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DEVELOPMENT OF SHELLING EFFICIENCY MODEL OF MELON SEED (*CITRULLULENATUSKUNTZE*) SHELLING MACHINE

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ABSTRACT

This study presents the development of a shelling efficiency prediction equation for a melon seed machine shelling process. Analytical approach of dimensional analysis was used in the prediction model development. The shelling rate model parameters of ; moisture content of melon seed, bulk density, feed rate, speed of shelling drum, shelling drum diameter and drum concave clearance of the machine were combined using pie terms theory to form both product and sum components equation of the prediction equations. The two component equations were subjected to evaluation test of bias and root mean square error to determine the appropriate model prediction equation while t-test was used for the significant level of the models developed. Developed prediction equation was validated using sufficient data from extensive testing operation of the shelling machine. A comparison of predicted and experimental data of the machine shelling efficiency showed a good fit with value of coefficient of determination as 0.86.

Keywords: Shelling efficiency; shelling rate; Component equation; Feed rate passes.

1. INTRODUCTION

1.1 Background of the Study

Melon (citrullulenatuskuntze), locally called "*egusi" in Nigeria,* is an annual herbaceous climber of the family cucurbitaceae. The cucurbitaceae are a large family found mainly in the warmer parts of all continents, and consist of 118 genera with about 825 species many of which are taken in one form or another (Schippers, 2004). The many uses of melon seeds cannot be achieved without processing operations. The operations involved in processing of fully ripe melon fruits into the form that is suitable for use are harvesting, gathering of the harvested fruits, softening of the fruits, extraction of the seeds, washing, drying and shelling. Among the post-harvest operations of melon seed, shelling is the most difficult and time consuming (Isiaka *et al.*, 2006). Melon seed shelling processing constraints such as seeds unshelled and breakage has been identified with many shelling machine processes. For this reason efforts have been made to develop machines which are capable of shelling melon seeds, increase the shelled seed output and also minimize the amount of damaged seeds (Okere, 2007). However, establishment of the fundamental relationship of the shelling parameters to quantify and measurably predict machine shelling process has not been exploited. It is pertinent to state that studies on modeling of shelling machines are not numerous while published studies on models of melon seed shelling machines do rarely exist. The development of seed shelling efficiency model enabled the prediction indices that are related to melon seeds properties such as; seed moisture content and bulk density, functional parameters of the shelling machine such as; feed rate, concave clearance and drum speed. Therefore a mathematical model for building decision support process which would allow users of the machine to predict the shelling process indices such as efficiency, losses and damage and relate such with functional and design parameters of the machine would be a welcomed development.

1.2 Modeling Process

The concept of model development for predicting the shelling efficiency process is based on strategy of modeling process which was formulated to predict accurately the responses of the system for a given wide range of variables in agreement with the machine output while the computed outputs were compared with the system observations.

Enaburekhan (1994) stated that a model usually proves most effective when systematic strategy is used to formulate the model. The strategy used consisted of model formulation, calibration and validation. In order to properly formulate the models, the process of seed shelling is described and the relationships of process variables with the machine parameters are established.

A typical material element for shelling consists of unshelled seed, seed without kernel, chaff, foreign particle (dirt) and inter-particle spaces. The sum of these constituent materials is considered as a shelling material. During shelling action, the shelling material is kept between the shelling drum and the concave. The material are subjected to rubbing and stripping action which is caused by impact generated on the materials from both the vanes of the shelling drum and vanes of the concave surface. These actions compressed, stretched and stripped off the outer cotyledons of the melon seeds as they move through the concave. The actions invariably create a material flow that would set in motion which causes high velocity of the mass of shelled seed, unshelled seed and chaff through a passage where it's collected. Hence successive actions that take place in the process are removal of the melon kernel from the seed cotyledon through impact actions and passage of both the shelled and unshelled seed to a collection point.

2. MATERIALS AND METHODS

2.1 Model Development

2.1.1 Model Assumptions: The assumptions made in an attempt to develop the predicting model in this study were:

i. The seed to be processed is homogenous. That is, the seeds shape, size, moisture content, stress and strength are uniform.
ii. The force acting on the seed has no selective orientation with respective to the impact surface of shelling unit
iii. Seed velocity is constant and is a continuous function of the position over the concave of the shelling unit
iv. The seed moves through the shelling unit as a continuous stratum due to negligible effect of seed collision

2.1.2 Prediction Equation Development: Shelling processes of the developed shelling machine are events which can be considered to be a random process where the occurrence of any one of the events must obey law of probability. Miu and Kutzbash (2008) used a probabilistic law to describe a threshing process as;

$$f(x) = \lambda e^{-\lambda x} \quad \text{……..} \qquad (1)$$

Where: x = is the threshing space length; λ = is the space increment between respective successive event changes (that is shelling rate).

However, the limitation of the equation (1) model is that it is only valid for both axial and tangential feeding systems. Considering a tran-axial feeding system of the developed shelling machine and other variables influencing the functional and design parameters of the machine, the model of equation (1) was further developed to adequately predict the shelling processes.

