EFFECT OF DRYING VARIABLES ON THE OPTIMUM PERFORMANCE OF A CENTRIFUGAL PALM NUTS CRACKER USING *DURA* CULTIVAR: A RESPONSE SURFACE METHODOLOGY APPROACH

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ABSTRACT

The crude method of cracking *Dura* palm nuts cultivar was fully mechanized by adopting newly developed drier and modified cracker to enhance productivity. The effect of drying variables on the *Dura* palm nuts cracking operation was established through the performance evaluation of the modified cracker. The modifications involved replacement of low-carbon steel material of beater and racking rings to high-carbon steel with application mechanical balancing to eliminate thrown forces. The Box-Behnken rotatable design was employed to generate 20 runs of the experiment. The Response Surface Methodology (RSM) was adopted to optimize the performance of the machines, and validated using desirability plots. The results of actual and predicted RSM plots confirmed run 12th as the optimum run having drying period (21 h), drying temperatures (60 ºC), and age of the palm tree (35 years). The desirability plots validated these results with variables values of 21.37 h (drying period), 63.26 ºC (drying temperature), and age 35 yrs. The run 12th had corresponding responses of cracking efficiency, un-cracked percentage, damage percentage, and final moisture content of 96%, 3%, 1%, and 10.2%, respectively.

KEYWORDS: *Dura* palm nuts; optimization; biomass fired forced- convection dryer; centrifugal cracker; cracking efficiency.

1. INTRODUCTION

The palm tree (*Elaeis guineensis* Jacq.) is generally referred to as the oil palm tree and is one of the important economic crops in the tropics that produce more oil per hectare than any oilseed (Barcelos *et al*., 2015). Globally, the industrial and domestic applications of palm kernel oil and cake are on increase astronomically as the world population increases (Ologunagba *et al*., 2010). The extracted palm kernel oil are used for soap making, glycerine, margarine, candle, pomade, oil based paint, polish and medicine (Ologunagba *et al*., 2010). The by-product of the crushed palm kernel is the palm kernel cake used as an ingredient for livestock feeds (Akinoso *et al*., 2009). In the large-scale oil palm mills, palm nuts are usually dried using palm nuts dryer before cracking operation at regulated processing conditions. Conversely, in the traditional oil palm mills, most especially in the Sub-Sahara Africa, the palm nuts are sun-dried for some days or weeks depending on the season and then followed by cracking operation without adequate scientific procedures, instrumentation, and control devices to regulate the drying and cracking parameters. This crude method, characterized by non-homogenous heat transfer during the sun drying operation, negates the optimum performance of the cracker. Mohd-Hafiz, and Abdul-Rashid (2011) studied the physical and optical characteristics of *Dura* and *Tenera* cultivars of oil palm trees and reported that as the age of cultivation of palm trees increased, the size of bunches increased. Likewise, Morakinyo and Bamgboye, 2015, reported that as the age of cultivation of palm trees increased from 20 to 50 years, mass, geometric mean diameter, and true density of *Dura* fruitlets increased from 3.71 to 11.56 g, 14.65 to 26.32, and 978.56 to 1180.32 kg/m^3 with corresponding percentage increase of 212%, 80%, and 21%, respectively. The *Dura* kernel was reported to be bigger in sizes than that of *Tenera* kernel cultivars (Koya and Faborode, 2005; Morakinyo and Bamgboye, 2016a; Morakinyo and Bamgboye, 2016b). The structural analysis of the palm nut shell was reported to consist 53.40% and 29.70% of lignin and cellulose respectively (Ikumapoyi and Akinlabi, 2006). This implies that more impact force is required for the cracking of palm nut harvested from the palm tree of higher age of cultivation, because thickness of palm nut shell increase relatively to age of the palm tree cultivation (Morakinyo and Bamgboye, 2019). In summary, the age of the palm trees influence the physical, mechanical, optical, thermal and aerodynamic properties of bunches, fruits, nuts, and shell. Invariably, it will influence their processing conditions such as drying time, temperature, and impact force required to achieve optimum performance of the cracker (Morakinyo and Bamgboye, 2019). The previous researcher such as Anita (2011) reported the required impact energies of 2.6, 1.82, and 0.97 Joules for the cracking of *Dura*, *Tenera*, and *Pisifera* palm nuts, respectively. Jimoh and Olukunle, 2012 reported the effect of oven-drying temperature on palm nuts cultivars between 120 -180 ^{o}C without considered their physical properties before cracking. These researchers outlined the final moisture content of *Dura* and *Tenera* cultivars of palm nuts to range from 10 – 12%. Idowu *et al*. (2016) posed the effect of moisture content on the cracking efficiency of palm nuts and outlined it to be 75.5% at steady drying temperature.

Olaoye and Adekanye (2018) reported that the cracking efficiency of palm nuts increase relative to the speed of the cracking mechanism and that the un-cracked percentage ranged from 1.3-5.3%. Furthermore, Umani *et al*. (2020) reported average cracking efficiency of the palm nuts to be 90% at a final moisture content of 7.82% but the optimum moisture content was not established for each palm nut cultivar. In the previous study, it was also reported that *Tenera* palm nuts cultivar has higher damage percentage than *Dura* palm nuts cultivar when both were subjected to the same drying and cracking conditions (Morakinyo, 2020). These limitations necessitated further studies by separating the palm nuts according to their cultivars and sizes before drying operation in order to optimize cracking characteristics of the cracker.

Response Surface Methodology (RSM) is one of the statistical tools utilized for optimizing the interaction between a set of independent variables of the processing operation parameters to establish the optimum response (Montgomery, 2009; Adeyanju *et al*., 2016). Some other researchers adopted regression models to estimate all combinations of variables and their effects within the test range (Awolu *et al*., 2016; Nishad *et al*., 2018; Fakayode and Akpan, 2019). The objective of this work was to investigate the effect of the interaction between drying variables on the optimum performance of the modified palm nuts cracker using *Dura* palm nuts cultivar by adopting Response Surface Methodology (RSM) approach.

