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ORIGINAL RESEARCH ARTICLE

MODELING THE RELATIONSHIP BETWEEN GRADING, MOISTURE CONTENT AND SCREEN APERTURES IN GROUNDNUT DECORTICATION

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ABSTRACT

Whole Groundnut kernels free of bruises attract foreign exchange earnings. The appropriate selection and the interactions between the processing parameters in groundnut decortication produces clean kernels. Therefore, the focus of this study was to establish mathematical equations in order to explore and predict the possible relationships between the process inputs (grading, moisture content and screen apertures) and the measured output (clean kernels, bruised kernels and split kernels) in decorticating three selected varieties of groundnut in-shell commonly cultivated in Nigeria with a view of maximizing their kernel quality. The varieties were Samnuts 10, 14 and 18. In doing this, individual relationships were explored one at a time by keeping other process parameters constant to ensure clear interpretations. The relationships between grading, moisture content and screen apertures versus the response (efficiency of clean, bruised and split kernels) were approximated using a linear and nonlinear (quadratic or polynomials) functions. Regression analysis and design expert software (multivariate) were used to develop the mathematical models that describe the relationships between these inputs and the measured outputs.

1.0 Introduction

Groundnut (*Arachis hypogaea* L.) is one of the world's principal oil seed crops that is rich in protein and has a high energy value. Groundnut is also an important food crop in many areas of semi-arid tropics (FAO, 1994). It is cultivated for its kernels, oil and hay for livestock (Nigam *et. al.*, 1999). Improvements in groundnut productivity and processing for a qualitative output are also crucial because of its potential to regain and increase export earnings. Growth in agriculture has generally been linked to development in other sectors which invariably contributes to poverty alleviation (Khan, 1999). Like most developing countries, majority of the rural dwellers in Nigeria depends on agriculture. In order to reduce poverty, agricultural sector must be revitalized. This will increase rural employment, trade and purchasing power for smallholder farming families, strengthen the economic capacity of rural women and improve household nutrition. It thus plays a key role in the agriculture-dependent economies of West Africa where its marketing and trade served as the major

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sources of employment, income and foreign exchange (Rai *et al.,* 1993; Revoredo and Fletcher, 2002; Ntare *et al.,* 2008).

Production of groundnut in Nigeria has immensely contributed to the economic development being one of the most popular commercial crops. Nigeria produces 41 % of the total groundnut production in West Africa (Echekwu and Emeka, 2005; FAOSTAT, 2010). Until 1969, Nigeria was the third largest exporter of groundnut in the world after India and China. Groundnut sector provided the basis for the agro-industrial development and contributed significantly to the commercialization and integration of the national rural sectors (Ntare *et al*, 2007).

However, groundnuts exported into Europe during the years of bumper harvests in Nigeria and other Sub-Saharan African countries (SSA) was done majorly in-shell because of high incidence of aflatoxin contamination on decorticated kernels is carcinogenesis. Aflatoxin is associated with bruises and breakages of kernels. This reduced the net profit of both the farmer and produce agent. Kernel quality as a method of measuring marketability is very essential in successful agricultural production as poor quality produce is characterized by gradual decline in value and vigour (Hartmann *et al.,* 1990). A good quality kernel has high economic value, better germination and free from disease and insect attack.

The greatest potential for providing clean decorticated kernels is the development of mathematical models that will predict the relationships between process input and measured output in order to obtain maximum kernel quality such that profit could be maximized for the production to be sustained. Such models could be utilized for the design and development of suitable home-processing equipment in order to reduce bruises and breakages on the decorticated kernels to meet the standards of the importing countries and in turn serves as leverage for creating jobs for the teaming unemployed youth population.

2.0 Methodology

Using the process modeling technique in design expert software, data obtained for clean, bruised and split kernels while decorticating the three selected groundnut varieties were model. The aim is to find a functional relationship that can adequately relate process input (grading, moisture content and sieve size) and process output (clean, bruised and split kernels).

Multiple regression analysis was used to develop the mathematical relationships between the respective independent variables (moisture content and screen apertures) that would predict the quality of kernel recovered from each grade of the three groundnuts in-shell varieties being decorticated in the study. The mathematical models being developed were basically focused on predicting the rate of clean kernel recovery.

