World Journal of Agricultural Research, 2020, Vol. 8, No. 3, 97-104
Available online at http://pubs.sciepub.com/wjar/8/3/5
Published by Science and Education Publishing
DOI:10.12691/wjar-8-3-5

Machine Crop Parameters' Model of Spike - Tooth Thresher for Soybean

Ilori T.A.[1], Dauda T.O.[2,*], Adewumi I.O[1]

[1]Department of Agricultural Engineering, Federal College of Agriculture, P.M.B 5029 Moor Plantation, Ibadan, Oyo State, Nigeria
[2]Institute of Agricultural Research and Training, Obafemi Awolowo University, Moor Plantation, Ibadan, Nigeria
*Corresponding author: todauda.iart@gmail.com

Received June 12, 2020; Revised July 13, 2020; Accepted July 22, 2020

Abstract The goal of regular modification of threshing machine is to increase soybean processing efficiency. This study was carried out to deconstruct the thresher's parameter - output relationship and to evolve a model for such relationship at the Engineering workshop of the Federal College of Agriculture, Ibadan, Oyo State Nigeria. Unthreshed soybeans, CGX14x1448 were used to evaluate the performance of a modified spike tooth thresher fabricated at the Workshop. The summary statistics of the machine output showed that concave clearance had percentage unthreshed soybean of 16.98%, percentage mechanically damaged seed of 8.625%, blown seed of 23.403kg and high seed loss of 44.241kg. Both the mean cleaning efficiency (94.175) and threshing efficiency (83.022) were very high. The trend of the cylinder speed however contrasts with those of concave clearance and moisture content. The percentage unthreshed (83.212%), percentage mechanical damage (16.792%) were in contrast to each other. Similarly, the threshing (44.108) and cleaning (23.321) efficiency were low. The relationships between cylinder speed and machine output showed an increasing trends for blown seed, percentage damaged seed and seed loss. Concave clearance - threshing efficiency can be predicted using 3 most parsimonious models (*xy*-inverse, exponential and simple linear model). High adjusted coefficients of determinations (R^2) were obtained for the best model of cylinder speed - threshing efficiency model. These were 0.9997 for the *xy* inverse and 0.9998 for quadratic 0.993 for exponential model with estimation variance of 0.00047 (quadratic), 0.000 for inverse xy and 0.000191 (exponential model). The practical application of the models is in the specificity of the measurement of the relationship between thresher's parameters and output.

Keywords: *chaff, linearity, orthogonality, specificity, cylinder, efficiency*

Cite This Article: Ilori T.A., Dauda T.O., and Adewumi I.O, "Machine Crop Parameters' Model of Spike - Tooth Thresher for Soybean." *World Journal of Agricultural Research*, vol. 8, no. 3 (2020): 97-104. doi: 10.12691/wjar-8-3-5.

1. Introduction

Harvesting is the most expensive operation in soybean production. Soybean [1] is usually harvested by cutting the top part from the land or by uprooting the whole plant. Threshing has simply been described as the separation technique by which the seed or grain is gotten out of the hull or chaff of the whole pot [2] and form part of the harvesting process of soybean. It may be in form of traditional pounding by stick or legs or by machine invention method. Some tools often made by local artisans are sometimes used for hand shelling and with these tools a worker can shell 8 - 15kg of maize per hour [1]. Mechanical thresher will usually consists of a threshing beating drum and a concave with stationary fingers. In addition, these machines often have devices to shake out the stain to clean and bag the gain. At harvest, the beans usually contain about 14% moisture content and are dried to about 12% moisture content for short storage of 6 - 12 months and 10-11% for longer storage. Drying at 66°C reduces oil content and 76°C causes discoloration [3]. Drying at relative humility of 40% or higher is recommended to prevent the seed coat from cracking and it is the most practical way to protect beans in storage [4]. Striking a balance between moisture content for post-harvest processing and storage condition constitute one of the challenge for post - harvest engineers.

This study focused on deconstructing the machine-crop parameters output of an existing soybean thresher for optimum soybean threshing performance as well as developing thresher-soybean parameters output models. Previous studies have paid attention to study of the influence of crop, machine and operating parameters on performance of cereal threshers [5], evaluation of local machine for threshing beans [6], maize shelling using hand powered sheller [7] and adaptation of portable thresher for sorghum, soybean and peanut handling [2]. The goal of regular modification in threshing machine is to turn up a machine with optimum soybean processing output. This would enhance efficiency in threshing machine design. This study thus seeks to answer the research question "what is the relationship(s) between threshing machine component and its output and can a model be developed for such relationship?" The objectives of the study were therefore to anatomize the threshing machine parameter - output relationship and to evolve a model for the relationship.