2 MATERIALS AND METHODS

2.1. Experimental Equipment and Materials

The materials for this study were *Dura* palm nuts cultivar (Figure 1) of initial moisture content of about 22.8% (wet basis). They were obtained from three different oil palm mills namely: Agbongbo village via Obafemi Awolowo University Research and Training Farm, Ile-Ife, Osun state Elere Adubi Oil Palm Mill, Itori, Ogun State and the University of Ibadan Teaching and Research Farm, Ibadan, Oyo State

Nigeria. The palm tree of 30 years of age in 2014 has grown to 35 years of age in 2019, hence 35 years of age of the same cultivar was used for this study and other years remain the same as reported by Morakinyo and Bamgboye (2015) by selecting aforementioned mills. The experimental machines were modified centrifugal impact palm nut cracker and forced-convection dryer, both were developed for this study and installed at the Department of Food Science and Technology, Faculty of Technology, Obafemi Awolowo University, Ile-Ife. Osun State, Nigeria.

(a) Serrated of Dura Fruit Showing Shell Thickness *(b) Serrated of Tenera Fruit Showing Shell Thickness*

(c) Dura Cultivar Palm Nut *(d) Tenera Cultivar PalmNut*

Figure 1: Serrated fruitlets and the palm nuts of *Dura* and *Tenera* cultivars

Source: Morakinyo and Bamgboye, 2019.

2.2 Experimental Design

The Box-Behnken rotatable design of Design-Expert 11.1.0 (Stat-Ease, Inc., 2019) software was adopted to generate the design of an experiment that will enhance the cracking efficiency of *Dura* palm nuts cultivar. The design of the experiment involved the selection of three independent variables at three levels of factorial design of the second-order polynomial model as shown in Table 1. The interaction of each variable was evaluated at a low, center, and high levels to generate 20 experimental runs as shown in Table 2. The independent variables were drying temperature, drying period, and age of the palm trees. The dependent variables were cracking efficiency, un-cracked, damage percentages, and final moisture content.

Table 1: Independent variables for Design of Experiment with coded levels

S/No	Independent variables	Symbol	Unit	Coded levels		
				-1	0	+1
1	Drying Temperature	A	°C	50	60	70
2	Drying Period	B	H	18	21	24
3	Age of palm tree	C	Yrs	20	35	50

2.3 The Experimental Procedures

The palm nuts were sorted and graded into three age categories (20, 35, and 50 years) as shown in Table 1 based on their axial dimensions and weights (Morakinyo and Bamgboye, 2015; Morakinyo and Bamgboye, 2016c). A sample of 100 pieces of palm nuts was selected randomly from each age category in triplicates for drying and cracking operations. Each age category was kept inside labeled black polyethylene bags to determine their physical properties using standardized procedures (Morakinyo and Bamgboye, 2015). The initial tare weight of 100 pieces of each category of age was obtained using electronic digital weighing balance, model: Scout Pro SPU 401 with a standard error of 0.001 mm before drying and after drying to determine final moisture content. A forced convention biomass-fired three -tray cabinet drier was used for the drying 100 pieces at steady drying temperatures of 50, 60, and 70 ^oC and drying retention periods of 18, 21, and 24 h for each age, respectively. The drying operation was carried out in triplicate. The cold samples from the desiccators were cracked using modified centrifugal impact palm nuts cracker at a constant speed of 1850 rpm reported by Morakinyo, 2020. It is a centrifugal impact cracker that consists rotor of four impact hammers and cracking ring, both were made of high carbon steel. The machine performance characteristics (responses) were measured in twenty experimental runs such as cracking efficiency, the un-cracked percentage, damaged percentage, and final moisture content.

2.4 Data Analysis

The Box-Behnken rotatable design was employed to generate 20 runs of the experiment. The Response Surface Methodology (RSM) was adopted to optimize the performance of the machines, and validated using desirability plots. A second-order polynomial regression model describing the quadratic surfaces for the interaction of independent variables and dependent responses was shown in Equation 1. The experimental data obtained were optimized using Response Surface Methodology contour plotting to show levels of interactions in 3-dimensional view. An analysis of variance (ANOVA) test was carried out to check the adequacy of the fitted model and to determine the level of significance of interaction among the variables at $p \leq 0.05$. The reliability of the regression model was validated using the coefficient of determination (R^2), coefficient of correlation (R), and Lack of Fit test. The optimum run of RSM was also validated using Desirability plots.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 \quad (1)$$

Where; Y= Predicted response/variable; β_0 = intercept coefficient (offset); β_1, β_2 and β_3 = line are terms (first-order); β_{11}, β_{22} and β_{33}= quadratic terms (second-order); β_{12}, β_{13} and β_{23} = interaction terms; X_1, X_2 and X_3 = un-coded independent variables.

2.5 Machines Descriptions

2.5.1 The description of biomass-fired force-convection drier

The adopted machines were the newly developed biomass-fired force-convection cabinet drier and the modified centrifugal impact palm nuts cracker. The biomass-fired force-convection cabinet consists of drying and biomass combustion chambers, centrifugal blower, and 2-stroke, air-cool internal combustion petrol engine of 2 hp with a speed of 1850 rpm. It was made of a galvanized steel sheet of 1.5 mm thickness with a vertical height of 1500 mm, a width of 580 mm, and the total length of 2500 mm (Figure

2). The biomass combustion chamber was sealed internally with corrugated stainless sheet as plate heat-exchanger which prevents the fumes and the ashes coming in contact with food material and enhanced effective heat conduction. The blower drive shaft was suspended internally by the blower housing through the help of the two flange radial ball bearings (306) and externally supported by the blower frame with the help of two Plummer radial ball bearing (306), respectively (Khurmi and Gupta, 2005).

