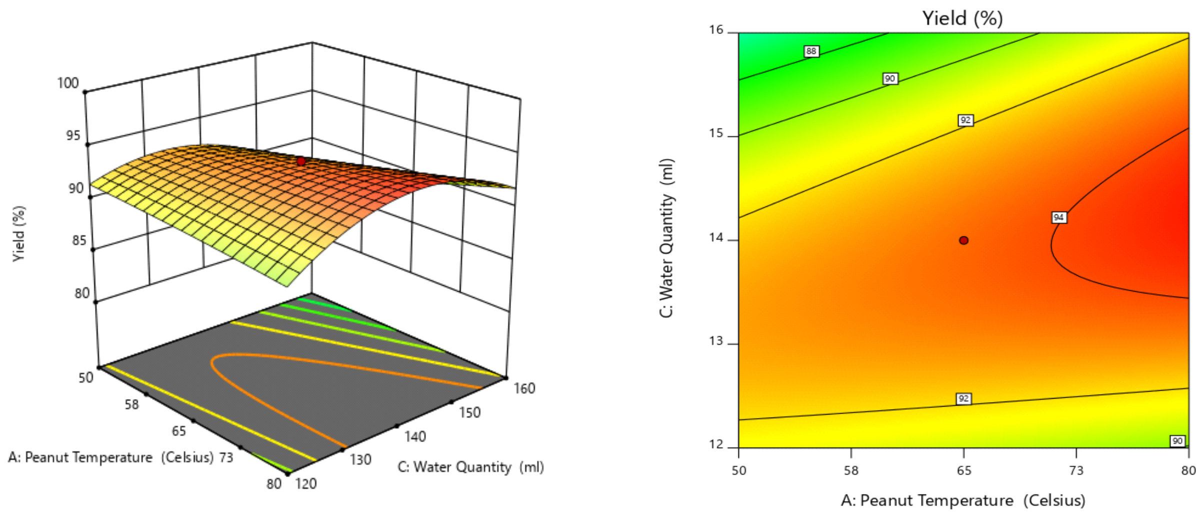

Figure 3. Contour plot and 3D surface plot of peanut temperature and water quantity interactions on oil yield

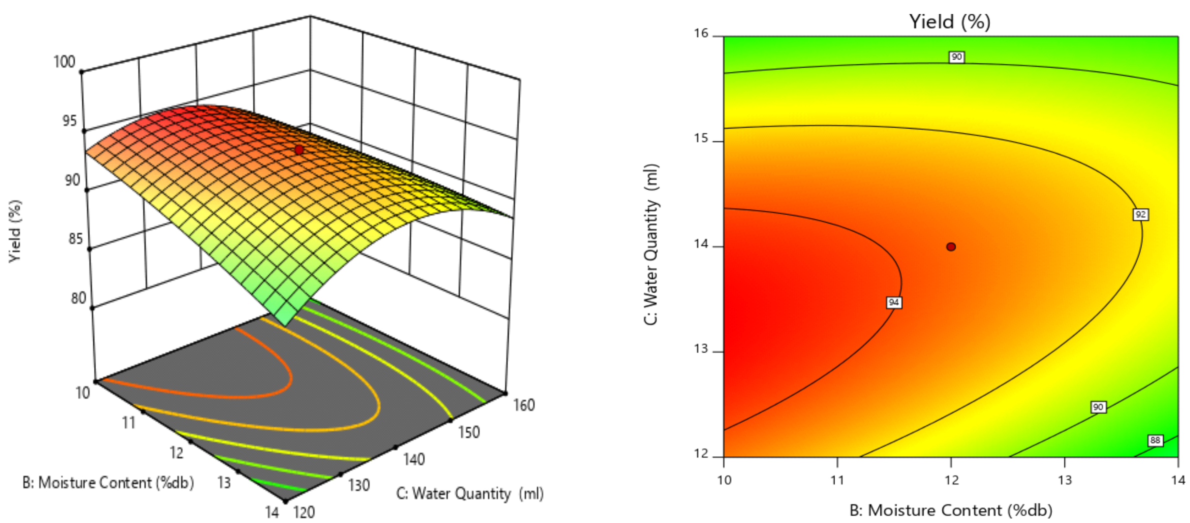

Figure 4 Contour plot and 3D surface plot of peanut moisture content and water quantity interactions on oil yield

Effect of peanut temperature and moisture content interactions on oil yield

Figure 2 shows the contour plot and 3D surface plot of peanut temperature and moisture content interactions on oil yield. In this study, it was observed that the oil yield increases as the peanut temperature introduced into the extracting machine increase while the oil yield decreases as the moisture content increases. With the interactions between peanut temperature and moisture content, the maximum oil yields obtained is 96% at 80°C, and 10% db, and the minimum oil yields obtained is 92% at 50°C and 14% db. This result corresponds to the investigation carried out by Orhevba et al. (2013) on the influence of moisture content on the yield of mechanically expressed neem seed kernel oil where it was discovered that the oil yield decreases as the moisture content of the peanut increases. Adejumo et al. (2013) also studied the effect of moisture content on oil yield from moringa oleifera seeds using soxhlet apparatus and it was observed that oil yield decreases as the moisture content decrease.

Effect of peanut temperature and water quantity interactions on oil yield

Figure 3 shows the contour plot and 3D surface plot of peanut temperature and water quantity interactions on oil yield. The effect of the interaction between peanut temperature and water quantity gives a maximum oil yield of 94% at 65°C and 140 ml. This study reveals that as the water quantity added to the peanut during extraction increases, the oil yield increases till it reaches 140 ml after which it started decreasing. A similar trend was observed in an investigation conducted by Alonge et al. (2003) on the effect of dilution ratio, water temperature, and pressing time on oil yield from groundnut oil expression using a screw press.

Effect of peanut moisture content and water quantity interactions on oil yield

Figure 4 shows the contour plot and 3D surface plot of peanut moisture content and water quantity interactions on oil yield. The interaction between peanut moisture content and water quantity gives a maximum oil yield of 94% at 65°C and 140 ml. The result shows that the oil yield increased with an increase in water quantity added to 140 ml after which a decline in the oil yield was observed. It was also discovered that the oil yield increases as the peanut moisture content decreases.

Conclusion

The oil extraction process from peanuts was optimized using Response Surface Methodology (RSM) with fractional factorial design (3^3) model of Central Composite Design (CCD). From this study, it was observed that all three factors affect the oil yield of peanut during extraction but the most significant among them is water quantity added during extraction. Three of the experimental runs gave the highest oil yield of 95% but the experiment with the optimum condition of oil extraction processing parameter was observed at 50°C, 10 db, 120 ml. The correlation coefficient (R-squared) of the model analysis was found to be 0.8901.

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Conflict of Interest

The authors declare no conflict of interest whatsoever.

Fig. 3. Contour plot and 3D surface plot of peanut temperature and water quantity interactions on oil yield.

Fig. 4 Contour plot and 3D surface plot of peanut moisture content and water quantity interactions on oil yield.

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