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Optimization of Mechanically Expressed Coconut (*Cocos Nucifera L.*) Oil Using Response Surface Methodology

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--***ABSTRACT***--
Coconut oil (Cocos nuciferaL.) has a unique role in the diet as an important physiologically functional food. The health and nutritional benefits that can be derived from consuming coconut oil have been recognized in many parts of the world for centuries. Optimization has found several applications in various processes widely used in the food industry and other industrial applications. In this study, the mechanical oil expression process for coconut was optimized using Response Surface Methodology. Experimental factors were moisture content, heating temperature, heating time and pressing time. Data analyses were done using multiple linear regression at p = 0.05. Predicted optimum conditions were validated using experimental values. Highest oil yield of 43.78% was obtained at moisture content of 14%, temperature of 90◦C, duration of 20 minutes and pressing time of 6 minutes. Predicted optimum oil yield of 43.67% at moisture content of 13.6% wet basis, temperature of 77.5^{o}C, duration of 19.0 minutes and pressing time of 5.8 minutes was obtained. Under these optimal conditions, the experimental value was 43.63% which was in agreement with those predicted by computation. It was established that the processing parameters (moisture content, pressing time, heating temperature and heating time) had significant effects on the quantity of oil recovery from coconut.

KEYWORDS – *Coconut oil, response surface methodology, optimization, oil yield.*

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I. INTRODUCTION

Coconut oil (*Cocos nucifera*L.) is an edible oil extracted from the kernel or meat of mature coconuts harvested from the coconut palm (*cocosnucifera*). The health and nutritional benefits that can be derived from consuming coconut oil have been recognized in many parts of the world for centuries and cannot be over-emphasized. Coconut oil forms a part of vegetable oil extracted from coconut palm (*Cocos nucifera*L.). According to research, coconut is the most extensively grown and used palm in the world with approximately 12 million hectares in cultivation serving as a major source of income and food for about 10 million families from over 80 countries (FAO, 2014; Bawalan, 2011).The coconut tree (*Cocos nucifera*) belongs to the family of Arecaceae (palm family) andthe only species of the genus *Cocos* (Royal Botanic Gardens) The term coconut can refer to the whole coconut palm or the seed, or the fruit, which, botanically, is a drupe, not a nut (Pearsall, 1999; Dalgado*et al.*, 2016).

Coconuts are widely exploited due to its versatility; traditional usage and in many industrial applications (James, 2015). In the tropics and subtropics, coconuts form a regular part of the diets of many humans and are also used as raw materials in many industries for production. Because of their large quantity of water (also called "milk"), they are said to be unique anddistinct from other fruits (Dalgado*et al.*, 2016). Coconuts are referred to as jelly-nuts or tender-nutswhen immature and could be harvested for their potable coconut water. But when mature, they can be used as seed nuts or processed to give oil from the kernel, charcoal from the hard shell, and coir from the fibrous husk. The oil and milk derived from it are commonly used in cooking and frying, as well as in soaps and cosmetics. According to research, it is reported that the husks and leaves can be used as materials to make a variety of products for furnishing and decorating. Also, the coconut has cultural and religious significance in certain societies, particularly in India, where it is used in Hindu rituals (Patil*et al.*, 2016).

Coconuts are grown in the coastal areas of the tropics and subtropics, 20°N and 20°S of the equator. Coconut is one of the most essential sources of healthy food products. Coconut are grown in various countries in most parts of the world, which constitutes nutrients and saturated fatty acids. The production of coconut is spread over the world in the humid tropics, mostly close to the seashore. The world leading producers of coconut are Philippines, Indonesia, India, Malaysia and Thailand. In tropical Africa, the crop is mostly produced in Mozambique, Cote d'Ivore, Tanzania and Nigeria (Vera*et al.*, 2001).

Coconut oil has found several importance in industrial applications, especially it can be used as a feedstock in soap-making. Research has it that, coconutoil containsa healthy fat that can help to lubricate the joints, and also reduce inflammation within the body. Compared to all other oil seeds, coconut has the highest percent of advantages as well as consistency in production which is less susceptible to abnormal climatic condition (Vera*et al.*, 2001).Oil extracted from oleaginous plants is termed vegetable oil (Ibrahim *et al*., 2005). The main objective of this study is to establish the optimum processing conditions for the oil yield of mechanically expressed coconut using response surface methodology.