2. Methodology

This study was carried out at the Engineering workshop of the Federal College of Agriculture, Moor Plantation Ibadan, Nigeria. The unthreshed soybean (CGX14x1448) sourced from the Crop Production Department of Federal University of Agriculture, Abeokuta while the thresher was originally fabricated at the Engineering Workshop. The materials used for the construction (metal sheet, iron rods, electrode, adoption of bearing and belt) were all sourced locally from various nearby markets. Samples from 100kg bulked unthreshed soybean were randomly selected for initial moisture content determination for preliminary study. The moisture content of the product was determine by oven dry method using American Society of Agriculture Engineering [8] standard as adopted for oil seed [9] in sponge gourd seed study. The mass of the sample was measured using electric weighing balance having sensitivity of 0.01g. Three sample weighing approximately 500g(wi) were oven dried at 103°C and weighed until the weight remain constant. The moisture content were obtained on wet basis for percent shells, percent kernel, chaff and seed respectively using equations 1,2,3 and 4.

(i) Percent shells

$$S = \frac{100 \times initial\ \ mass\ \ of\ \ chaff}{Initial\ \ mass\ \ of\ \ unthreshed} \tag{1}$$

(ii). Percent kernel (k)

$$K = \frac{100 \times initial\ \ mass\ \ of\ \ seed}{Initial\ \ mass\ \ of\ \ unthreshed} \tag{2}$$

(iii). Moisture content of chaff, percent wet basis (C)

$$C = \frac{100 \times loss\ \ in\ \ mass\ \ of\ \ chaff}{Initial\ \ mass\ \ of\ \ chaff} \tag{3}$$

(iv). Moisture content of seed, percent wet basis (D)

$$D = \frac{100 \times loss\ \ in\ \ mass\ \ of\ \ Seeds}{Initial\ \ mass\ \ of\ \ seeds}. \tag{4}$$

Sample for the experiments were selected randomly from the back lots and conditioned using Visvanethan (1993) methods of conditioning to higher moisture

$$Q = \frac{A_i\ (b-a)}{100-b} \tag{5}$$

and lower moisture

$$Bf = \frac{A_i\ (100-a)}{100-b}. \tag{6}$$

Q = Mass of water to be added (kg), A_i = Initial mass of the sample (kg), a = initial moisture content of sample % (w.b), b = Final (desired) moisture content % (w.b) and Bf = Final of the sample after drying. Samples were carefully packed and labeled separately in double layers low-density polythene bag and stored in refrigerator for about a week for proper moisture distribution. The samples were kept in the refrigerator to cool the heating effect of respiratory seed in an enclosed or sealed polythene bag and were only exposed when they were to be used. The seed materials were divided into four randomly selected lots for the experiment and the size of the seed was determined using micrometer screw gauge. The coefficient of friction for four different structured materials at different moisture content was determined using incline plane method (of structural materials like plywood, galvanized steel sheet, mild steel and glass). The speed levels were varied using speed varying device on the petrol engine for powering the machine while tachometer was used to determine the level. The thresher adjustment (treatments) were 4 levels of cylinder speed (200rpm, 400rpm, 600rpm, and 800rpm), 4 concave clearance (45, 55, 65, and 75mm) and 4 levels of moisture content (5.5, 10.5, 15.5 and 20.5%). The data obtained were boostrap to obtained n = 7.

The evaluation was carried out using the following formulae [10], [11] and [12];

Percentage of unthreshed seed

$$U_t = {U_t}/{Q_t}. \tag{7}$$

Threshing efficiency,

$$TE(\%) = 100 - U_t. \tag{8}$$

Cleaning efficiency

$$CE(\%) = \frac{C}{W_t} \times 100 \tag{9}$$

Mechanical Damage

$$DS(\%) = \frac{Q_b}{Q_T} \times 100 \tag{10}$$

Percentage Blown Seed

$$BS = \frac{W_b}{Q_t} \times 100 \tag{11}$$

and Percentage Seed Loss

$$SL(\%) = \frac{Q_{loss}}{Q_t} \times 100 \tag{12}$$

Where U = Weight of unthreshed seed at all outlet per unit time (kg), Q_T = Total seed input (kg)
C = Weight of whole of seed at all outlet per unit time (kg), W_t = Weight of damage seed outlet per unit time (kg), Q_b = Weight of damaged seed collected at all outlet per unit time (kg), W_b = Weight of whole seed collected at chaff outlet per unit time (kg), Q_{loss} = Weight of all seeds (Whole, damaged, unthreshed) at chaff and other outlets other than grain outlet (kg) and Q_t = Weight of whole seed collected at seed out let per unit time (kg).