2.1.3 Seed Shelling Efficiency Model: The relationship between the total number of the shelled seeds (S_s) and the whole quantity of the seed in the shelling process is derived by integrating equation (1) over the shelling rate (λ) (Miu and Kutzbash, 2008). Thus;

$$S_s = \int_0^{x-L} \lambda e^{-\lambda x} = S_s = 1 - e^{-\lambda L} \text{…..} \qquad (2)$$

While the unshelled seed S_u is obtained as;

$$S_u = 1 - S_s \text{ …} \qquad (3)$$

Substituting equation (2) into (3), we get:

$$S_u = 1 - (1 - e^{-\lambda x}) = S_u = e^{-\lambda x}$$

The seed shelling efficiency model was developed from equation (4) using the functional parameters assumed to influence the shelling rate(λ_s) of the machine such as shelling drum speed (S_p); feed rate (f_r); seed content (m_c); concave clearance (C_c); shelling drum diameter (S_d); feeding rate passes (r_f) and bulk density of the seed (ρ_d).

The functional relationship was expressed in term of dependent variable of shelling rate (λ_s) as a function of independent variable of dimensionless groups as:

$$\lambda_s = f(S_p, f_r, m_c, C_c, S_d, r_f \rho_d) \quad \ldots.. \quad (5)$$

Since seed moisture content, (m_c) and the repeated number of feeding rate pass, (r_f) have no dimension hence equation (5) becomes:

$$f(\lambda_s, S_p, C_c, f_r, S_d, \rho_d) = 0 \ldots\ldots \quad (6)$$

Table 1 shows the variables, their dimensions with corresponding dimensional expression, component auxiliary equations and coefficient matrix of determinant of the variables. Buckingham Pie theorem was used to determine the number of pie terms required to form the component prediction equations as:

$$s = n - b \quad \ldots\ldots \quad (7)$$

Where: s = number of Pie term; n = number of variables; and b = number of basic dimensions.

There are six variables and three basic dimensions in table 1, hence; s = 6-3 = 3.

Table 1: Variables with corresponding dimensional expression, component auxiliary equations and dimensional matrix of the six determinant variables

Variable	Symbol	Unit	Dimension (M,L,T)
Shelling rate	λ_s	kg/s	MT^{-1}
Drum speed	S_p	m/s	LT^{-1}
Feed rate	f_r	kg/s	MT^{-1}
Concave clearance	C_c	mm	L
Seed bulk density	ρ_d	kg/m^3	ML^{-3}
Drum diameter	S_d	mm	L

Dimensional expression of the six variables $\left(MT^{-1}\right)^{x_1}\left(LT^{-1}\right)^{x_2}\left(MT^{-1}\right)^{x_3}\left(L\right)^{x_4}\left(ML^{-3}\right)^{x_5}\left(L\right)^{x_6} = 0$

Auxiliary equations with the dimensional matrix of the six variables is in the form:

$$\begin{array}{lcccccc}
 & \lambda & S_p & f_r & C_c & \rho_d & S_d \\
M:\ x_1 + x_4 + x_5 = 0 & 1 & 0 & 0 & 0 & 1 & 0 \\
L\ :x_2 + x_3 - 3x_5 + x_6 = 0 & 0 & 1 & 1 & 1 & -3 & 1 \\
T\ \ :-x_1 - x_2 - x_4 = 0 & -1 & -1 & -1 & 0 & 0 & 0
\end{array}$$

Solving the dimensional matrix of the table 1, the three dimensionless groups obtained are:

$$f\left(\frac{f_r}{\lambda_s}, \frac{S_d}{C_c}, \frac{\rho_d S_p C_C}{\lambda_s}\right) = 0 \quad \text{........} \qquad (8)$$

This is re-written as:

$$\frac{f_r}{\lambda_s} = f\left(\frac{S_d}{C_c}, \frac{\rho_d S_p C_c}{\lambda_s}\right) \quad \text{......} \qquad (9)$$

Therefore the three Pie terms used in the model formulationare; π_1, π_2 and π_3 and related as:

$$\pi_1 = f(\pi_2, \pi_3)\text{.....} \qquad (10)$$

Plots of π_1 against π_2, holding π_3 constant and π_1 against π_3 holding $\pi_2$constant would establish two component equations as;

$$(\pi_1)_{\overline{3}} = f_1(\pi_2,\ \overline{\pi_3})\text{......} \qquad (11)$$

and

$$(\pi_1)_{\overline{2}} = f_1\ (\bar{\pi}_2, \pi_3)\text{......} \qquad (12)$$

Shafii *et al.* (1996) stated that in order to verify that an equation is correct, at least 2m-3 tests need to be conducted, where m is the number of the pi terms. Therefore, to verify that equation 11 is correct, there is need for at least ((2x3) -3) tests to be conducted, such that:

$(\pi_1)_{\overline{3}}$ is held constant at $\overline{\pi_3}$ and π_2 is varied to give a component equation $(\pi_1)_{\overline{3}}$;

$(\pi_1)_{\overline{2}}$ is held constant at $\bar{\pi}_2$ and π_3 is varied to give a component equation $(\pi_1)_{\overline{2}}$; and

$(\pi_1)_{\overline{2}}$ is held constant at $\bar{\pi}_2$ and π_3 is varied to give a component equation $(\pi_1)_{\overline{2}}$.