II. MATERIALS AND METHODS

2.1 Experimental Design

The effects of processing factors (moisture content, heating temperature, heating time, and pressing time) on the oil recovery of coconut were investigated. The Factorial Central Composite Rotatable Design (CCRD) of Response Surface Methodology was used in designing the experiment which was made up of 4 factors at 5 levels each (Box *et al*., 1978). A total of thirty (30) experimental runs were conducted for each expression process combinations. The expression process levels were chosen with respect to related literature, preliminary investigations and moisture content of coconut at harvest. Five levels of moisture content (5, 8, 11, 14 and 17 %wet basis) were chosen. Five level of heating temperature (45, 60, 75, 90 and 105^{o}C). Five levels of heating times (3, 6, 9, 12, and 15 mins) and Five levels of pressing time (3, 4, 5, 6 and 7 minutes) as adopted by Ossom*et. al*.(2020).

2.2 Experimental Procedure

Dehusked coconut fruits used for this study were obtained from Itam Market in AkwaIbom State, Nigeria. The nuts were deshelled manually by hitting them on a slopping concrete floor to allow the coconut water to drain out and the white meat gouged out of the shell using knife. The white meats will then be grated. The grated coconut meats will be dried using an oven set at temperature of 105℃ for 6h sprayed in a thin layer tray.

According to Khan *et al.*(1983) Pre-pressing conditions such as particle size, roasting temperature, roasting time, pressure, pressing time, and moisture content have been known to affect the yield and quality of oil during expression. Efficient mechanical expression therefore involves a careful establishment of optimal pressing conditions for different seed because the best preparation is somewhat different for each oil bearing seed. This is the most important step in processing oil seeds(Alonge*et. al.*, 2004).

The moisture content was then calculated in wet basis using the Equation (1).

$$M_c = \frac{WW - DW}{WW} \times 100 \qquad \text{Equation 1.}$$

Where M_c = moisture content (%); WW = wet weight of sample or the initial weight of sample (g); DW = dry weight of sample or the final weight of sample (g)

The samples were conditioned to desired moisture content levels by oven drying method using equation (3.2), and the actual moisture content was determined using standard method of ASABE (2006).

The conditioned samples were heated at different temperatures and times. Also, different pressing times were applied using a manually operated oil press in the Food Engineering laboratory, University of Uyo. The oil yield was calculated using Equation (2)

$$Y = \frac{W_o}{W_g} \times 100 \qquad \text{Equation 2.}$$

where Y = Oil yield (%); W_g= Weight of coconut (kg); W_o= Weight of oil expressed (kg)

2.3 Mechanical Method of Oil Extraction

A manually operated oil press (Fig. 1) was used for the mechanical extraction of oil. Three hundred grammes of shredded coconut were used in each run. The shredded coconuts were fed into the machine with the use of two circular nets, one attached into the machine after which the sample was poured in. The covering mesh was covered and the materials were then pressed by the movement of a plunger all the way down till it presses out the oil with the use of a screw jack. Thereafter, the oil started dripping beneath the machine to collect the extracted oil. After oil extraction, the mechanical press was unscrewed with the use of a lorry jack and removed the left over residue (cake). The oil was collected and weighed in a beaker.

Fig. 1: Mechanical Screw Press

2.4 Response Surface Methodology (RSM)

A Design Expert software package for design of experiments was employed in analyzingthe experimental design and also used to generate model equations for the expression process conditions. The models that were employed in analysing the expression process for coconut were linear, two factorial interaction(2FI), quadratic and cubic. The values that were obtained from the model were compared with the predicted values. The P-value (probability of error value) was used as a tool to check the significance of each regression coefficient which also indicated the interaction effect of each cross product. SPSS window 20.0 software package was used to analyse the tests of between-subjects effects of processing conditions on oil yield. The experiment was repeated at the optimal conditions in order to validate the optimal parameters as recommended by Islau*et al*. (2002).

