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OPTIMIZATION OF MECHANICAL EXPRESSION OF CASTOR SEEDS OIL *(RICINUS COMMUNIS)* USING RESPONSE SURFACE METHODOLOGY

J. O. Olaoye[1] and R. A. Busari[2]

[1]*Department of Agricultural and Biosystems Engineering, University of Ilorin, P. M. B. 1515, Ilorin 240001, Kwara State, Nigeria.*
[2]*Food, Agricultural and Bio-Engineering Department, Kwara State University, Malete, Kwara State, Nigeria.*

Corresponding Author's email address: jolanoye@unilorin.edu.ng

Abstract
The effect of the processing parameters of Castor seed on its oil yield was investigated. The castor seeds were passed through drying, crushing and separation into seeds and shells. These processing conditions were further succeeded by seed roasting and subsequent mechanical expression of the roasted nut by means of screw press in the course of its preparation for oil expression. Seed samples were conditioned by adding calculated amount of distilled water to obtain different moisture levels from the initial moisture content of the seeds. Samples were roasted at the temperatures of 83.18, 90.00, 100.00, 110.00 and 116.82˚C, over periods of 6.59, 10.00, 15.00, 20.00 and 23.41min, seed moisture content of 6.32, 7.00, 8.00, 9.00 and 9.68 % wb, respectively and the oil was expressed using a screw roaster-expeller. Optimization of the oil expression process was achieved by applying Central Composite Rotatable Design of Response Surface Methodology. The optimal conditions for oil yield within the experimental range of the studied variables were 7%, 110˚C and 20 min; moisture content, roasting temperature and roasting duration respectively. These values of the optimum process conditions were used to predict optimum value of oil yield to be 25.77%. A second-order model was obtained to predict oil yield as a function of moisture content, heating temperature and duration. Thus the result from this research work has established the optimal conditions for mechanical extraction of oil from castor seed. Closed agreement between experimental and predicted yield was obtained.

Keywords: Castor seed, oil expression, oil yield, optimization, Response Surface Methodology

1.0 Introduction
Castor plant is scientifically known as *Ricinus communis* which belongs to the family of Euphorbiaceae. It was first found in Africa, where it grows in the wild and can be cultivated in the both tropical and subtropical countries (Caye *et al.,* 2008). Castor beans contain about 35 – 55 percent oil by weight for high yield breed type and approximately 1413 liter per hectare in cultivated regions (Kulkami and Swant, 2003). Figures 1 and 2 show the typical Castor plant in wild and bunch of castor fruits on the plant respectively, while Figures 3 and 4 show dried Castor bean seeds collected from the wild and fresh castor bean seeds. Castor oil is one of few naturally occurring glycerides of high purity and 90% of the fatty acid is Ricinoleic acid (Akpan *et al.,* 2006). This coupled with its exceptional solubility in methanol, it became the prior oil for transesterification to biodiesel, requiring a minimum amount of catalyst and heating requirement on reaction temperature that reducing production costs (Bello and Makanju, 2011).

Figure 1: A typical Castor plant in the wild

Figure 2: Bunch of Castor fruit on the plant

Figure 3: Dried Castor fruit collected

Figure 4: A typical Castor bean seeds

Castor oil and its derivatives are used in the production of paints, varnishes, lacquers, and other protective coatings, lubricants and grease, hydraulic fluids, soaps, printing inks, linoleum, oil cloth and as a raw material in the manufacturing of such chemicals as *sebacic acid* and *undecylenic acid*, used in the production of plasticizer and Nylon (Bello and Makanju, 2011).Castor oil is non-edible oil which can be used as a replacement for edible oils in many industrial applications. It has a good shelf life compared to other vegetable oils if it is not subjected to excess heat (Ogunniyi, 2006).