The component equations may be combined to form the general prediction equation by multiplication as:

$$\pi_1 = c\ (\pi_1)_{\overline{3}}\ (\pi_1)_{\overline{2}} \quad \text{.....} \qquad (13)$$

Where: c is a constant.

To determine the constant C in equation 13, let assume that the component equations are simply multiplied to form the general equation as:

$$\mathrm{F}(\pi_1, \pi_3) = f_1(\pi_2, \bar{\pi}_3) f_2(\bar{\pi}_2, \pi_3) \text{ .....} \quad (14)$$

If this assumption is true, the first set of Pie terms with π_3 constant, gives

$$(\pi_1, \pi_3) = f_1(\pi_2, \bar{\pi}_3) f_2(\bar{\pi}_2, \pi_3) \ldots \quad (15)$$

Which implies that:

$$f_1(\pi_2, \bar{\pi}_3) = \frac{F(\pi_2, \bar{\pi}_3)}{f_2(\bar{\pi}_2, \bar{\pi}_3)} \ldots \quad (16)$$

The second set of Pie terms, with π_2 constant, from equation 14 gives,

$$(\bar{\pi}_2, \bar{\pi}_3) = f_1(\bar{\pi}_2, \bar{\pi}_3) f_2 \, (\bar{\pi}_2, \pi_3) \ldots \quad (17)$$

From which

$$f_2(\pi_2, \bar{\pi}_3) = \frac{F(\bar{\pi}_2, \bar{\pi}_3)}{f_1(\bar{\pi}_2, \bar{\pi}_3)} \ldots \ (18)$$

Putting the values of $f_1(\pi_2, \bar{\pi}_3)$ and $f_2(\bar{\pi}_2, \pi_3)$ from equations 16 and 18 respectively into equation 14 would give;

$$F\,(\pi_2, \pi_3) = \frac{F\,(\pi_2, \bar{\pi}_3) F\,(\bar{\pi}_2, \pi_3)}{f_2(\bar{\pi}_2, \bar{\pi}_3) f_1\,(\bar{\pi}_2, \bar{\pi}_3)} \ldots \quad (19)$$

However, both π_2 and π_3 are constant in the denominator of equation 19 which is found from equation 14.
Thus,

$$F(\bar{\pi}_2, \bar{\pi}_3) = f_1(\bar{\pi}_2, \bar{\pi}_3) f_2 \, (\bar{\pi}_2, \bar{\pi}_3) \ldots \quad (20)$$

Hence,

$$F\,(\pi_2, \pi_3) = \frac{F\,(\pi_2, \bar{\pi}_3) F\,(\bar{\pi}_2, \pi_3)}{F(\bar{\pi}_2, \bar{\pi}_3)} \quad \ldots.. \quad (21)$$

From equation 21, constant, C in equation 13 could be deduced as:

$$C = \frac{1}{(F(\bar{\pi}_2, \bar{\pi}_3)),} \ldots\ldots. \quad (22)$$

Also, equation 21 shows the form of the general equation and indicates that the two component equations must have the same form. The component equations were determined by holding the π_2 constant at a value of $\bar{\pi}_2$, but if valid, it could also have been determined from a set of data in which $\pi_2 = \bar{\pi}_2$. Then,

$$F(\bar{\pi}_2, \pi_3) = \frac{F\,(\pi_2, \pi_3) F\,(\bar{\pi}_2, \pi_3)}{F(\bar{\pi}_2, \pi_3)} \ldots \quad (23)$$

The right –hand side of equation 21 must equal the right-hand side of equation 23. Hence,

$$\frac{F\,(\bar{\pi}_2, \pi_3)}{F(\bar{\pi}_2, \bar{\pi}_3)} = \frac{F\,(\bar{\pi}_2, \pi_3)}{F(\bar{\pi}_2, \pi_3)} \ldots \quad (24)$$

Also, if π_3 had been held constant at different value, $\bar{\pi}_3$

$$\frac{F\,(\pi_2, \bar{\pi}_3)}{F(\bar{\pi}_2, \bar{\pi}_3)} = \frac{F\,(\pi_2, \bar{\pi}_3)}{F(\bar{\pi}_2, \bar{\pi}_3)} \ldots \quad (25)$$

2.14 Evaluation Test of the Shelling Efficiency Model

Bias and root mean square error (RMSE) were used for the evaluation of the model as bias and root mean square error are among the best overall measures of models performance (Willmott, (1982). While the t-test was used to evaluate the significance level of the model to indicate whether the degree of association of the two groups of variables were statistically significant or not at prescribed percentage of probability level.