III. RESULTS AND DISCUSSION

3.1 Results for Oil Yield of Coconut

The average summary of the oil yield results at various expression processcondition combinations using 4 factors, 5 levels factorial Central Composite Rotatable Design (CCRD) of Response Surface Methodology (RSM) is presented in Table 1.

Table 1: Oil yield of coconut at various expression process conditions

Runs	MC (%)	Ht (mins)	HT (^{o}C)	PT (mins)	Oil Yield (%)
1	11	15	75	3	27.62
2	8	10	60	4	31.11
3	14	10	60	4	34.54
4	8	20	60	4	31.30
5	14	20	60	4	38.53
6	8	10	90	4	33.66
7	14	10	90	4	34.40
8	8	20	90	4	35.08
9	14	20	90	4	39.36
10	11	15	45	5	35.43
11	11	5	75	5	33.66
12	5	15	75	5	30.88
13	11	15	75	5	41.54
14	11	15	75	5	41.39
15	11	15	75	5	41.48
16	11	15	75	5	41.40
17	11	15	75	5	41.44
18	11	15	75	5	41.50
19	17	15	75	5	34.47
20	11	25	75	5	36.54
21	11	15	105	5	34.43
22	8	10	60	6	32.52
23	14	10	60	6	38.46
24	8	20	60	6	31.20
25	14	20	60	6	41.87
26	8	10	90	6	33.40
27	14	10	90	6	37.75
28	8	20	90	6	36.88

29	14	20	90	6	43.78
30	11	15	75	7	40.86

Table 1 shows result for the oil yield at various levels combination of moisture content, heating temperature, heating time and pressing time. For the range of expression process conditions considered in the expression process of oil from coconut, the highest oil yield of 43.78% was obtained at a moisture content of 14%wb, heating time of 20 minutes, heating temperature of 90^{o}C and pressing time of 6 minutes, while the lowest oil yield of 27.62% was obtained at a moisture content of 11%wb, heating time of 15 minutes, heating temperature of 75^{o}C and pressing time of 3 minutes (Table 1).

In comparison, Adejumo*et al.* (2013) while working on moringa seeds obtained an optimum oil yield of 33.7% at a heating temperature of 100^{o}C and a heating time of 30 minutes using soxhlet extraction method. Mohammed *et. al.* (2003) while working on moringa obtained a yield of 31% using organic solvent for extraction. Anwar *et al.* (2006) while working on moringa obtained an oil yield of 30.36, 35.26 and 38.37% respectively from one drought (Layyah) and two irrigated regions (Rahim Yar Khan, Jhang) of Punjab, Pakistan using hexane as solvent for extraction. Ossom*et al*. (2020) while working on Soursop seeds obtained the highest oil yield of 29.42% at moisture content of 15%, heating temperature of 80^{o}C, heating time of 25 mins and pressing time of 6 mins using mechanical method of expression. Sirisomboon and Kitchaiya (2008) reported that the total amount of oil extracted from jatrohpakernels depend mainly on the extraction time and temperature, moisture content and particle size of the oil bearing material, with the oil extracted during the first 20 minutes of extraction.

Increase in temperature from 50-80^{o}C increased oil yield, but oil yield decreased with increase in heating temperature up to 90^{o}C (Fig. 4). Increase in heat treatment leads to hardening of samples, thereby offering increased resistance to pressure application during expression, leading to decrease in oil yield of samples (Fig. 3). Oil yield obtained from samples heated at 50^{o}C were considerably lower than those obtained from the other heating temperatures. This could be attributed to insufficient heat treatment given to samples during heating. Oil yield increased with increasing time for samples up to 30 minutes after which further increase in time caused a decline in oil yield (Fig. 6). Samples heated at 50^{o}C needed more time to allow for the coagulation of protein, increasing fluidity of the oil, breakdown of oil-cells and adjustment of moisture content to the optimum level, while samples heated at 80^{o}C needed a relatively shorter time to achieve all these and further heat treatment decreases the oil yield. Increase in heating time increased the oil yield up to 6 minutes, beyond which further increase in heating time decreased the oil yield. Thus, the highest oil yield of 43.218% was obtained when sample was heated at 60^{o}C for 6 minutes to 7 minutes (Figs. 7 & 8).