2.5.2 The description of modified centrifugal palm nuts cracker

The modified centrifugal impact palm nuts cracker was made of low-carbon steel with total dimensions of 1000 × 750 ×150 (mm) (Morakinyo, 2020). It consists of centrifugal impeller, impeller shaft, cracking ring, cracking ring housing, radial ball bearing and bearing housing, hopper and discharge chute, pulleys, v-belt, support frame and 2-stroke, air-cool internal combustion petrol engine, driven as shown in Figure 3. The speed of this cracker was reduced to 1850 rpm with the help of the choke of the petrol engine instead of a high-speed electric motor of 2850 rpm previously reported as (Morakinyo, 2019b) to reduce palm nut damage percentage. The centrifugal impeller was made of high-carbon steel material; consist of a bushing and four equal weights of the impeller blades and the bushing was of ϴ 60 ×ϴ 30 ×140 mm carbon-steel material. Impeller blades were of a rectangular shape of 75 × 140 ×15 mm, welded at angle 90 degrees to each other. (Morakinyo, 2020). The ring housing enclosed rings and at the bottom of the rings, a discharged chute of 70 ×70 mm hole was made to discharge cracked palm nut shell and kernel out of the cracking rings. The frame of the cracker was made of angle iron of 60 × 60 × 5 mm for stability and rigidity purposes (Morakinyo, 2020).

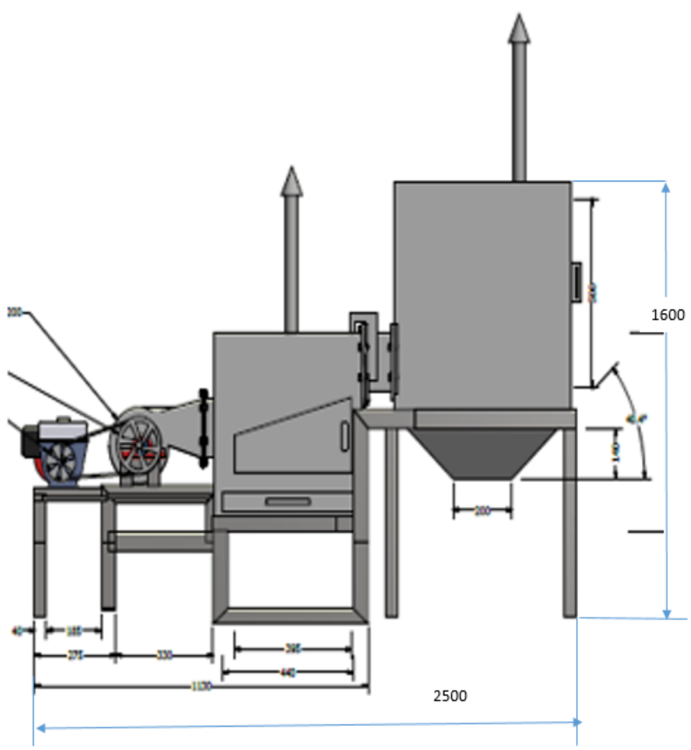
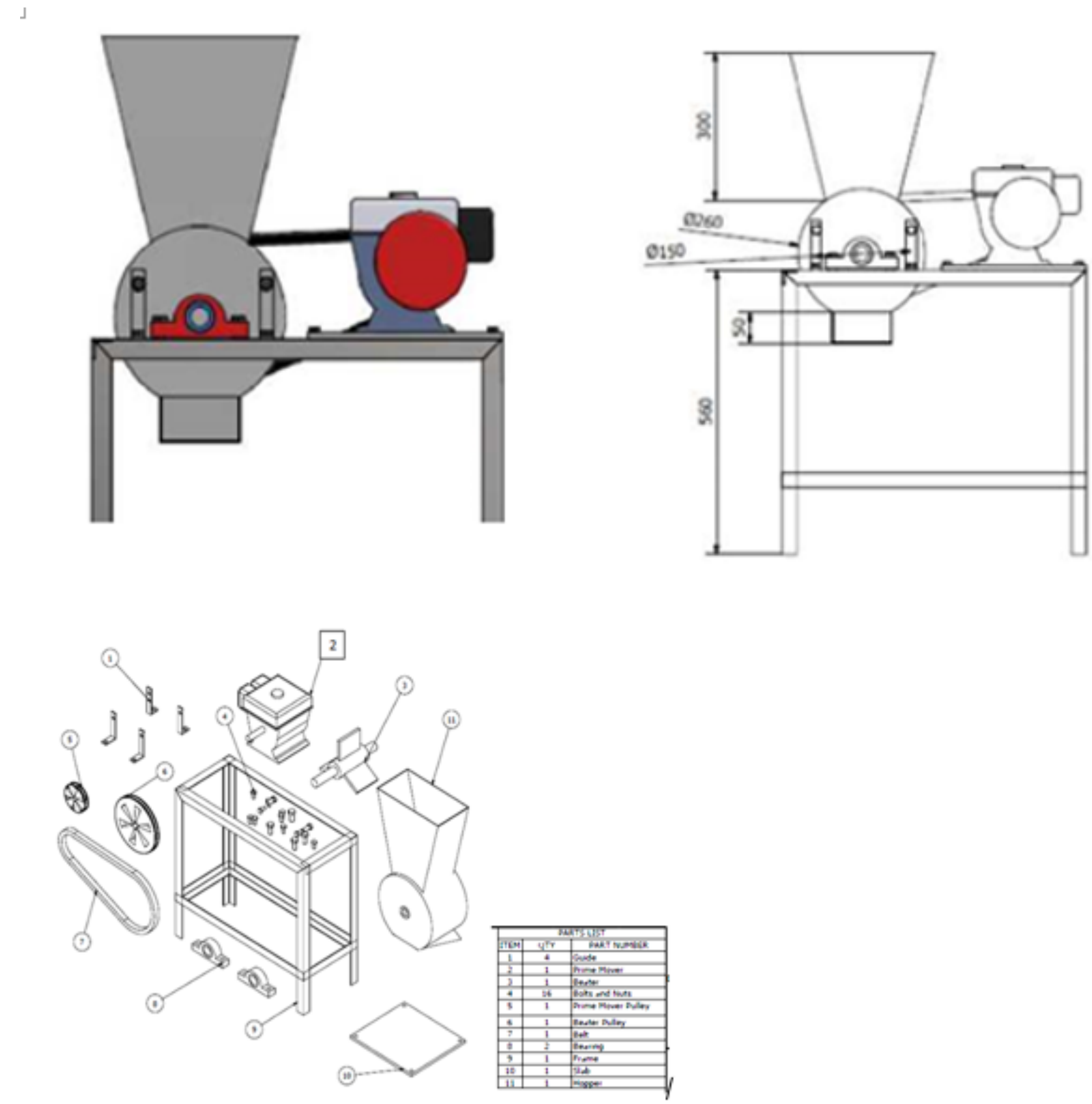