Linear and quadratic mathematical models were tested for each grade of the three groundnut varieties in order to obtain possible relationships and then select the best relationships (models). The relationships between the combination of the independent variables and the response/dependent variable (clean kernels) were also established for each grade of the three groundnut varieties.

Residual plots for the selected models of each grade of the three groundnut varieties were developed to indicate the relationships on the effects of clean kernels recovery on each combination of the independent variables. Microsoft Excel Statistical Package (2010) was used to develop the residual and surface response plots.

2.1 Experimental procedure

Three groundnut varieties were selected for the study. They were Samnuts 10, 14 and 18. Each of the three groundnut in-shell varieties were graded into three different grades according to its geometric size with the aid of the developed grader. Each grade from the three varieties was then subjected to three moisture regimes (8, 10 and 20 %) and was decorticated with all the three screens (8, 10 and 12 mm) constructed. The initial decorticating trials for each variety were conducted with ungraded samples of all the grades at the chosen moisture content regimes to serve as control. All decortications were replicated three times in order to minimize error. The measured parameters studied were clean, bruised and split kernels and the process conditions (factors of interest) employed are grading, moisture content and screen apertures. These factors were varied at various levels and their effects on the quality of the clean kernels were studied and measured via three varieties of groundnut in-shell.

2.2 Procedure for model development

Multi-variable (multivariate) method of modelling was adopted. Microsoft Excel Statistical Package (2010) was used for the regression analysis to establish relationships that exist between the independent and dependent/response variable (clean kernels recovery). The data used for these analyses were arranged into linear and quadratic terms as shown in Table 1. Regression models of linear, interactions, quadratic, linear plus quadratic, linear plus interaction and full quadratic were derived from these arrangements as the case may be. Based on the *F*-values, the *P*-values for each variable, coefficient of determination, (R^2), and the adjusted R^2 values, best models were selected for each groundnut grade. Plots of observed and predicted values of clean kernels recovery were used to select the best model based on the highest values of R^2 using Microsoft Excel Statistical Package (2010). Since maximizing kernel quality is the goal of this study, clean kernel recovery was considered as dependent variable (or response variable). Similarly, generalized mathematical models showing the relationships between clean kernels recovery and the independent variables of each grade of the three groundnut varieties were developed using regression analysis. Plots of the observed against predicted values of clean kernels recovery for the respective grades of the three groundnut varieties were also presented.

Table 1: Format used for multi-variable relationship modelling

Clean Kernels (Y)	Linear		Interaction (MC×SA)	Quadratic	
	MC	SA		$(MC)^2$	$(SA)^2$
Y_1	MC_1	SA_1	MC_1SA_1	$(MC_1)^2$	$(SA_1)^2$
Y_2	MC_2	SA_1	MC_2SA_1	$(MC_2)^2$	$(SA_1)^2$
Y_3	MC_3	SA_1	MC_3SA_1	$(MC_3)^2$	$(SA_1)^2$
Y_4	MC_1	SA_2	MC_1SA_2	$(MC_1)^2$	$(SA_2)^2$
Y_5	MC_2	SA_2	MC_2SA_2	$(MC_2)^2$	$(SA_2)^2$
Y_6	MC_3	SA_2	MC_3SA_2	$(MC_3)^2$	$(SA_2)^2$
Y_7	MC_1	SA_3	MC_1SA_3	$(MC_1)^2$	$(SA_3)^2$
Y_8	MC_2	SA_3	MC_2SA_3	$(MC_2)^2$	$(SA_3)^2$
Y_9	MC_3	SA_3	MC_3SA_3	$(MC_3)^2$	$(SA_3)^2$

Y_{1-9} - Clean kernels recovered, MC_{1-3} – Moisture content at 8, 10 and 20 % levels, SA_{1-3} – Screen aperture of 8, 10 and 12 mm

3.0 Results and Discussion

3.1 Modelling clean kernel recovery

The regression model for clean kernels recovery from the three grades of the groundnut varieties (Samnuts 10, 14 and 18) considered in this study. The ANOVA and regression output for the selected models for grades I, II and III samples of three groundnut varieties were shown in Tables 1 – 12. From the regression output, the relationship between clean kernels recovery (dependent/response variable) and the combinations of the two independent variables (moisture content and screen aperture) in linear, quadratic and interaction terms were derived. The selected equations were based on the significant higher *F*-values, coefficient of determination, R^2, the number of significant variables with respect to their *P*-values. Other models were rejected based on the insignificant levels of *F*-values in some cases.