The bias and root mean square errors for the component equations were determined using equations 26 and 27 respectively:

$$\text{Bias} = \frac{1}{N}\sum_{i=1}^{n}(P_i - M_i)\ldots \qquad (26)$$

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{n}(P_i - M_i)^2}\ldots \qquad (27)$$

Where: P and M = the paired predicted and observed values of the variable investigated respectively; N = the number of observations.

To carry out the t-test evaluation, equation (28) was used:

$$t = \frac{\bar{X} - \mu}{\left(\frac{S_d}{\sqrt{n}}\right)} \quad \ldots \qquad (28)$$

Where: $\bar{X}$ = mean of the sample; μ = the two sample means; S_d = standard deviation; n = number of observations.

2.1.5 Validation of the Model: Model validation involves comparing the observed values with predicted results.Yusuf (2001) reported that the coefficient of determination (r^2) has been used widely as a quantitative index of correlation between predicted and observed values because it generally describes the proportion of the total variance explained by the model. In this study, the validation of the developed model was performed by comparison between the predicted and observed shelling efficiency with goodness of fit and analysis of regression. This was carried out by a plot of observed values against predicted values with fit of a straight line through the data at a zero intercept. The slope and coefficient of the determination (r^2) value are then used as indices of agreement with observed data

3. RESUTS AND DISCUSSION

3.1 Prediction Model

The prediction of shelling efficiency of the shelling process using the developed model entailed dimensionless plots of π_1 against π_2 holding π_3 constant and π_1 against π_3 holding π_2 constant as shown in Figures. 1-3. The component equations relating the different variables during the model development stage using dimensional analysis were generated through the use of values obtained from the dimensionless plots. The high coefficient of correlation (r) ranging from 0.894 to 0.980 is an indication of good relationship between π_1 and π_2, π_1 and π_3 which implies it's adequate to describe the relationships. The generated component equations were combined by summation function to give the prediction equations.

3.2 Summation Function of Component Equation

Glenn (1950) stated that if it is assumed that:

$F(\pi_2, \pi_3) = f(\pi_2) + g(\pi_3)$ … (29)

Then,

$F(\bar{\pi}_2, \pi_3) = f(\bar{\pi}_2) + g(\pi_3)$ … (30)

From which;

$g(\pi_3) = F(\bar{\pi}_2, \pi_3) - f(\bar{\pi}_2)$ … (31)

Similarly,

$f(\pi_2) = F(\pi_2, \bar{\pi}_3) - g(\bar{\pi}_3)$ …... (32)

Equation 29 may therefore be written as:

$$F(\pi_2, \pi_3) = F(\pi_2, \bar{\pi}_3) - g(\bar{\pi}_3) + F(\bar{\pi}_2, \pi_3) - f(\bar{\pi}_2) \ldots \quad (33)$$

$$= F(\pi_2, \bar{\pi}_3) + F(\bar{\pi}_2, \pi_3) - F(\bar{\pi}_2, \bar{\pi}_3) \quad ..(34)$$

Equation 34 shows that if the component equations are to be combined by addition to form the general prediction equation, a constant must be subtracted from the sum of the component equations.

According to Glenn (1950), the constant of the summation can be evaluated from any of the component equations. Hence, by applying component equations with the equations data from Figures 1-3;

$(\pi_1)_{\bar{2}} = a + b\,\pi_3 = 54.39 + 4.36 \times 10^{-3}\pi_3$,

$(\pi_1)_{\bar{3}} = e + d\pi_2 = 9.62 + 1.47 \times 10^{6}\pi_2$ and

$(\pi_1)_{\bar{2}} = e + b\,\pi_3 = 43.68 + 8.04 \times 10^{-3}\pi_3$

Where: $\bar{\pi}_2 = 5.10 \times 10^{-6}$ and $\bar{\pi}_3 = 6.43 \times 10^{3}$.

Therefore, the component equation by sum is obtained from substituting values into equation 35;

$\pi_1 = 9.62 + 1.47 \times 10^{6}\,\pi_2 + 54.39 + 4.36 \times 10^{-3}$

$\pi_3 - (54.39 + 4.36 \times 10^{-3} \times 6.43 \times 10^{3})$

$\pi_1 = 1.47 \times 10^{6}\,\pi_2 + 4.36 \times 10^{-3}\,\pi_3 - 18.415$ … (35)

Table 2 presented results of the bias and the root mean square error for the sum equation between the predicted model and observed values of the shelling operation of the machine. Using these values, the calculated t-test was determined as:

$$t_{cal} = \frac{(2.168 - 0)}{15.83859/\sqrt{27}} = 0.7113$$

Since the value of calculated t_{cal} is less than the tabular t value (t_{tab} at 0.01 is 2.771), it implies that the predicted and measured data are not significantly different at 5 % probability level.