In developed countries, the extraction of edible and non-edibleoilswasnormally carried out using large-scale processing facilities while in developing countries oil expression is associated with drudgeries due no processing facilities, small scale processing units, social-economic constraints evident in many farming communities and low level of technological development (IDRC, 1997; Bechmann, 2004). The usual practice in developing nations is to introduce cheap and simple technology in the rural areas that can be quickly acceptable and adopted, which will, therefore, have an immediate impact on the livelihoods of the communities and at the same time impact positively on the national and state economic growth. In so doing it is sometimes necessary to introduce technology that might otherwise not be considered the most efficient but which under the circumstances will be the most convenient or appropriate (Somasekhar, 2001).
For the expression of oil from oil-seeds, a number of mechanical devices are in use in developing countries. Some of these devices are traditional and have been in use for centuries, while others have

been introduced in recent years specifically for use in the small scale sector of developing economies. The principle of operation of these machines includes the application of direct hydraulic pressure for a considerable amount of time and the oil is allowed to slowly infuse out of the mass of compressed kernels to finally drain off to the collector. Another method is the use of screw oil expeller. This works by compressing the product in a caged barrel-like cavity. The machine uses friction and continuous pressure from the screw drives to move and compress the seed material. The oil seeps through small openings that do not allow seed fiber solids to pass through while the pressed seeds are formed into a hardened cake and extruded through the end of the cavity (Singh and Bargale, 2000; Hyman, 2005 and Axtel, 1992).

The yield from oil-bearing seeds is dependent on the quality of the oilseeds and no method of extraction can compensate for this (Mwithiga and Moriasi 2007).At the same time, the extraction process needs to be well managed in order to extract as much oil from the seed. Also, there are a number of factors that can be manipulated during extraction process in order to increased oil yield. These factors include the moisture content of oil seeds, the size of particles and roasting temperature, roasting duration and the pressure applied during extraction (Mwithiga and Moriasi 2007). The effect of these factors has been studied by a number of researchers (Mwithiga and Moriasi 2007; Baryeh, 2001and Ajibola *et al.,* 1990). In all these studies the authors have established that there exists an optimum value of moisture content for each product at which oil yield is highest when other variables are held constant (Baryeh, 2001; Ajibola *et al.,* 1990). Southwell and Haris (1992) while working with sunflower established that unheated sunflower kernels gave a lower oil yield when compared with heated and conditioned samples. Reports from the investigation carried out on the mechanical expression of oil from conophor nut by Fasina and Ajibola (1989) showed that oil yield from melon seed increased with increase in temperature from 50–65℃ but decreased with further increase in heating temperature to 110^{o}C. It was observed that samples became more hardened with increasing heat treatment, thereby offering increased resistance to pressure application during expression, thus the decrease in oil yield. High oil yield was obtained at the heating time of 20 and 28 min for samples heated at 65, 80 and 95℃. The highest oil yield of 39.6% was obtained when the sample was heated at 65℃ for 28 min and at safe storage condition. The moisture level for most oil seeds were not specified prior oil expression. Determination of oil extraction conditions for castor seeds must be established in screw expeller.

The study examines the relationship between roasting temperature, moisture content and roasting duration on the oil yield of castor seeds within reasonable operating limits of screw expeller and determines the optimum conditions for the extraction of oil. Response Surface Methodology (RSM) is an efficient statistical technique for optimization of wide level of investigation of multiple variables to predict the best performance conditions with a minimum number of experiments reducing the cost of investigation.

2.0 Materials and Methods

2.1 Collection and Processing of Sample

Castor seeds were harvested from the wild in Ilorin metropolis of Kwara State, Nigeria, dried, crushed and separated into seeds and shells and cleaned of any foreign materials and dirt by handpicking. The seeds were further dried in the oven at 60°C for 7hrs to a constant weight in order to remove its moisture content to bone dried weight. Moisture content simulation for conditioning of castor oil seed by Olaoye (2000) was adopted.These processes were further succeeded by seed roasting and subsequent mechanical expression of the roasted nut by means of screw press.

2.2 Experimental Design for Oil Expression

RSM is a collection of mathematical and statistical techniques that are useful for the modelling and analysis of problems in which a response is influenced by several independent variables and the objective is to optimize this response (Montgomery, 2001). A standard RSM design called a central composite design (CCD) was applied to study the castor oil extraction variables. This method is suitable for fitting a quadratic surface and it helps to optimize the factors with a minimum number of experiments, as well as to analyze the interaction between the factors.