The data obtained were subjected to summary statistics analysis (mean, variance and skewness), visual analysis and bivariate correlation analysis. Regression analysis of the relationships between each of concave clearance, cylinder speed and moisture content. These represents the dependent variable, Y while the threshing efficiency, cleaning efficiency, Mechanical seed damage, percentage blown seed and percentage seed loss represents the independent variables, X_i in each case. Each of the dependent Y was regressed against X_i

$$Y = f(X_i) \tag{13}$$

i = 1, 2, 3, 4 and 5.

This function was evaluated for simple linear, quadratic, power, exponential, *x*-inverse, *xy*-inverse models. The most parsimonious of the models was determined using, model statistics such as coefficient of determination (R^2), regression analysis of variance, variance of the estimation and Durbin-Watson Statistics. Durbin Watson statistics which test for autocorrelation in the residuals from a statistical regression is defined by the relationship;

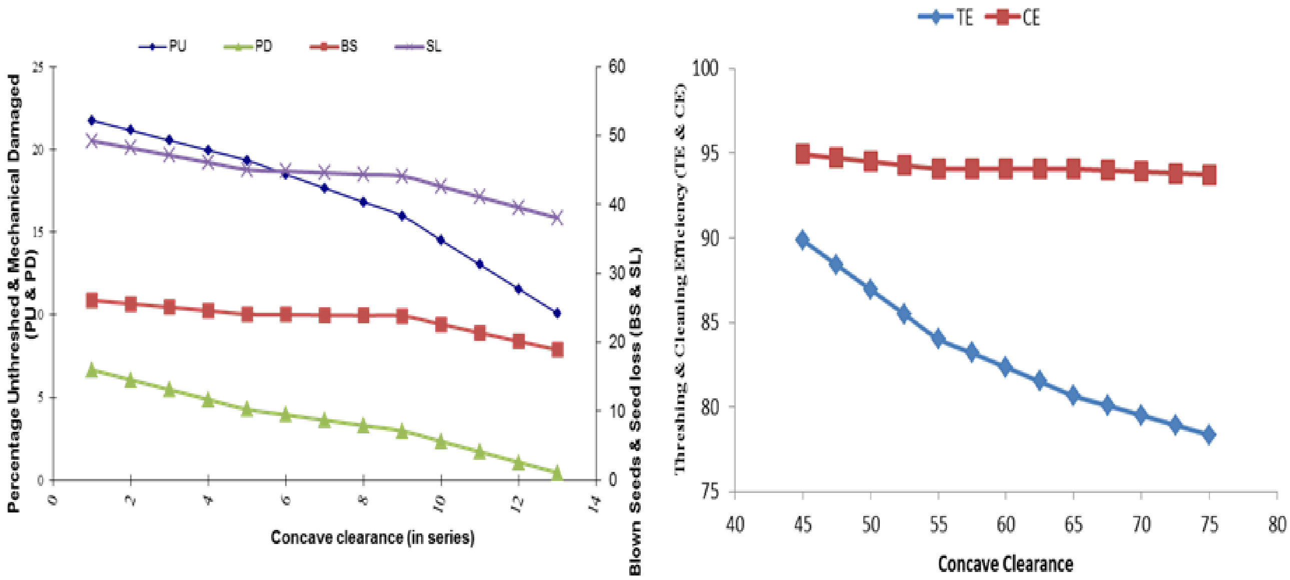
$$DW = \frac{\sum_{t=2}^{T}(\ell_t - \ell_{t-1})^2}{\sum_{t=1}^{T}\ell_t^2} \tag{14}$$

Where e_i is the residual at the specified time.

3. Results

Summary Statistics and Correlation analysis of the Soybean Machine output variables.