Hence sum component equation is adequate for the prediction equation.

3.2 Shelling Efficiency Predictions Equation

The general prediction equation developed for shelling efficiency is:

$\pi_1 = 1.47 \times 10^6 \pi_2 + 4.36 \times 10^{-3} \pi_3 - 18.415$

Substituting the dimensionless parameters into prediction equation gives equation 36. Putting λ in the equation 4, the resulting model is given as;

$$\lambda = -18.415 \times 10^{-4} f_r C_c + 147 S_d f_r + 0.0436 \rho_b S_p C_c^3 \quad \ldots (36)$$

$$S_u = e^{-(-18.415 \times 10^{-4} f_r C_c + 147 S_d f_r + 0.0436 \rho_b S_P)^x} \quad \ldots (37)$$

Hence the shelling efficiency; S_E would be predicted as:

$$S_E = (1 - S_u) \times 100\ \% \quad \ldots (38)$$

3.3 Validation

The bias and root mean square error between the predicted and observed seed shelling efficiency of the machine testing operation showed bias of 0.566 and root mean square error of 1.60,Table 3. This value of root mean square error between the predicted and measured values indicates a better model because it shows that there exist but a little deviation between the predicted and measured values. Figure 4 shows the comparison between the predicted and observed measured data with the regression equation of:

$$Y = 0.795X + 18.85 \quad \ldots (39)$$

A good linear relationship with line of best fit was achieved and a correlation coefficient (r^2) of 0.867 was obtained.

4. CONCLUSION

A prediction model for melon seed shelling efficiency was developed using analytical approach of dimensional analysis. A t-test evaluation procedure of bia and root mean square indicates that sum equation of the component equations is adequate for the model. The model was validated by comparing the measured data from the melon shelling machine and the observed data of the developed model of high correlation coefficient (r^2) of 0.867.