The independent variables selected for the study were (i) A; moisture content; (ii) B; reaction temperature and (iii) C; reaction time. A statistical optimization was conducted using CCD; a 2^3 full factorial CCD for the three variables, consisting of 8 factorial points, 6 axial points and 6 replicates at the center points were employed, implied 20 experiments were required. The variables and levels were fixed based on information from the literature and trial experiments (Ajala *et al.*, 2016). The operating parameters selected were moisture contents (6.32, 7.00, 8.00, 9.00 and 9.68 % wb), roasting temperature (83.18, 90.00, 100.00, 110.00 and 116.82 °C) and roasting duration (6.59, 10, 15, 20 and 23.41 minutes) while responses were product fractions. Table 3.1 shows the experimental ranges and levels of independent variables while Table 3.2 shows experimental design for oil expression. The center points were used to determine the experimental error and the reproducibility of the data. The independent variables are coded to the (−1, 1) interval where the low and high levels are coded as −1 and +1, respectively. The axial points are located at (± α, 0, 0), (0, ± α, 0) and (0, 0, ± α) where α is the distance of the axial point from center and makes the design rotatable. In this study, the (α) value was fixed at 1.682 (rotatable). The correlation between the operating parameters (independent variables) and the dependent response (oil yield) was determined using a quadratic model of a second-order polynomial as shown in Eqn. (1).

$$Y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n} \beta_{ii} {x_i}^2 + \sum_{i=1}^{n-1} \sum_{j=1+1}^{n} \beta_{ij} x_i x_j \qquad (1)$$

Where:

Y represents the predicted response; β_0 is the constant coefficient; β_i is the linear coefficient; β_{ii} is the quadratic coefficient; β_{ij} is an interaction coefficient; x_i and x_j are the coded values of the independent variables.

Response Surface Plots was used to illustrate and explain the relationship that exists between processing conditions under investigation with respect to oil yield. This was graphically presented in 3D graph.

2.3 Oil Extraction

The roasting of the castor bean seeds was done in the roasting chamber of expeller with the aid of a heating element. The screw press received roasted castor seeds from the roaster via an outlet opened to the hopper and moved gradually the aid of the screw threads. The decreasing screw pitch along the shaft and screw height provided the compressing force needed to squeeze out the entrapped oil from the castor seeds. The residue (cake) from which the oil is expressed was forced out of the cake outlet as flakes and the oil was collected at the bottom. The clear transparent liquid obtained after was collected and poured into a clean container, weighed and the yield calculated. The oil yield, Y was calculated from eqn. 2

$$Y = \frac{W_1 - W_2}{W_1} x\, 100\ \% \qquad (2)$$

Where,

W_1 = weight of un-milled castor seed; W_2 = weight of cake sample (after milling)

3.0 Results and Discussion

The outcome of the experimental design in percentage yield of castor oil was presented in Table 1. The maximum yield of 26.5% (at corresponding moisture content, heating temperature and duration of 6.68%, 100.00°C and 15 mins., respectively) and minimum oil yield of 23% (at corresponding moisture content, heating temperature and duration of 6.32%, 100.00°C and 15 mins., respectively) were obtained. The result showed that the three independent variables were relevant to the castor oil yield in the mechanical extraction process, as different levels of process conditions gave different oil yield of castor. Table 2 shows the ANOVA for the response (oil yield) surface quadratic model.

The p-values of the terms A (< 0.0001), B (0.0082), A^2 (0.0164), B^2 (0.0244), C^2 (0.0012), AB (0.0155), show that the model are significant at $p \leq 0.05$ while B, BC, AC are not significant with P-value above 0.05. Among all the model terms or variance in Table 2, it was observed that A (moisture content) has the highest influence in the regression model with F-value of 785.39 followed by C (heat duration) with F-value of 10.79. This implies that moisture content plays a significant role in the developed model followed by C. The significance of the model developed was tested by the R^2 and Adj. R^2 value. The obtained for R^2 and Adj. R^2, are 0.9883 and 0.9778, respectively. The fitness of a model is determined by the R^2 (coefficient of determination) and the value should not be less than 0.80 (Akintunde *et al.*, 2015). Also since the R^2 and the Adj. R^2 are close to 1 which implies that the model fits the data well.