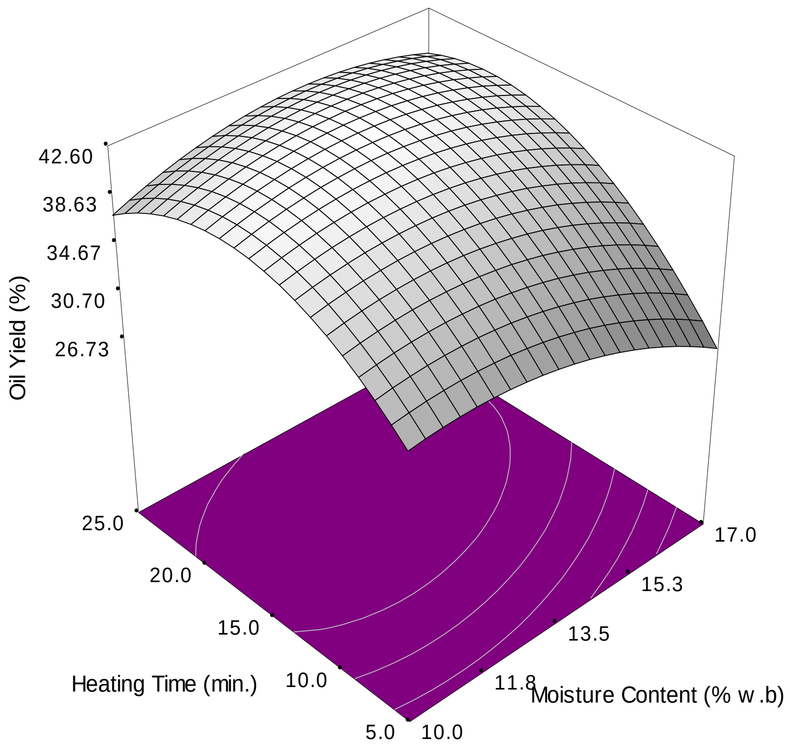

Fig. 3: Effect of heating time and moisture content on oil yield of coconut

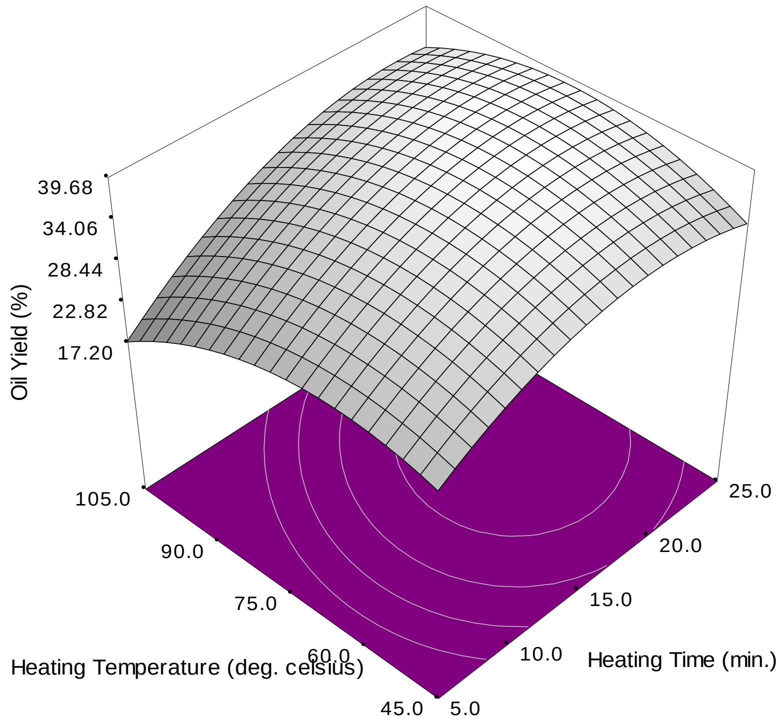

Fig. 4: Effect of Heating Temperature and Heating Time on oil yield of Coconut.