Figure 2: Pictorial View of the Biomass-fired force-convection cabinet drier



PARTS LIST		
ITEM	QTY	PART NUMBER
1	4	Guide
2	1	Prime Mover
3	1	Beater
4	16	Bolts and Nuts
5	1	Prime Mover Pulley
6	1	Beater Pulley
7	1	Belt
8	2	Bearing
9	1	Frame
10	1	Slab
11	1	Hopper

Figure 3: Pictorial (Front elevation) and Exploded views of the Centrifugal Impact Palm Nut Cracker

Source: Morakinyo, 2020.

2.6 Performance Evaluation of the Machines

2.6.2 Cracking efficiency

The cracking efficiency was determined according to Gbabo *et al*. (2013), as the ratio of the number of cracked palm nuts to the total number of the palm nuts fed into the cracking machine expressed in percentage as depicted in Equation (2).

$$C_{EFF} = \frac{N_C}{N_T} \times 100 \quad (2)$$

Where C_{EFF} is the Cracking efficiency (%), N_C = the number of the cracked
N_T is the initial total number of the nuts subjected to cracking operation initially.

2.4.3 Un-cracked percentage

The un-cracked percentage was reported to be the ratio of the un-cracked palm nuts to the total number of the palm nuts before cracking. This was determined using Equation (3) expressed in percentage as reported by Gbabo *et al*. (2013).

$$UC_{\%} = \frac{N_{UB}}{N_T} \times 100 \quad (3)$$

Where $UC_{\%}$ = Un-cracked Percentage, N_{UB} = the number of unbroken shelled nuts
N_T is the total number of nuts subjected to cracking operation initially.

2.4.4 Damaged percentage

The damaged percentage was reported to be the ratio of any type of damage, either half or full broken nut or kernel to the total number of nuts fed into the cracker expressed in percentage. This was measured using the expression reported by Gbabo *et al*. (2013) depicted as Equation 4.

$$D_{\%} = \frac{N_B}{N_T} \times 100 \quad (4)$$

Where; $D_{\%}$ is the damaged percentage, N_B = the total number of any type of broken nuts or kernel.
N_T is the initial total number of the nuts subjected to cracking operation initially.

2.4.5 Final Moisture Content

The final moisture content of each age category on a dry basis of the *Dura* palm nuts cultivar of three different ages (20, 35, and 50 years) bases on their years of the palm trees cultivated to produce the palm nuts were determined using the oven drying method according to ASABE Standards (2006).

3. RESULTS AND DISCUSSION

3.1 Performance Evaluation Results

The performance evaluation results of twenty experimental runs based on the interaction of three independent variables at three levels were shown in Table 2 and their responses which were cracking efficiency, recovery efficiency, damaged percentage, and moisture content. In Table 2, at a constant drying temperature of 50 ^{o}C, with increase in drying time from 18 - 24 h across age 20 - 50 years, the maximum cracking efficiency was 91%, while at 60 ^{o}C, the maximum cracking efficiency across all other variables was 96%, and finally, at 70 ^{o}C, irrespective of increase in any other variables, the maximum cracking efficiency obtained was 93%. In the same trend, un-cracked percentage was at minimum value across all drying temperature and at drying time of (21 h) and at age of 35 years of palm trees cultivation that produce the palm nuts. This observation was found with damage percentage and final moisture content. This indicated that, drying of *Dura* palm nuts beyond 60 ^{o}C and 21 h will not enhance optimum cracking efficiency, minimum un-cracked and damage percentages. More importantly, as year of cultivation of the palm tree increases beyond 35 years of age, the optimum cracking efficiency decreases from 96 to 85%, since more of lignin and cellulose could have been formed in the shell that required more impact force, unless drying period is increased to create void in-between shell and kernel for effective cracking at lower final moisture content (Ikumapoyi and Akinlabi, 2006). This same observation was reported on cracking and separation of shell from the palm kernel of Dura cultivar by Olaoye and Adekanye (2018).

3.2 Cracking Efficiency

In Table 2, the actual maximum cracking efficiency of 96% occurred at run 12th with corresponding variables of (21 h), at 60 ºC, and 35 years for the drying period, drying temperatures, and age, respectively. However, the results of the ANOVA in Table 3 indicate that the quadratic regression modeling equation and model terms were significant at $p \leq 0.05$. The drying period contributed more to the level of significance among all variables in respect of the cracking efficiency.