3.1 Model Parameters:

3.1.1 Quadratic parameter

The single effect of each of the quadratic terms are significant ($p < 0.05$) (Table 2). This implied that moisture content (A, %), roasting duration (C, min.) and roasting temperature (B, °C) have an individual significant effect on the percentage yield of castor oil.

3.1.2 Interaction parameters

The interaction parameter terms of the variables, only moisture content (A, %), and roasting temperature (B, °C) have significant effect at $p < 0.05$ on the percentage yield of castor oil while moisture content (A, %), and roasting duration (C, min.) and roasting temperature (B, °C) and roasting duration (C, min.) did not show any significant ($p < 0.05$) effect on the percentage yield of castor oil. This suggests that simultananeous variation of multiple processing conditions has potential of inducing counteracting influence on the oil yield.

3.2 Effect of Variables on percentage oil yield from Castor seeds

The interaction effects of moisture content, heat duration, and heat temperature on the oil extraction yield were studied using the interaction plot and 3D surface plot of response surface methodology.

Table 1: Experimental data obtained for oil yield, viscosity, and caloric value

S/N	Standard Order of Run	X_1 = Factor 1 moisture content	X_2 = Factor 2 heating temperature	X_3 = Factor 3 heating time	Response 1 oil yield (%)	Response 2 viscosity (cSt)	Response 3 caloric value (kcal.)
1	1	7.00	90.00	10.00	25	7.15	70.1
2	6	9.00	90.00	20.00	23.5	7.12	70.2
3	14	8.00	100.00	23.41	24	6.2	70.8
4	8	9.00	110.00	20.00	23.2	5.83	71.2
5	18	8.00	100.00	15.00	24.5	6.9	70.7
6	15	8.00	100.00	15.00	24.5	6.9	70.7
7	2	9.00	90.00	10.00	23.1	7.1	70.3
8	3	7.00	110.00	10.00	25.5	5.82	71.2
9	13	8.00	100.00	6.59	23.9	7.1	70.3
10	16	8.00	100.00	15.00	24.5	6.9	70.7
11	9	6.32	100.00	15.00	26.5	6.6	70.5
12	10	9.68	100.00	15.00	23	6.8	70.6
13	19	8.00	100.00	15.00	24.5	6.9	70.7
14	4	9.00	110.00	10.00	23.1	5.81	71.2
15	5	7.00	90.00	20.00	25.6	7.2	70.2
16	20	8.00	100.00	15.00	24.5	6.9	70.7
17	7	7.00	110.00	20.00	26	5.8	71.2
18	12	8.00	116.82	15.00	24.1	5.51	71.38
19	11	8.00	83.18	15.00	24.2	7.17	70
20	17	8.00	100.00	15.00	24.5	6.9	70.7

Table 2: ANOVA for Response Surface Quadratic Model of Castor Oil Yield

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	17.95	9	1.99	94.01	< 0.0001	Significant
A: M.C	16.67	1	16.67	785.39	< 0.0001	
B: Heat Temp	0.014	1	0.014	0.64	0.4411	
C: Heat Time	0.23	1	0.23	10.79	0.0082	
A^2	0.18	1	0.18	8.29	0.0164	
B^2	0.15	1	0.15	7.01	0.0244	
C^2	0.43	1	0.43	20.17	0.0012	
AB	0.18	1	0.18	8.48	0.0155	
AC	0.045	1	0.045	2.12	0.1760	
BC	0.020	1	0.020	0.94	0.3545	
Residual	0.21	10	0.021			
Lack of Fit	0.21	5	0.042			
Pure Error	0.000	5	0.000			
Cor Total	18.17	19				

It was obvious that an increase in oil yield was observed with the decrease moisture content and increase heat temperature. The oil yield was maximum at 25.79 % when the heat temperature was 110.00°C and moisture content of 7 % while the minimum yield was achieved at 23.28 % when the heat temperature was 90.00°C and the moisture content was 9.00 %. These imply that as temperature increase more cell wall was broken and resulted in more oil yield.