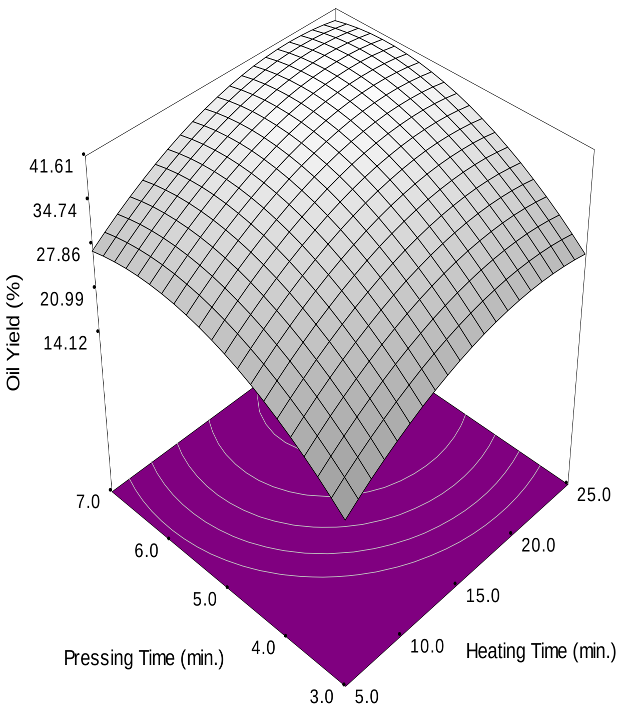

Fig. 5: Effect of pressing time and heating time on oil yield of Coconut

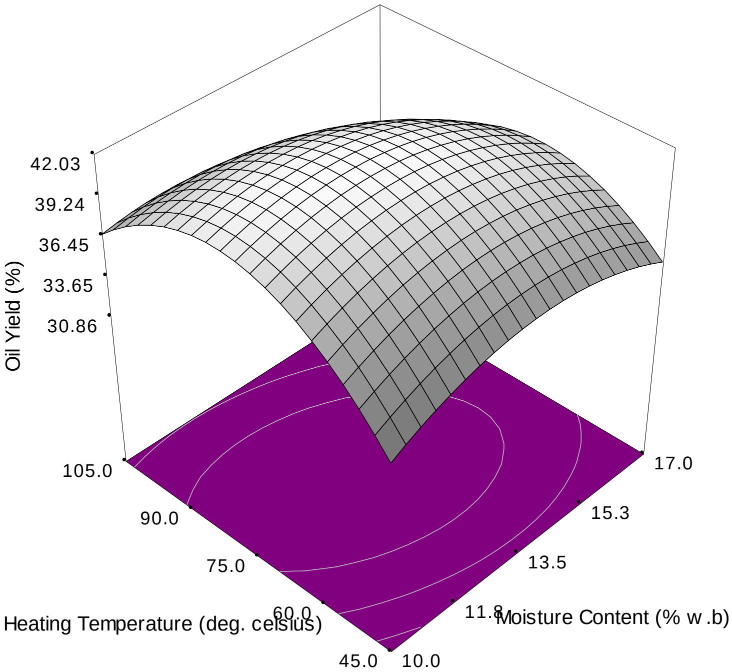

Fig. 6: Effect of Heating Temperature and Moisture Content on oil yield of Coconut.