Table 2: Results of the Experiment of *Dura* Palm Nuts Cultivar Cracking Operation

Run	A: Drying Temperature (ºC)	B: Drying Period (h)	C: Age (yrs)	Cracking Efficiency (%)	Un-cracked Percentage (%)	Damage Percentage (%)	Final Moisture Content (%)
1	50	18	20	76	20	4	13.2
2	60	18	35	80	19	1	12.1
3	60	24	35	82	10	6	8.8
4	60	21	20	90	9	1	11.7
5	60	21	35	94	3	3	10.6
6	70	18	20	80	16	4	12
7	50	24	50	89	8	3	9.5
8	70	24	50	85	2	13	8.7
9	60	21	50	94	5	1	10.5
10	50	24	20	83	14	3	8.9
11	60	21	35	95	4	1	10.4
12	60	21	35	96	3	1	10.2
13	60	21	35	94	5	1	10
14	60	21	35	94	4	2	10
15	70	24	20	78	11	11	8.5
16	50	18	50	76	22	2	12.8
17	70	18	50	90	6	4	11.6
18	60	21	35	94	4	2	10
19	70	21	35	93	5	2	10.5
20	50	21	35	90	9	1	10.8

Alade *et al*. (2020) obtained average cracking efficiency and damaged percentage of 92.35% and 4.59%, respectively, at the final moisture content of 13.4% for both *Dura* and *Tenera* palm nuts cultivars. This result was found to be lower than values obtained in this study because both cultivars were dried at the same steady temperature.

Babatunde and Okoli (1988) reported cracking efficiencies in the range of 87.50% – 94.50% at the final moisture content range between 9% and 11%. This same trend of lower efficiency was reported by Ndukwu and Asoegwu (2010). The cracking efficiency between 63.78% - 84.56%, was also reported by Ajewole (2014) and Oke (2007) reported 63.4% and 90% with a rotor speed of 1650 and 2500 rpm, respectively. Udo *et al*. (2015) also outlined an average cracking efficiency of 93% at varying axial dimensions of the palm nuts. These reports indicate that all independent variables such as drying temperature, drying period, and age used in the current study were critical factors and significantly contributed to the cracking efficiency of *Dura* palm nuts cultivar. Hence, *Dura* palm nuts should be dehydrated separately from the *Tenera* palm nuts before the cracking operation since both differed in their physical, mechanical, and thermal properties. The coefficient of determination (R^2) was 0.9619, showing a high level of correlation among the variables and which implies that this model could explain 96.19% of the data. The coefficient of correlation (R) was found to be (0.9807), this indicated that the actual experimental cracking efficiency correlated to that of predicted values obtained at 98.07%. Adequate precision of 16.22 was obtained this indicated a greater signal to noise ratio of greater than 4 required for a model to be regarded as a good one. This further shows the desirability level (93%) of the regression model depicted below as Equation 5.

$$C = 93.54 + 1.20A + 1.50B + 2.70C - 3.37AB + 1.37AC - 0.375BC - 0.59A^2 - 11.09B^2 - 0.0909C^2 \quad (5)$$

where C = Cracking Efficiency, 93.54 = intercept coefficient (offset); A, B and C are the drying temperature, retention period and age, respectively at linear terms (first-order), A^2, B^2, and C^2 are quadratic terms (second-order), AB, AC, and BC: interaction terms.

In Figure 4 of Response Surface plots of 3D, the predicted optimum cracking efficiency was found to be 96% which occurred at the drying temperature of 60 °C, age of 35 years of palm trees that produce the palm nuts and at the drying period of 21 h. Comparing this predicted cracking percentage values to that of the actual experimental value, it is clearly established that the optimum cracking efficiency is 96% which occurred at the experimental run 12th in Table2.

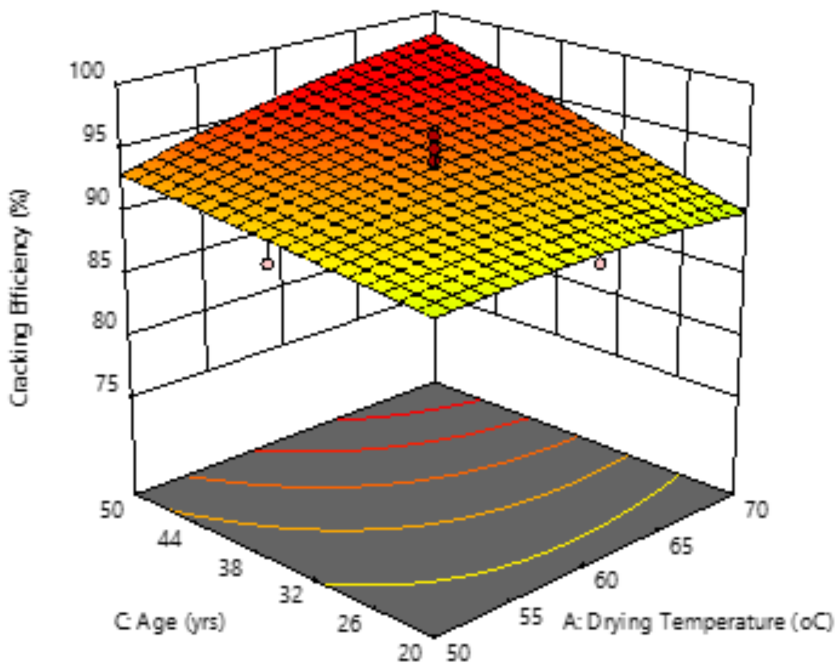


Figure 4: Surface Response 3D plot showing the effect of the age of the palm tree at the drying period of 21 h on the cracking efficiency.

3.3 Un-cracked Percentage

In Table 2, the minimum un-cracked percentage occurred at the experimental run 8th which clearly indicate 2% value, with corresponding damage percentage of 13%. It run 8th is undesirable value when compare with run 12th of 3% of un-cracked percentage since it has lower damage percentage of 1%. However, this observation validated the experimental run 12th as the best and optimum experimental run, due to its minimum damage percentage and a moderate final moisture content value of 10.2% that enhances the highest cracking efficiency of 96%. It was observed that at the drying temperature of 70 ºC and drying period of 24 h, the damage percentage increased to 13%, while the moisture content decreased to 8.7% with corresponding cracking efficiency of 85%. This moisture content is not economical, because it was observed that at these drying conditions, some of the nuts had over dried. The maximum un-cracked percentage of 22% occurred at run 16th in Table2, having corresponding lower cracking efficiency of 76%.