Similarly, regression and appropriate equation models for clean kernels recovery from the three grades of Samnuts 10, 14 and 18 having highest R^2 value are as presented in equations 1 – 7:

i) Grade I

Samnut 10:

$$CK = 53.73 - 2.807MC - 3.108SA + 0.04921(MC \times SA) + 0.09417MC^2 + 0.581SA^2 \quad (1)$$

Samnut 18 :

$$CK = 11.185SA - 0.728MC - 0.5002 \quad (2)$$

ii) Grade II

Samnut 10:

$$CK = 0.511MC + 24.36SA - 62.96 + 0.177(MC \times SA) - 0.08908MC^2 - 1.150SA^2 \quad (3)$$

Samnut 14:

$$CK = 21.77SA - 22.09 - 1.593MC + 0.149(MC \times SA) - 1.130SA^2 \quad (4)$$

Samnut 18:

$$CK = 82.87 - 0.720MC - 13.90SA + 1.161SA^2 \quad (5)$$

iii) Grade III

Samnut 10:

$$CK = 8.495MC + 32.28SA - 113.64 + 0.552(MC \times SA) - 0.454MC^2 - 2.270SA^2 \quad (6)$$

Samnut 14:

$$CK = +2.742MC + 37.88SA - 78.43 + 0.732(MC \times SA) - 0.314MC^2 - 2.844SA^2 \quad (7)$$

Where, CK= Clean kernel, MC= moisture content, SA= Screen Aperture

3.2 Plots of observed and predicted values of clean kernels recovery

The plots of the observed against predicted values of clean kernels recovery from grade I, II and III samples of Samnuts 10, 14 and 18 were presented Figures 1 – 7. The plot shows that the residuals were in a linear, quadratic and interaction manner on the graphs suggesting that the variance of the original observations were constant. The higher level of variance (R^2) that accounted for clustered graph indicated smaller and unbiased differences between observed and predicted values of clean kernels recovery; hence a well fitted regression model for prediction. This also indicated that the terms in the model developed were adequate, hence a well fitted regression line/models for prediction. The plots also revealed that an increase in screen aperture would lead to higher values of clean kernels recovery. It also revealed slight decrease in clean kernels recovery when moisture content increases. However, higher clean kernels recovery resulted from a combination of larger screen aperture and increase in moisture content.

The plots also revealed that increase in screen aperture would lead to lower values of clean kernels recovery probably because a larger percentage of the pods would pass through the screen undecorticated due to the smaller size of the grade. Similarly, it was observed that slight increase in clean kernels recovery would be realized with increase in moisture from 8 – 10 % mainly because the smaller pods will swell thereby reduce the chances of passing undecorticated. However, a right combination of increase in screen aperture and moisture content produced slightly higher clean kernels recovery.

4.0 Conclusion

Mathematical model equations that could explore and predict the possible relationships between moisture content and screen aperture on one hand and kernel quality in terms of clean kernels recovery for the three varieties of groundnuts in-shell were developed. The relationship existing between the performances indices were found to be adequately expressed by regression equations using linear and non-linear (quadratic or polynomials) functions.

It could be generalized that the consistencies in obtaining higher values of coefficient of determination, R^2, in multi-variables modelling also confirmed a direct relationship between clean kernels recovery and independent variable (moisture content and screen aperture). It should also be noted that the fittings expressed in equations 1 – 7 holds true if the values of moisture content of the decorticated groundnuts and screen apertures of the decorticator are greater than zero.