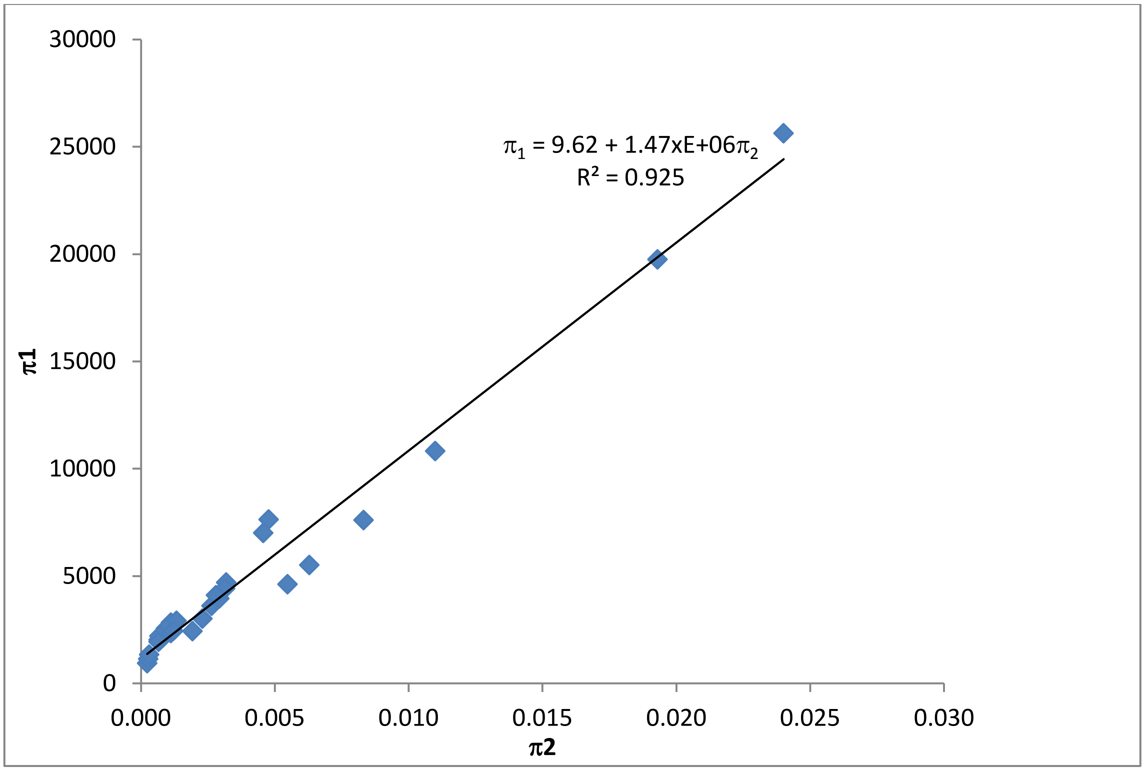

Fig. 1: Plot of π_1 against π_2 at π_3 = constant

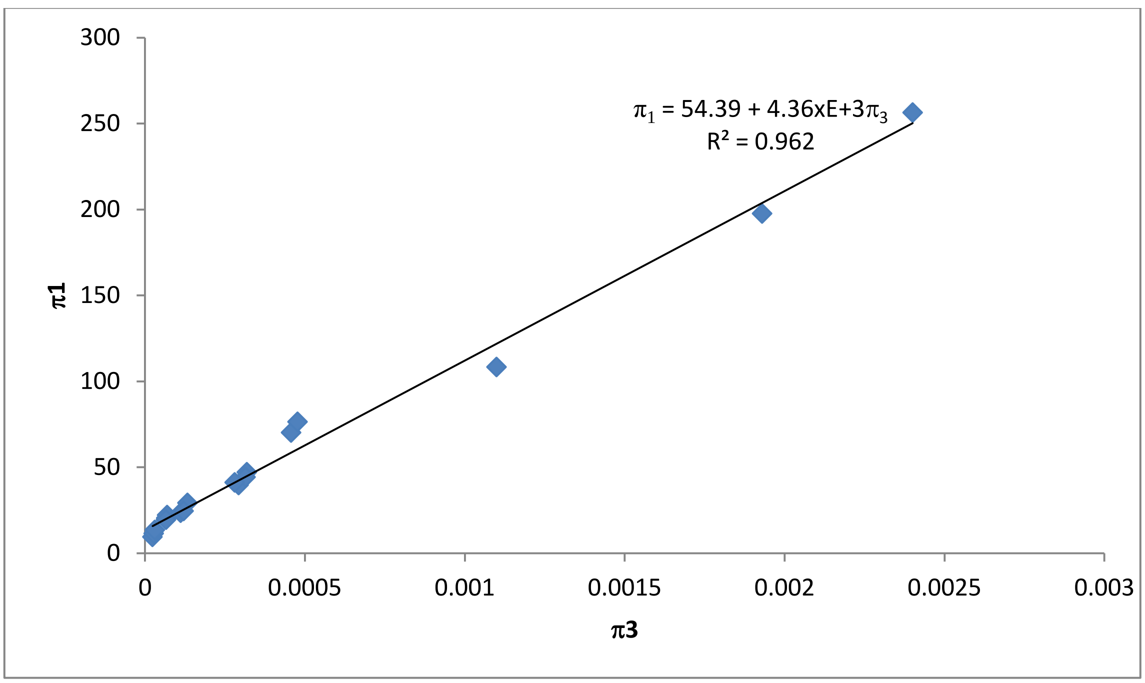

Fig. 2: Plot of π_1 against π_3 at π_2 = constant

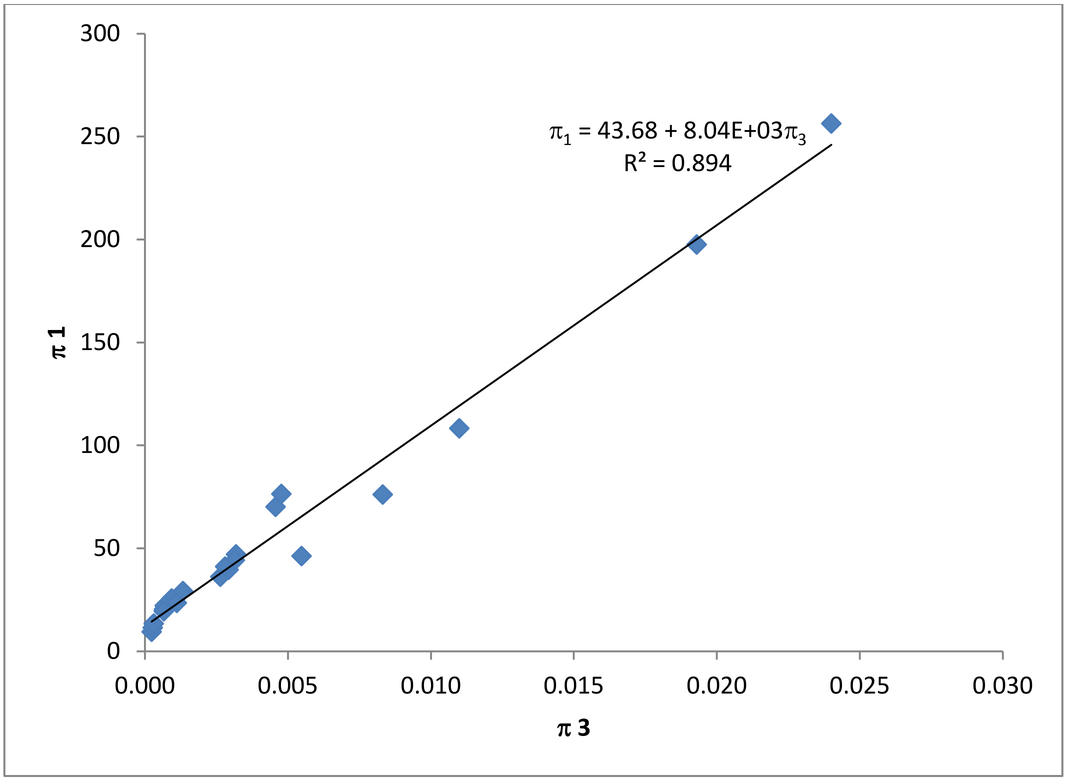

Figure 3: Plot of π_1 against π_3 at π_2 = constant (the second time)