This result was in the same trend previously reported by Umani *et al*. 2020 that outlined the average un-cracked percentage of *Dura* palm nuts to be in the range of 8.61% to 24.72% as the rotor speed increases from 1600 rpm to 3550 rpm. Invariably, this result added more values in comparison to previous studies due to the application of effective drying variables that enhances the performance characteristics of the modified centrifugal palm nuts cracker. The result of the ANOVA in Table 3 shows that the quadratic regression modeling equation and model terms were significant at $p \leq 0.05$ while the drying period contributed more than any other variables to the level of significance regards to un-cracked percentage. The coefficient of determination (R^2) value was (0.9297), which indicates that this model could describe 92.97% of the experimental data, while the coefficient of correlation (R) between the actual and predicted values of the recovery percentage was 0.9642. Adequate precision of 12.355 obtained, indicated a greater signal to noise ratio higher than 4 which shown the desirability level of the regression model depicted below shown as Equation 6.

$$Y= 5.06–3.30A–3.80B–2.70C+1.37AB-1.87AC-0.875BC+0.0909A^2+7.50B^2+0.0909C^2 \quad (6)$$

Where; Y = Un-Cracked Percentage, A, B and C are the drying temperature, retention period and age, respectively at linear terms.

Table 3: ANOVA of Quadratic model and Regression Coefficients for Responses of *Dura* Palm Nuts Cultivar

Source	Df	Cracking Efficiency		Un-cracked percentage		Damaged percentage		Final content Moisture (Linear)	
		Coeff.	P-value	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value
Model	9	+93.54	0.0001	+5.06	0.0001	+1.250	< 0.0001	+10.52	< 0.0001
A	1	+1.20	0.0695	-3.30	0.0009	+2.100	0.0002	-0.39	0.0122
B	1	+1.50	0.0293	-3.80	0.0003	+2.100	0.0002	-1.73	< 0.0001
C	1	+2.70	0.0010	-2.70	0.0036	+0.000	1.0000	-0.12	0.3979
AB	1	-3.37	0.0005	+1.37	0.1153	+2.000	0.0007		
AC	1	+1.37	0.0639	-1.87	0.0405	+0.500	0.2537		
BC	1	-0.375	0.5825	-0.875	0.2982	+0.500	0.2537		
A^2	1	-0.59	0.6111	0.0909	0.9480	+0.864	0.2481		
B^2	1	-11.09	< 0.0001	+7.50	0.0002	+2.860	0.0023		
C^2	1	-0.090	0.9372	0.0909	0.9480	+0.364	0.6168		
R^2		0.9619		0.9297		0.9339		0.9119	
R		0.9807		0.9642		0.9664		0.9549	
Adj.R^2		0.9276		0.8664		0.8743		0.8953	
Ad.Preci.		16.22		12.36		15.1713		22.929	
F-value		28.05		14.69		15.690		55.17	
Lack of Fit		13.35	0.0155	48.02	0.0037	10.300	0.1205	2.73	0.0729
CV%		2.13		25.20		35.390		5.00	

A, B, and C are the drying temperature, drying period, and age, respectively at linear terms (first-order), P-values less than 0.05 indicate model terms are significant while those higher than 0.05 are insignificant.

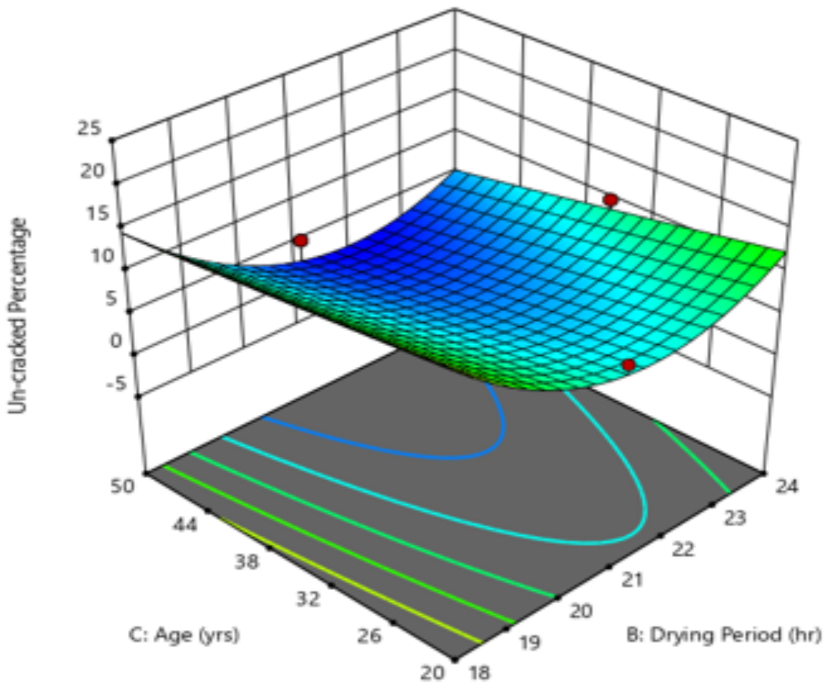


Figure 5: Surface Response 3D plot showing the effect of age and drying temperature of 60 ^oC on the un-cracked percentage.