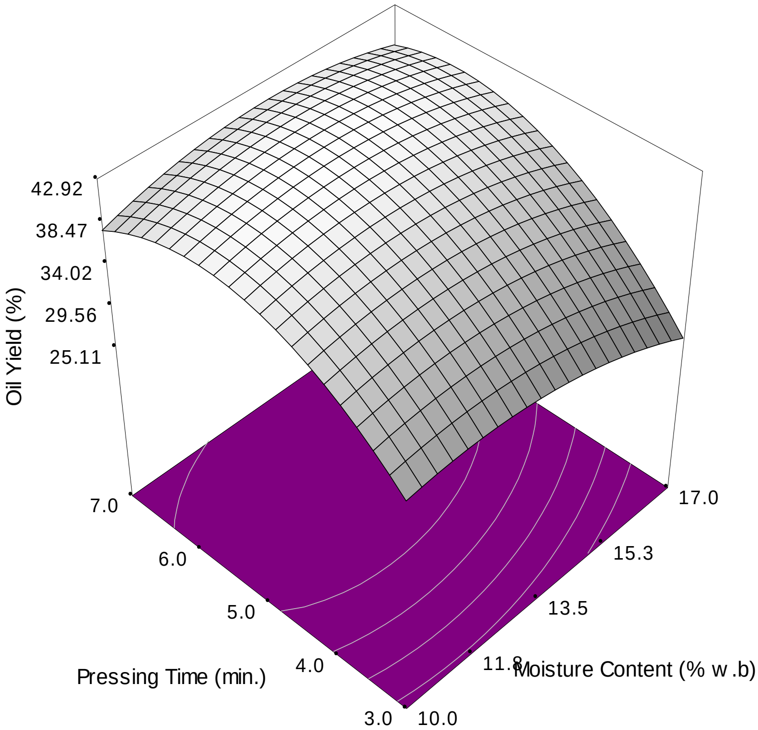

Fig. 7: Effect of Pressing time and Moisture Content on oil yield on oil of Coconut

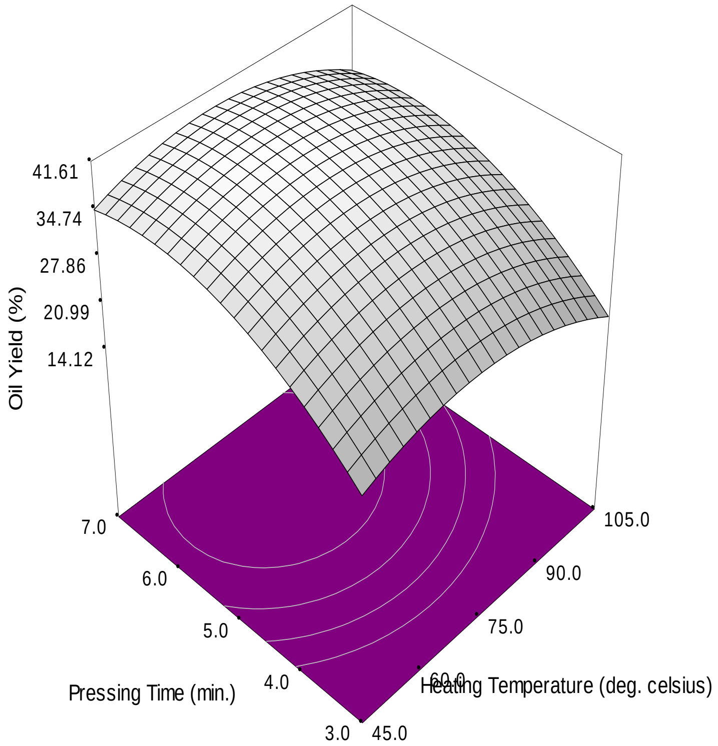

Fig. 8: Effect of Pressing time and heating temperature on oil yield of Coconut

3.3 Optimization of the Expression Process of Coconut using oil Yield as Response

Four different models namely linear, two factorial interaction (2FI), quadratic and cubic were used to analyze the expression process for coconut and the models were fitted to the experimental data using Design Expert software. The appropriate model was chosen based on the selection of the highest order polynomial where the additional terms are significant and the model is not aliased, insignificant lack-of-fit and the maximization of the "Adjusted R-Squared" and the "Predicted R-Squared" (Table 2). Considering these, the linear and quadratic models were suggested. In terms of higher coefficient of determination (R^2) and lower standard deviation values, the quadratic model was finally chosen ahead of the linear model to predict the oil expression process for coconut. The final equation is given below:

Y = -69.21042+ 4.37181Mc + 0.97497HT + 0.47808Ht + 13.96208Ap -0.21382Mc2 -6.04722HT2 – 0.052725Ht2 – 1.53313Ap2 - 0.015278McHT + 0.060917McHt +0.25375McAp + 8.01667HTHt + 3.08333HTAp + 0.013000HtAp Equation 4

(Std. Dev. = 2.15, R-Squared = 0.8668, Mean = 36.55, Adj R-Squared = 0.7425, C.V. = 5.89, Pred R-Squared = 0.2328, PRESS = 400.59, Adeq Precision = 8.633)

where, Y = Oil yield, % Mc = Moisture content, %wb , HT = Heating temperature, ^{o}C, Ht = Heating time, mins, PT = Pressing time, mins.

3.4 Validation of Model

An excellent agreement between the observed and predicted values for oil yield from coconut was obtained from the parity plot between the predicted and the actual values. There is a high correlation (R^2 = 0.8668) between the predicted and experimental values for coconut oil yield which indicated that the predicted values and experimental values are in reasonable agreement. It means that the data fitted well with the model and gave a convincingly good estimate of response for the expression process in the range studied. In the range of 5-17% wet basis for moisture content, 45-105^{o}C for heating temperature, 5-25 minutes for heating time and 3-7 minutes for pressing time, predicted optimum oil yield of 43.67% at moisture content of 13.6%, temperature of 77.5^{o}C, duration of 19.0 minutes and pressing time of 5.8 minutes was obtained. Under these optimal conditions, the experimental value was 43.63% which was in agreement with those predicted by computation. Deviations between experimental and predicted values were low and ranged from 0.01-2.39. This shows that the model chosen predicted the oil yield adequately (Table 3).

Table 2: Model comparison for oil yield.

Source	Std. Dev.	Adjusted R-Squared	Predicted R-Squared	R-Squared	PRESS	
Linear	3.43	0.4375	0.3475	0.2575	387.72	Suggested
2FI	3.68	0.5066	0.2470	0.1562	440.62	
Quadratic	2.15	0.8668	0.7425	0.2328	400.59	Suggested
Cubic	1.43	0.9724	0.8858	-2.9653	2070.57	Aliased

Table 3: ANOVA for response surface quadratic model for oil yield.

Source	Sum of Square	DF	Mean Square	F Value	Prob > F
Model	452.61	14	32.33	6.97	0.0003
A	65.71	1	65.71	14.17	0.0019
B	25.23	1	25.23	5.44	0.0340
C	3.87	1	3.87	0.84	0.3751
D	28.26	1	28.26	6.09	0.0261
A^2	101.57	1	101.57	21.90	0.0003
B^2	47.66	1	47.66	10.28	0.0059
C^2	50.78	1	50.78	10.95	0.0048
D^2	64.47	1	64.47	13.90	0.0020
AB	13.36	1	13.36	2.88	0.1103
AC	7.56	1	7.56	1.63	0.2210
AD	9.27	1	9.27	2.00	0.1778
BC	5.78	1	5.78	1.25	0.2816
BD	0.068	1	0.068	0.015	0.9055
CD	0.034	1	0.034	7.380E-003	0.9327
Residual	69.56	15	4.64		
Lack of Fit	69.54	10	6.95	2011.82	< 0.0001
Pure Error	0.017	5	3.457E-003		
Cor Total	522.17	29			

IV. CONCLUSION

The oil expression from coconut at various process conditions using mechanical method of oil expression was optimized. It was established that the processing conditions (moisture content, pressing time, heating temperature and heating time) influenced the quantity of oil recovery from coconut. In the light of this, the following conclusions were made:

i. The optimization of the processing conditions carried out using Response Surface Methodology gave an optimum oil recovery of 43.78% when coconut was conditioned to a moisture content of 14% wet basis, heated at 90^oC for 20 minutes and at a pressing time of 6 minutes.

ii. The model equation generated gave a satisfactory coefficient of determination (R^2 = 0.8668). The coefficient of determination demonstrated an excellent correlation between the independent variables. Thus, considering the range of variables studied, the model chosen adequately predicted the yield for coconut oil expression.

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