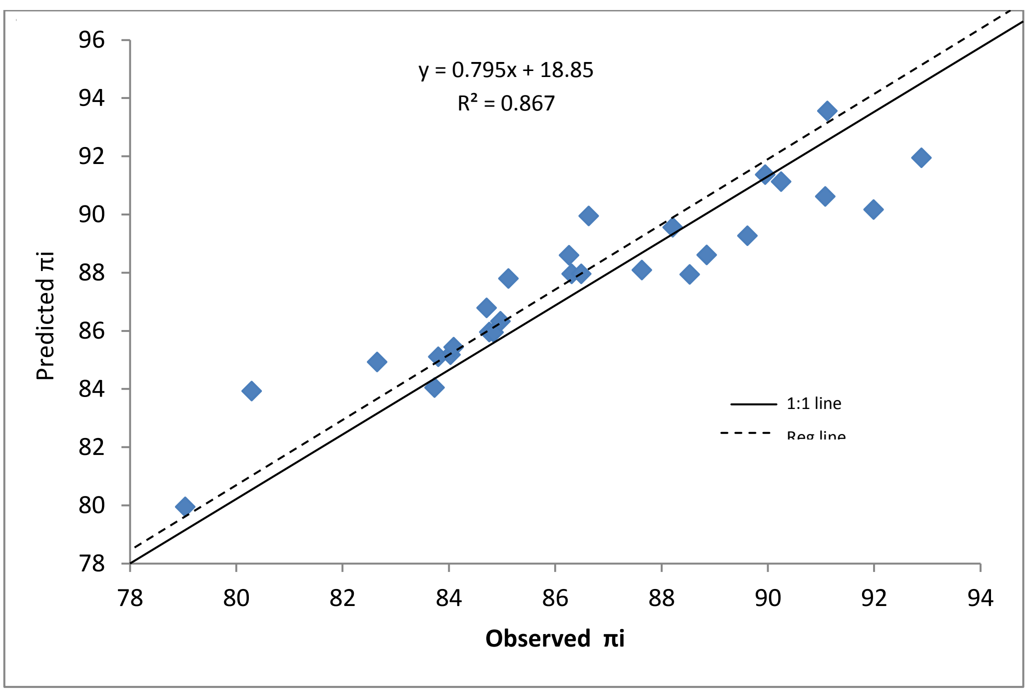

Figure 4: Plot of predicted π_1 against observed π_1 of shelling efficiency

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Table 2: Bias and root mean square error of sum equation for machine testing operation

Pie terms					
		π_1			
π_2	π_3	Predicted (Pi)	Observed (Oi)	$(P_i\text{-}O_i)$	$(P_i\text{-}O_i)^2$
3021846	0.0023	68.45141438	72.1	- 3.648585624	13.31217706
2133306	0.0081	67.14528561	45.8	21.34528561	455.6212177
5519063	0.0062	72.122339	82.97	-10.847661	117.6717491
2437688	0.0019	67.59269918	55.26	12.33269918	152.0954692
2832953	0.0011	68.17373574	28.69	39.48373574	1558.965388
3617963	0.0026	69.32770741	67.53	1.797707408	3.231751925
2561194	0.0009	67.77424915	47.1	20.67424915	427.4245778
4622551	0.0054	70.80446315	75.9	-5.095536848	25.96449577
7610871	0.0083	75.19730585	84.36	-9.162694147	83.95496403
7013908	0.0046	74.3197547	85.48	-11.1602453	124.5510752
19756072	0.0019	93.05072373	91.22	1.830723729	3.351549371
4704448	0.0031	70.92484278	73.83	-2.905157221	8.439938482
7639139	0.0048	75.23884486	81.11	-5.871155139	34.47046267
10826994	0.0011	79.92497626	87.55	-7.625023739	58.14098703
2036714	0.0067	67.00328882	83.74	-16.73671118	280.117501
2211849	0.0069	67.2607384	55.42	11.8407384	140.2030858
1943062	0.0065	66.86561992	37.34	29.52561992	871.7622317
25632130	0.0024	101.6885323	97.59	4.098532268	16.79796675
2348970	0.0011	67.4622806	83.54	-16.0777194	258.4930612
3959115	0.0029	69.8292024	84.57	-14.7407976	217.2911139
943719.8	0.0023	65.39656809	74.95	-9.553431906	91.26806117
2920483	0.0013	68.30240598	89.16	-20.85759402	435.0392282
4421544	0.0031	70.50897337	87.01	-16.50102663	272.2838797
1143218	0.0027	65.68983271	76.92	-11.23016729	126.1166573
1344749	0.003	65.98608339	63.79	2.196083392	4.822782266
4112150	0.0028	70.05416202	90.14	-20.08583798	403.4408873
2449457	0.0012	67.6099968	89.16	-21.5500032	464.4026379
				-58.52397342	6649.234897