3.4 Damage Percentage

In Table 2, the optimum damage percentage of 1% occurred in run 12th having corresponding variables of 60 ^oC, 21 h, and 35 years for drying temperature, period, and age of palm trees, respectively. This result was lower than the damage percentage reported by Alade *et al*. 2020 of 4.59% at the final moisture content of 13.4% of the *Dura* palm nuts. This implies that this final moisture content of 13.4% reported could not enhance the performance of palm nut cracker effectively but promote damage percentage. Umani *et al*. 2020 reported damage percentage between 7.41% - 22.23% against the rotor speeds increase from 2962 to 3550 rpm, respectively. The result of ANOVA in Table 3 , shown that the quadratic regression modeling equation and model terms except age were significant at $p \leq 0.05$, in which drying period and temperature contributed equally to the level of significance. The coefficient of determination (R^2) value was (0.9339), which suggests that the model could explain 93.39% of the data, while the coefficient of correlation (R) between the actual and predicted values of the damage percentage was 0.9664, which is 96. 64% of correlation. Adequate precision of 15.1713 indicated a greater signal to noise ratio higher than 4 which shown the desirability level of the regression model depicted below as Equation 7.

$$D = 1.25+2.10A+2.10B+0.000C+2.000AB+0.500AC+0.500BC+0.864A^2+2.86B^2+0.364C^2 \quad (7)$$

Where; D = Damage Percentage, A, B and C are the drying temperature, retention period and age, respectively at linear terms.

In Figure 6 of Response Surface plots (3D), the predicted optimum damage percentage occurred at the middle of the quadratic curves with a range of between 1-1.5% with the corresponding values of the drying variables of 60 ^oC (drying temperature), 21 h (drying period), and at 35 years of the age of the palm tree that produce the palm nuts. This result is almost the same with optimum experimental value for damage percentage validated experiment run 12th.

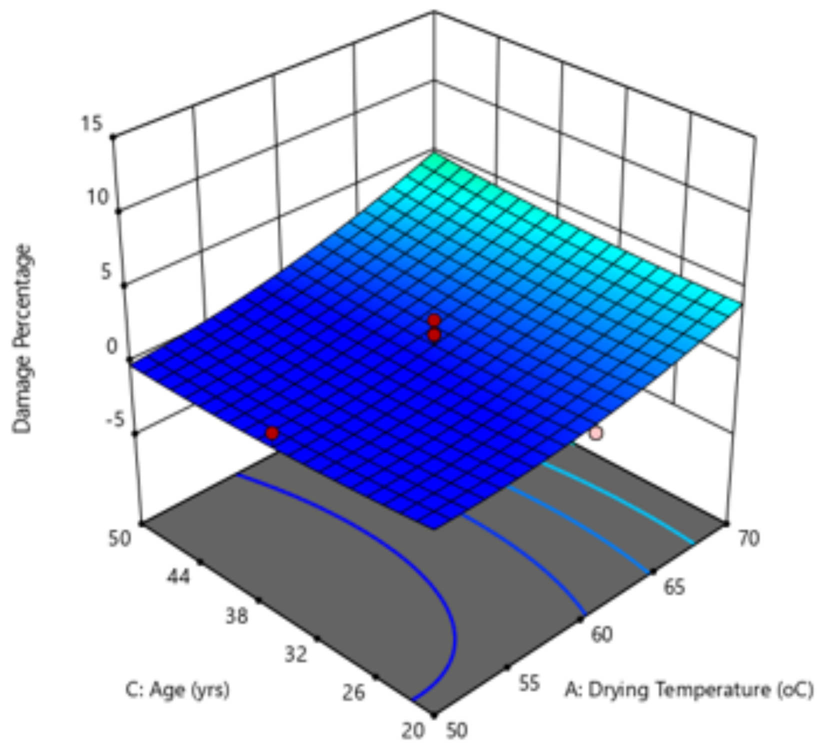


Figure 6: Surface Response 3D plot showing the effect of age at drying period of 21 h. on the damage

3.5 Moisture Content

In Table 2, run 12th shown the optimum final moisture content of 10.2% with corresponding variables of drying temperature, period, and age of palm trees of 60 ºC, 21 h, and 35 years, respectively, due to minimum damage percentage of 1%. From Table2, the highest cracking efficiency occurred when the final moisture content was 10.2%, while the lowest cracking efficiency of 76% occurred at the final moisture content of 13.2%. The same trend was reported by Omoruyi and Ugwu (2015) that outlined the cracking efficiency to be higher when the final moisture content was 9.0% and lower at 13% in both *Dura* and *Tenera* palm nuts cultivars. The result of ANOVA in Table 3 shows that the quadratic regression modeling equation was significant at $p \leq 0.05$, while only the drying period among all other model terms contributed to the level of significance. The coefficient of determination (R^2) value was (0.9119), which infers that this model could explain 91.19% of the data, while the coefficient of correlation (R), indicating the level correlation between the actual and predicted values of the recovery percentage was 0.9549, that is 95.49% of correlation. Adequate precision of 22.93 indicated a greater signal to noise ratio than 4 which shown the desirability level of the regression model depicted below shown as Equation 8.

$$M = 10.54 - 0.3900A - 1.73B - 0.1200C \quad (8)$$

Where; M = Moisture content, A, B, and C are the drying temperature, drying period, and age, respectively at linear terms (first-order).

In Figure 7 of Response Surface plots (3D), the predicted optimum final moisture could found to be in a range between 10.0-10.2% at the middle of the contour with the corresponding value of the drying variables 60 °C (drying temperature), 21 h (drying period), and at 35 years of the age.