The summary statistics of the machine output showed that concave clearance had percentage unthreshed soybean of 16.98%, percentage mechanically damaged soybean of 8.625%, blown seed of 23.403kg and high seed loss of 44.241kg. Both the mean cleaning efficiency (94.175) and threshing efficiency (83.022) were very high (Table 1). The visual analysis (Figure 1) of the concave clearance and some thresher's output variable returned declining trend with increasing concave clearance. There were however disparity in the rate of decrease of these trends. Also, orthogonality of the percentage unthreshed with other output variables (Percentage mechanical damaged, blown seeds and seed loss) was noticed (Figure 1A). Similar results were obtained for concave clearance and threshing as well as cleaning efficiency with the rate of decreasing was more sudden in threshing efficiency than cleaning efficiency (Figure 1B).



Pu = Percentage un-threshed; PD = Percentage Damaged; BS =blown seeds; SL =seed loss ; TE = Threshing Efficiency and CE = Cleaning efficiency.

Figure 1. Relationships between Concave Clearance and Threshing machine Performance

The trend of the cylinder speed however contrasts with those of concave clearance and moisture content. The percentage unthreshed (83.212%), percentage mechanical damage (16.792%) were in contrast to each other.

Table 1. Summary Statistics of the Machine - Soybean Parameters

	Concave (mm)		Moisture Content (%db)		Speed(rpm)	
	Mean ± SE	Variance	Mean ± SE	Variance	Mean ± SE	Variance
PU	16.98 ± 1.044	14.172	16.777 ± 0.163	0.344	83.212 ± 0.482	3.0173
PD	8.625 ± 1.262	20.709	8.537 ± 0.140	0.254	16.792 ± 0.459	2.736
BS	23.403 ± 0.586	4.462	23.248 ± 0.149	0.287	94.239 ± 0.613	4.891
SL	44.241± 0.902	10.567	44.101 ± 0.088	0.101	8.636 ± 0.296	1.141
CE	94.175 ± 0.0967	0.122	94.232 ± 0.204	0.538	23.321 ± 0.523	3.552
TE	83.022 ± 1.032	13.847	83.252 ± 0.16	0.362	44.108 ± 0.235	0.716

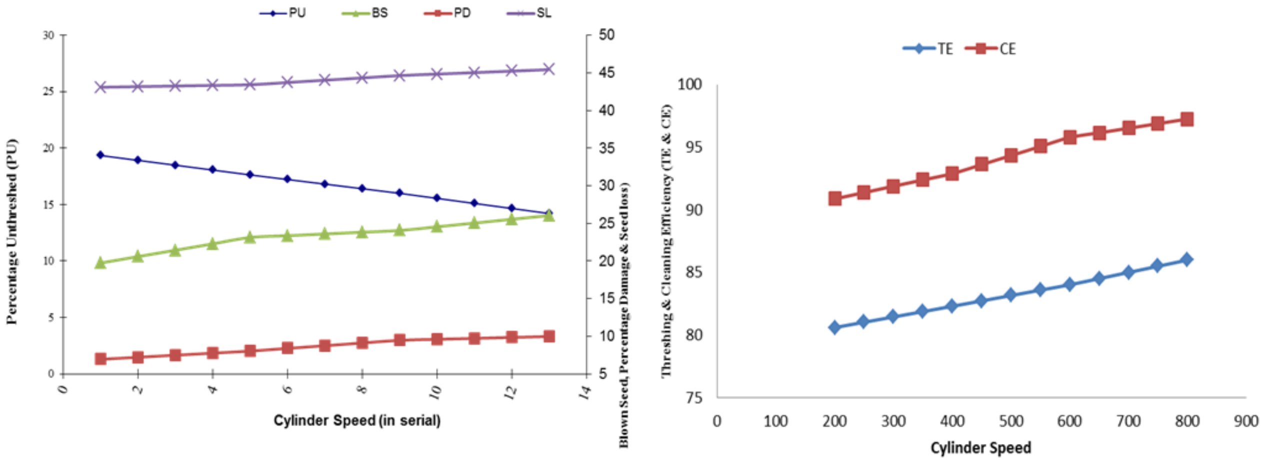
Pu = Percentage un-threshed; PD = Percentage Damaged; BS =blown seeds; SL =seed loss; TE = Threshing Efficiency and CE = Cleaning efficiency.