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Table 3: Bias and root mean square error of sum equation for machine performance evaluation

f	*Cc*	*fCc*	*Sd*	*Pd*	*Sp*	Cc^3	$PdSpCc^3$	Predicted	Observed	Pi-Si	$(Pi\text{-}Si)^2$
2	8	16	140	337.5	1250	512	216000000	90.17	91.99	-1.82	3.3124
1	10	10	140	337.5	910	1000	307125000	87.96	86.31	1.65	2.7225
3	12	36	140	337.5	780	1728	454896000	85.18	84.03	1.15	1.3225
2	8	16	140	324.7	1250	512	207808000	89.27	89.616	-0.346	0.119716
1	10	10	140	324.7	910	1000	295477000	86.79	84.71	2.08	4.3264
2	12	24	140	352	780	1728	474439680	85.96	84.76	1.2	1.44
1	8	8	140	352	1250	512	225280000	90.62	91.08	-0.46	0.2116
3	10	30	140	324.7	910	1000	295477000	88.61	88.85	-0.24	0.0576
3	12	36	140	352	780	1728	474439680	84.05	83.73	0.32	0.1024
2	8	16	140	337.5	1250	512	216000000	91.13	90.25	0.88	0.7744
3	10	30	140	337.5	910	1000	307125000	87.96	86.49	1.47	2.1609
2	12	24	140	324.7	780	1728	437643648	85.95	84.84	1.11	1.2321
2	8	16	140	352	1250	512	225280000	93.56	91.12	2.44	5.9536
3	10	30	140	324.7	910	1000	295477000	88.09	87.63	0.46	0.2116
1	12	12	140	337.5	780	1728	454896000	79.95	79.04	0.909	0.8281
1	8	8	140	352	1250	512	225280000	89.56	88.21	1.35	1.8225
1	10	10	140	324.7	910	1000	295477000	87.8	85.12	2.68	7.1824
3	12	36	140	352	780	1728	474439680	85.44	84.09	1.35	1.8225
2	8	16	140	337.5	1250	512	216000000	91.95	92.89	-0.94	0.8836
3	10	30	140	324.7	910	1000	295477000	88.6	86.26	2.34	5.4756
1	12	12	140	324.7	780	1728	437643648	84.93	82.65	2.28	5.1984
2	8	16	140	352	1250	512	225280000	89.95	86.63	3.32	11.0224
3	10	30	140	337.5	910	1000	307125000	87.94	88.53	-0.59	0.3481
1	12	12	140	337.5	780	1728	454896000	83.93	80.29	3.64	13.2496
1	8	8	140	352	1250	512	225280000	91.37	89.95	1.42	2.0164
3	10	30	140	352	910	1000	320320000	86.33	84.97	1.36	1.8496
2	12	24	140	324.7	780	1728	437643648	85.11	83.8	1.31	1.7161
										15.293	**77.36302**

REFERENCES

Enaburekhan, J.S. (1994). Mathematical and optimization modeling of the threshing process in a stationary grain thresher. Unpublished PhD Thesis submitted to the department of agricultural Engineering, Ahmadu Bello University, Zaria.

Glenn. M. (1950).*Simulitude in engineering*. The Ronal Press Company, New York, p25-47

Isiaka M., A.M.I El- Okene and T.A. Oyedele, (2006).Determination of physical properties of melon seed.*Proceeding of the Nigerian Institution of Agricultural* Engineer, 28: 322 – 326

Miu P.I and Kutzbach, H.D. (2008) Modeling and simulation of grains threshing and separation in threshing units.Part 1.*Computer and Electronic in Agriculture* 60: 96 – 104

Okere, O.M. (2007). Performance Evaluation of a Melon Sheller.An unpublished Bachelor of Engineering Degree project, Department of Agricultural Engineering, Ahmadu Bello University, Zaria- Nigeria.

Schippers R.R. (2004). African indigenous vegetables.An overview of the cultivated species.Nation Resources Institute, University of Greenwich. Pp55 – 63

Shafii, S., Upadhayaya, S. K. and Garrett R. E. (1996). The importance of experimental design to the development of Empirical prediction equation: a case study. *Transactions of the America Society of Agricultural Engineers* 39(2): 377-384.

Willmott, C.J. (1982). Some comments on the evaluation of model performance. American Meteorological Society Bullentin, 63(11):1309-1313.

Yusuf, D.D. (2001). Mathematical modeling of tillage machine-soil interaction effect on maize grain yeild. PhD Thesis submitted to the department of agricultural Engineering, Ahmadu Bello University, Zaria.