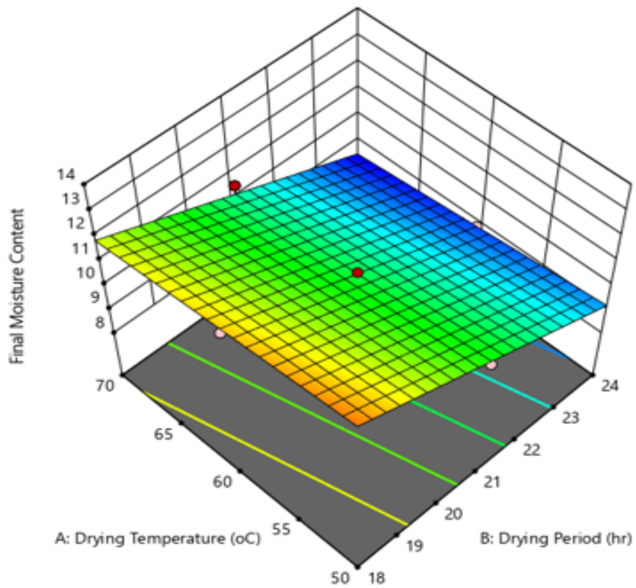


Figure 7: Surface Response 3D plot showing the effect of drying temperature at the age of 35 Yrs. on the Final moisture content.

3.6 Optimization of variables using Desirability model

This desirability solution of the optimum iterative step indicate optimum drying variables and responses to be 63.258 °C, 21.369, and 35 years; 93.75%, 3.70%, 2.41% and 10.20% for drying temperature, drying period and age; cracked efficiency, un-cracked percentage, damage percentage, and final moisture content, respectively. Figure 8 of desirability plots indicate optimum responses as cracking efficiency (93.76%), un-cracked percentage (3.65), damage percentage (2.45%), and final moisture content (10.20%). These desirable variables values correspond to desirability solution values and closer to the actual variables deduced from the experimental Table 2. Hence, RSM plots predicted values and desirability solution values validated experimental run 12th to be the optimum run, having optimum responses of cracking efficiency, un-cracked percentage, damage percentage, and final moisture content.

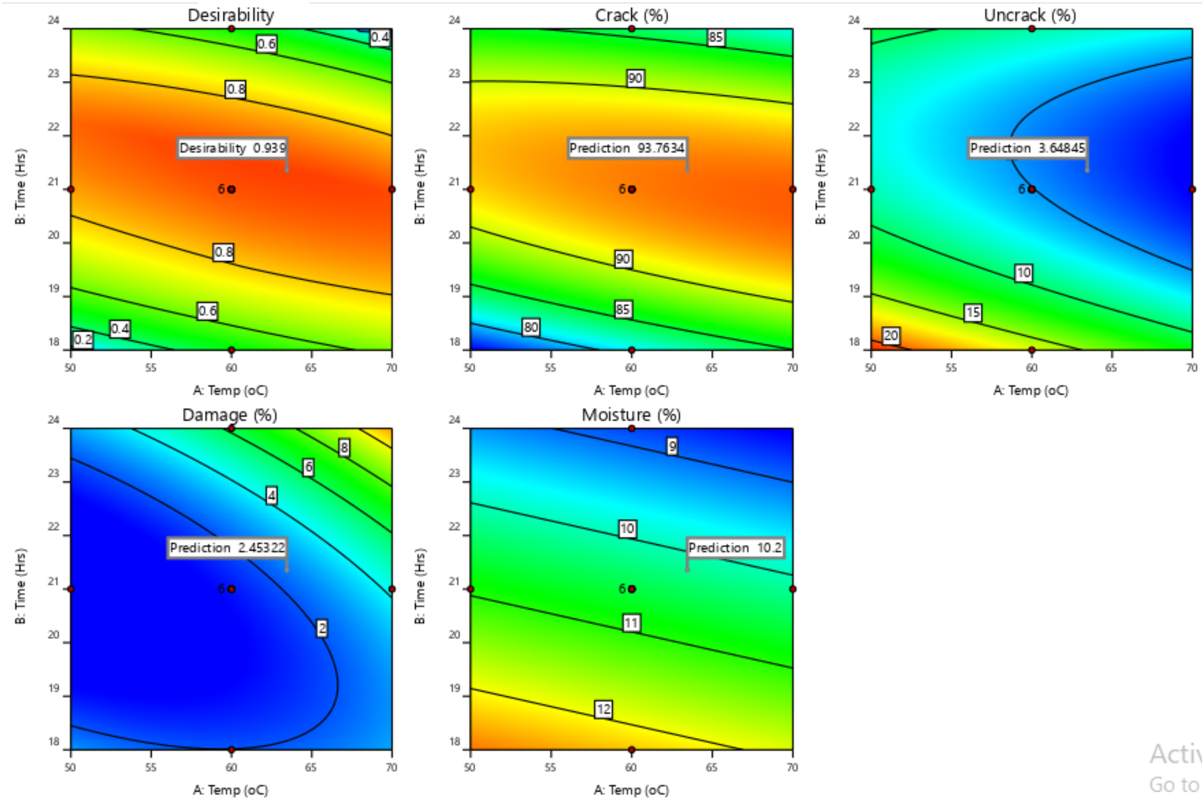


Figure 8: Desirability Plot at optimum independent variables showing optimum cracking percentage, un-cracked percentage, damage percentage and final moisture content of 96%, 3%, 1%, and 10.5%, respectively at desirability of 1.

4. CONCLUSION

The results of the performance evaluation of both machine in sequence of operations and predicted RSM plots confirmed run 12th as the optimum run having drying period (21 h), drying temperatures (60 ^oC), and age of the palm tree (35 years). Furthermore, the desirability plots validated these results with variables values of 21.37 h (drying period), 63.26 ^oC (drying temperature), and age 35 yrs. The run 12th had corresponding responses of cracking efficiency, un-cracked percentage, damage percentage, and final moisture content of 96%, 3%, 1%, and 10.2%, respectively. Hence, the separation of the palm nuts cultivars according to their physical properties and cultivars prior to the drying operation and cracking had contributed tremendously to increase in the cracking efficiency from 75.5-85.0% to 96% and decrease the un-cracked percentage to 3% and damage percentage to 1% for *Dura* palm nuts cultivar.

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