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Table 1: Analysis of variance for selected quadratic model for the grade I groundnut in-shell (Samnut 10)

Source	Sum of Square	Mean Square	F	Sign. F	Degrees of Freedom
Regression	2118.5	423.70	421.70	0.000182	3
Residual	3.014	1.005			5
Total	2121.5				8

Other parameters

R	R^2	Standard Error	No. of Observations
0.999	0.999	1.002	9

Table 2: Regression output for quadratic model for grade I groundnut in-shell (Samnut 10)

	Coefficient	P value	Std Error	-95%	95%	t Stat
b0	53.73	0.06842*	19.26	-7.559	115.01	2.790
b1	-3.807	0.04608*	1.157	-7.490	-0.124	-3.290
b2	-3.108	0.450	3.584	-14.51	8.298	-0.867
b3	0.04921	0.296	0.03898	-0.07483	0.173	1.263
b4	0.09417	0.08928*	0.03797	-0.02668	0.215	2.480
b5	0.581	0.04642*	0.177	0.01734	1.145	3.280

*Significant at 95% confidence level.

Table 3: Analysis of variance for selected model for the grade I groundnut in-shell (Samnut 18)

Source	Sum of Square	Mean Square	F	Sign. F	Degrees of Freedom
Regression	3133.5	1566.7	456.39	3E-07	2
Residual	20.60	3.433			6
Total	3154.1				8

Other parameters

R	R^2	Standard Error	No. of Observations
0.997	0.993	1.853	9

Table 4: Regression output for linear model for grade I groundnut in-shell (Samnut 18)

	Coefficient	P value	Std Error	-95%	95%	t Stat
b0	-50.02	1.87635E-05*	4.112	-60.08	-39.96	-12.16
b1	-0.728	0.000820*	0.118	-1.016	-0.440	-6.187
b2	11.18	9.91376E-08*	0.378	10.26	12.11	29.57

*Significant at 95% confidence level.

Table 5: Analysis of variance for selected quadratic model for the grade II groundnut in-shell (Samnut 10)

Source	Sum of Square	Mean Square	F	Sign. F	Degrees of Freedom
Regression	400.31	80.06	11.72	0.03491	5
Residual	20.49	6.831			3
Total	420.81				8

Other parameters			
R	R^2	Standard Error	No. of Observations
0.975	0.951	2.614	9

Table 6: Regression output for quadratic model for grade II groundnut in-shell (Samnut 10)

	Coefficient	P value	Std Error	-95%	95%	t Stat
b0	-62.96	0.299	50.21	-222.76	96.85	-1.254
b1	0.511	0.876	3.017	-9.092	10.11	0.169
b2	24.36	0.07988*	9.345	-5.376	54.11	2.607
b3	0.177	0.180	0.102	-0.147	0.500	1.741
b4	-0.08908	0.435	0.09902	-0.404	0.226	-0.900
b5	-1.150	0.08863*	0.462	-2.620	0.321	-2.488

*Significant at 95% confidence level

Table 7: Analysis of variance for selected quadratic model for the grade II groundnut in-shell (Samnut 18)

Source	Sum of Square	Mean Square	F	Sign. F	Degrees of Freedom
Regression	2257.7	752.57	267.30	6E-06	3
Residual	14.08	2.815			5
Total	2271.8				8

Other parameters			
R	R^2	Standard Error	No. of Observations
0.997	0.994	1.678	9

Table 8: Regression output for quadratic model for grade II groundnut in-shell (Samnut 18)

	Coefficient	P value	Std Error	-95%	95%	t Stat
b0	82.87	0.03596*	29.11	8.039	157.70	2.847
b1	-0.720	0.00107*	0.107	-0.994	-0.447	-6.762
b2	-13.90	0.06641*	5.942	-29.18	1.373	-2.340
b3	1.161	0.01124*	0.297	0.399	1.924	3.915

*Significant at 95% confidence level.