The effect of moisture content and heat time was studied using the 3D surface plot in Figure 6 which depicts the interaction between moisture content and heat time. Increase in oil yield was observed with the decrease moisture content and increase heat time. These imply that as roasting duration increases more cell wall were broken and resulted to more oil yield. Minimum oil yield of 23.27 % was recorded at moisture content of 9.00 % when the heating duration was 10 min. while maximum oil yield of 25.77 % was achieved at moisture content of 7.00 % when the heating duration was 20.00 min. Figure 7 presents the effects of heat time and heat temperature on oil yield. From the figure, it was obvious that an increase in oil yield was observed with the increase heat time and heat temperature at first, and then the trend was reversed when heat time reached 20.00 min. and heat temperature of 110.00°C. It can be deduced from the analysis of variance (ANOVA) results from figures 5 - 7 that the combined effects of moisture content, heating duration and heating temperature have a significant effect on the oil yield from castor bean seed.

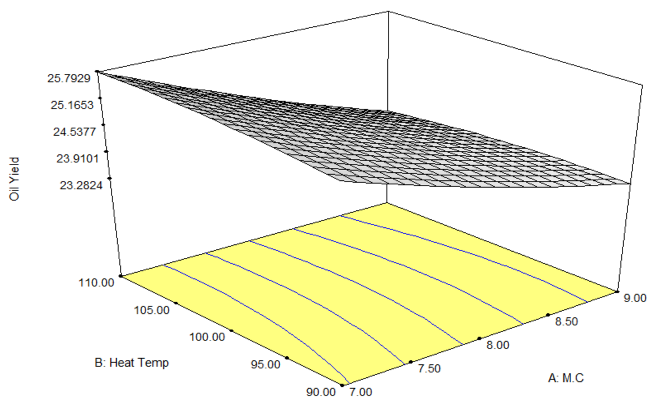

Figure 5: Response surface plots showing the effect of moisture content and heat temperature and their interactive effect on the % recovery of oil.

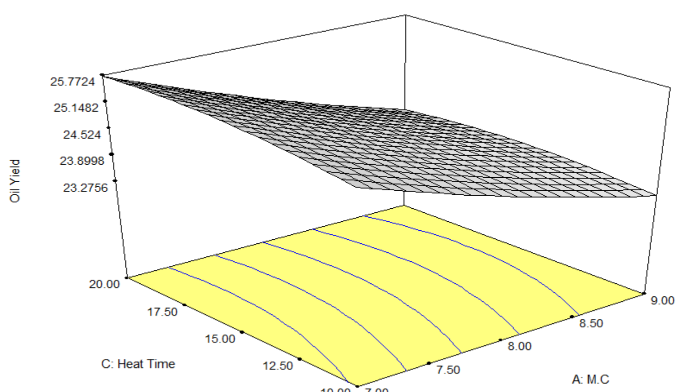

Figure 6: Response surface plots showing the effect of heat time and moisture content and their interactive effect on the oil recovery.

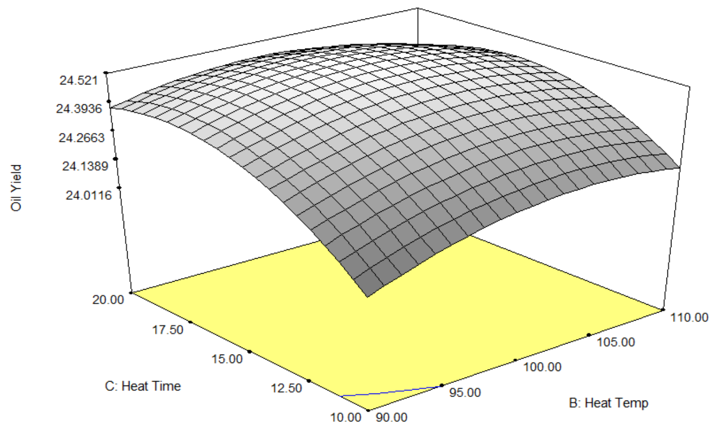

Figure 7: Response surface plots showing the effect of heat time and heat temperature and their interactive effect on the oil recovery.