Similarly, the threshing (44.108) and cleaning (23.321) efficiency were low (Table 1).

Similarly, the relationships between cylinder speed and machine output showed an increasing trends for blown seed, percentage damaged seed and seed loss (Figure 2A). The trend of percentage unthreshed seed however returned a declining trend with an increasing cylinder speed (Figure 2A). Similar increasing trend were obtained for both cleaning and threshing efficiency (Figure 2B). It is thus noteworthy that percentage unthreshed is orthogonal to other machine output parameters. The implication of these results are that some of the machine output variables (like percentage unthreshed against cleaning and threshing efficiency) were inversely related and that some of the variables depends on the others. The mean percentage unthreshed of the moisture content was 16.777kg and both the mean percentage damage (8.537%) and blown seeds (23.248) were relatively low. Mean seed loss (44.101), cleaning (94.232) and threshing (83.847) efficiency were very high like in the concave clearance (Table 1). The visual analysis of the trend of machine output relative to moisture content indicated a decreasing trend for blown seed and increasing trends for both percentage unthreshed and percentage mechanical damaged seed (Figure 3A). Also, the cleaning and threshing efficiency declined with increasing moisture content (Figure 3B). The seed loss however remained almost constant with the increasing moisture content.

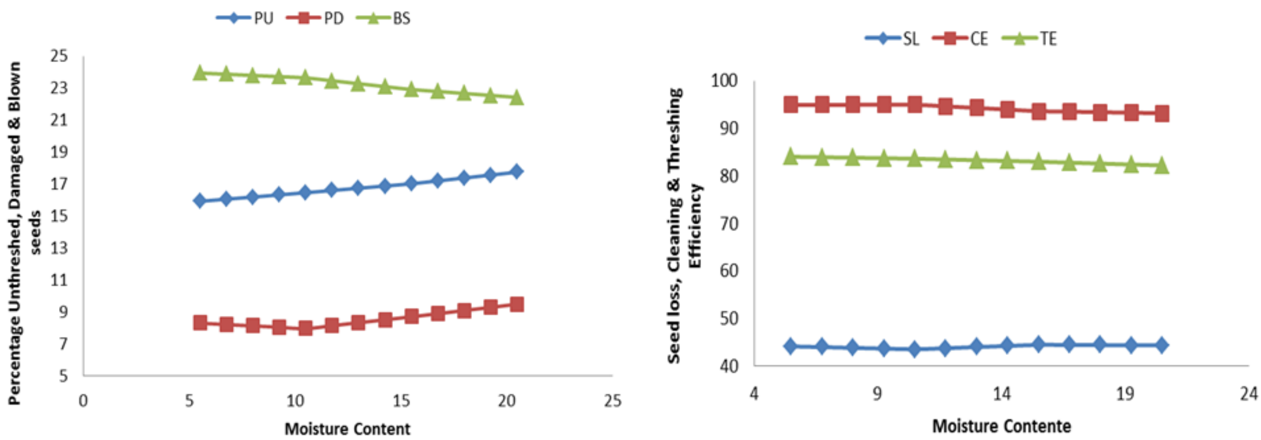
Concave Clearance - Thresher Output Models.

The concave clearance - soybean output variable model analysis indicated that each of the variables can be predicted using different model forms. Concave clearance - threshing efficiency can be predicted using 3 most parsimonious models (xy-inverse, exponential and simple linear model - Table 2). Using the model statistics and diagnostics (F statistics, adjusted coefficient of determination-R^2, estimation variance and Durbin-Watson statistics), the inverse model, $Y = \frac{x}{(-0.186 + 0.0152x)}$ gives the best estimates of the threshing efficiency of the soybean machine. For the concave clearance - percentage unthreshed model, 3 most parsimonious models include; the quadratic, the logarithmic and the xy-inverse model (Table 2). The quadratic model ($Y = 10.573 + 0.618x - 0.008x^2$) had the highest adjusted coefficient of determination, R^2 (0.998), minimum estimation variance (0.028) and highest Durbin-Watson Statistics (0.974). This was followed by the xy-inverse with the adjusted coefficient of determination, R^2 (0.902), estimation variance of zero and the Durbin-Watson statistics 0.486 (Table 2).



Pu = Percentage un-threshed; PD = Percentage Damaged; BS =blown seeds ; SL =seed loss ; TE = Threshing Efficiency and CE = Cleaning efficiency.