Table 9: Analysis of variance for selected quadratic model for the grade III groundnut in-shell (Samnut 10)

Source	Sum of Square	Mean Square	F	Sign. F	Degrees of Freedom
Regression	1659.6	331.93	12.84	0.03075	5
Residual	77.56	25.85			3
Total	1737.2				8

Other parameters			
R	R^2	Standard Error	No. of Observations
0.997	0.995	5.085	9

Table 10: Regression output for quadratic model for grade III groundnut in-shell (Samnut 10)

	Coefficient	P value	Std Error	-95%	95%	t Stat
b0	-113.64	0.329	97.69	-424.53	197.24	-1.163
b1	8.495	0.244	5.870	-10.19	27.18	1.447
b2	32.28	0.174	18.18	-25.57	90.14	1.776
b3	0.551	0.06855*	0.198	-0.07804	1.180	2.788
b4	-0.454	0.09969*	0.193	-1.067	0.159	-2.357
b5	-2.270	0.08580*	0.899	-5.130	0.591	-2.525

*Significant at 95% confidence level

Table 11: Analysis of variance for selected quadratic model for the grade III groundnut in-shell (Samnut 14)

Source	SS	SS%	MS	F	F Signif	Degree of freedom
Regression	3219.6	95	643.92	11.63	0.03529	5
Residual	166.13	5	55.38			3
Total	3385.7	100				8
Other parameters						
R	R^2		Standard Error		No. of Observations	
0.975	0.951		7.442		9	

Table 12: Regression output for quadratic model for grade III groundnut in-shell (Samnut 14)

	Coefficient	P value	Std Error	-95%	95%	t Stat
b0	-78.43	0.621	142.97	-533.42	376.56	-0.549
b1	2.724	0.772	8.591	-24.62	30.07	0.317
b2	37.88	0.250	26.61	-46.79	122.56	1.424
b3	0.732	0.08537*	0.289	-0.189	1.653	2.531
b4	-0.314	0.346	0.282	-1.211	0.583	-1.115
b5	-2.844	0.119	1.315	-7.030	1.343	-2.162

*Significant at 95% confidence level.

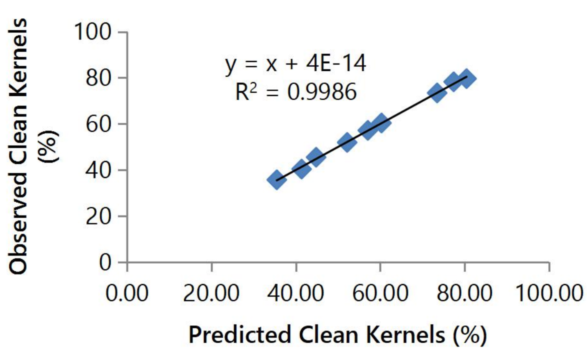

Figure 1: Observed versus predicted values of clean Kernels from multi-variable regression model for grade I groundnut in-shell (Samnut 10)

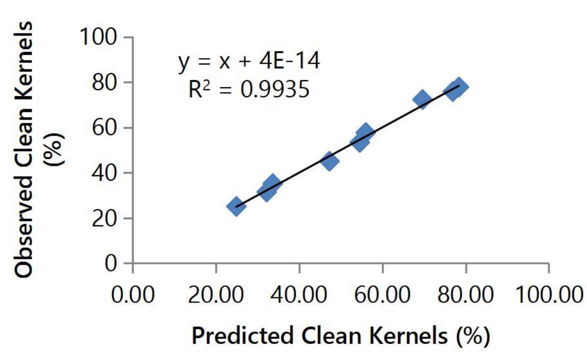

Figure 2: Observed versus predicted values of clean kernels from multi-variable regression model for grade I groundnut in-shell (Samnut 18)

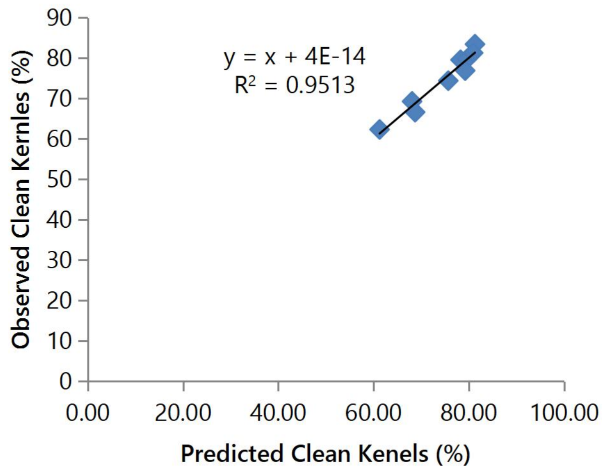

Figure 3: Observed versus predicted values of clean kernels from multi-variable regression model for grade II groundnut in-shell (Samnut 10)