3.3 Process Optimization and Validation

One of the main objectives of this study was to find the optimum process parameters which the oil expression will be optimum or maximum. The function of desirability was applied using Design Expert software version 6.0.6 in order to compromise the response. In the optimization analysis, the target criteria were set, in ranges and response was set to be maximum. The optimum oil yield was validated using the data generated from the experiment. To confirm the accuracy of the model, expression was carried out under the optimum condition. Experimental oil yield was found as 25.77 % while predicted oil yield was 26.00 %. The percentage error was calculated to be 0.88 which confirmed the validity of the model equation. Table 4 presents the percentage error, experimental and predicted value while the relationship between predicted and experimental values of oil yields is shows in Figure 8.

The coefficient of the response surface model equation for yield of castor oil is given by Eqn. (3) which describes the relationship between the percentage oil yield and actual values of independent operating parameters moisture content (A), roasting temperature (B) androasting duration (C), their respective interactions.

Table 4: Optimum conditions for oil expression and percentage error

Optimum conditions for oil expression			Experimental value (%)	Predicted value (%)	Percentage error (%)
Moisture content (%)	Heating temperature (°C)	Heating duration (min.)			
7.00	110.00	20.00	25.77	26.00	0.88

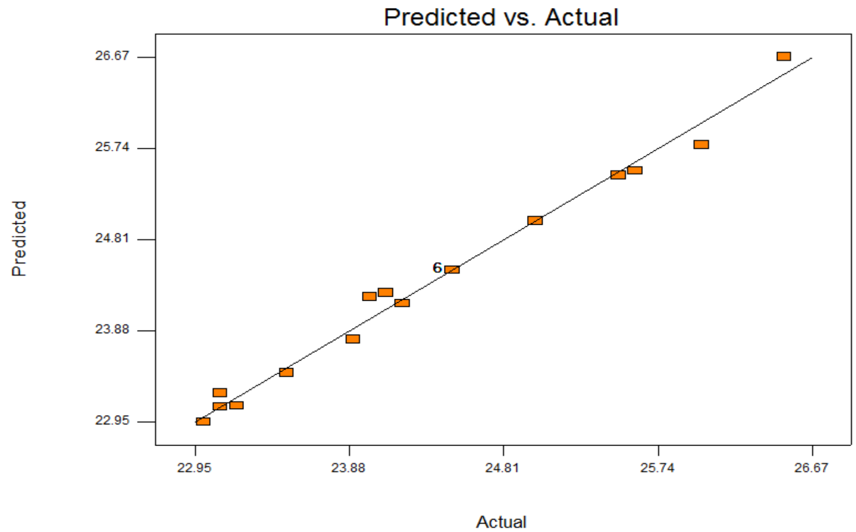

Figure 8: Predicted oil yield versus experimental oil yield.

$$Y = 12.68804 - 1.14776X_1 + 0.34141X_2 + 0.45270X_3 + 0.11051X_1^2 - 1.0626E - 0.003X_2^2 - 6.893E - 0.003X_3^2 - 0.015000X_1X_2 - 0.015000X_1X_3 - 1.00000E - 0.003X_2X_3 \quad (R^2 = 0.9883) \quad (3)$$

4.0 Conclusion

The study revealed that moisture content has the highest influence in the regression model with highest F-value followed by heating duration and heating temperature. This implies that moisture content plays a significant role in oil expression of any vegetable oil extraction. The result suggested optimum values as 7%, 110°C and 20 minutes; moisture content, heating temperature, and heating duration, respectively at corresponding optimum oil yield of 25.77% while predicted oil yield was 26.00 % and the percentage error was calculated to be 0.88. This methodology could, therefore, be successfully employed to any process where an analysis of the optimum, effects and interaction of many experimental factors are studied.

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