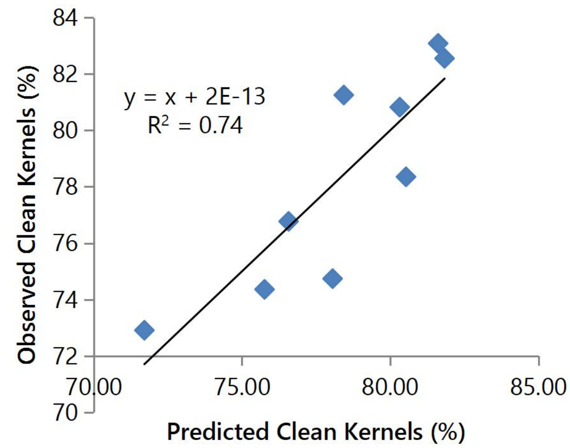

Figure 4: Observed versus predicted values of clean kernels from multi-variable regression model for grade II groundnut in-shell (Samnut 14)

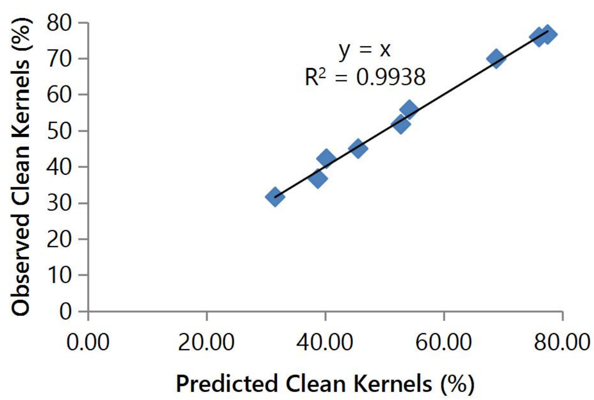

Figure 5: Observed versus predicted values of clean kernels from multi-variable regression model for grade II groundnut in-shell (Samnut 18)

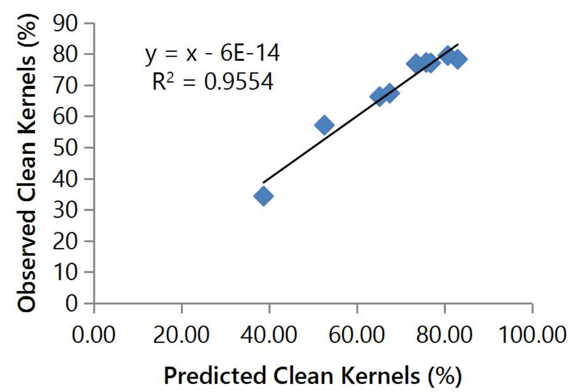

Figure 6: Observed versus predicted values of clean kernels from multi-variable regression model for grade III groundnut in-shell (Samnut 10)

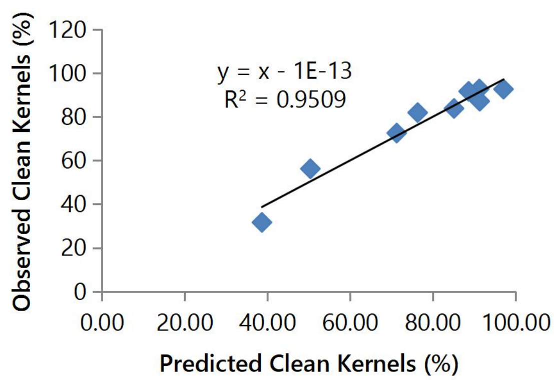

Figure 7: Observed versus predicted values of clean kernels from multi-variable regression model for grade III groundnut in-shell (Samnut 14)