Figure 2. Relationships between Cylinder Speed & Threshing Machine Performance



Pu = Percentage un-threshed; PD = Percentage Damaged; BS =blown seeds ; SL =seed loss ; TE = Threshing Efficiency and CE = Cleaning efficiency.

Figure 3. Relationships between Moisture content and Threshing Machine Performance

Table 2. Summary of Speed - Soybean variables Relationships and their Statistics

Dependent variables	Models	F-statistics	Adjusted R^2	Variance (estimates)	D-wattson Statistics
Threshing Efficiency	$Y = \frac{1}{x(0.0127 + 0.000001x)}$	0.9997	41985.293**	0.000	0.4287
	$Y = 78.8567\ell^{0.0001x}$	0.9993	18966.340**	0.00191	0.3391
	$Y = 79.1019 + 0.00730x + 0.000002x^2$	0.9998	38499.578**	0.00047	0.7099
Percentage Unthreshed	$Y = 21.038 - 0.0085x$	0.9998	50324.476**	0.000652	0.471
	$Y = 20.948 - 0.0081x - 0.00000042x^2$	0.9998	33012.129	0.000497	0.570
	$Y = 21.560\ell^{-0.0005x}$	0.9969	4115.567**	0.0081	0.2911
Cleaning Efficiency	$Y = 88.587 + 0.0113x$	0.9897	1157.918**	0.0502	0.4885
	$Y = 87.878 + 0.0146x - 0.000003x^2$	0.9915	699.861**	0.0416	0.5671
	$Y = 88.724\ell^{0.0001x}$	0.989	1042.599**	0.056	0.467
Pod Damage	$Y = 1.4748x^{0.287}$	0.982	651.175**	0.00029	0.570
	$Y = 5.923 + 0.0054x$	0.9769	507.755**	0.0264	0.4033
	$Y = 5.162 + 0.00896x - .000004x^2$	0.9883	506.300**	0.0134	0.5853
Blown Seed	$Y = 18.919\ell^{0.0004x}$	0.9356	196.555**	0.214	0.388
	$Y = 7.348x^{0.1878}$	0.983	698.390**	0.00012	0.6356
	$Y = -2.913 + 4.277\ln x$	0.9828	686.610**	0.0611	0.6693
Seed Loss	$Y = \frac{x}{3.1626 + 0.0356x}$	0.9722	420.244**	0.000	0.6649
	$Y = 1/(0.0238 - 0.000002x)$	0.9719	416.098**	0.000	0.4646
	$Y = 42.0119\ell^{0.0001x}$	0.971	415.832**	0.02005	0.4523

The quadratic model is thus the preferred model for estimating concave clearance - percentage unthreshed relationship. Concave clearance - cleaning efficiency relationship can be estimated using x-inverse, quadratic and linear model (Table 2). Their respective adjusted coefficients of determination, R^2 were 0.901, 0.911 and 0.989 for inverse, quadratic and simple linear model. Also, both the estimation variance and Durbin-Watson statistics were 0.012 (x-inverse), 0.011 (quadratic), 0.222 (simple linear) and 0.482 (x-inverse), 0.584(quadratic) and 0.554 (simple linear model - Table 3). The quadratic model is thus the preferred model for estimating concave clearance - percentage unthreshed relationship. Concave clearance - cleaning efficiency relationship can be estimated using x-inverse, quadratic and linear model (Table 2). Their respective adjusted coefficients of determination, R^2 were 0.901, 0.911 and 0.989 for inverse, quadratic and simple linear model. Also, both the estimation variance and Durbin-Watson statistics were 0.012 (x-inverse), 0.011 (quadratic), 0.222 (simple linear) and 0.482 (x-inverse), 0.584(quadratic) and 0.554 (simple linear model - Table 3). Based on these statistics, the simple linear model is thus the most parsimonious of the 3 models considered. Quadratic model and simple linear models are the most favourable among the investigated models for the concave clearance-percentage mechanical damaged relationships. The quadratic model however gave the highest coefficient of determination (R^2) of 0.988, higher F-Statistics (514.862) and minimum estimation variance 0.239 thus it is the best model for the relationships (Concave clearance -percentage mechanical damage - Table 2).

Simple linear, quadratic and exponential model were the 3 most suitable models for concave clearance-blown seed relationship. The adjusted coefficient of determination (R^2) and F-statistics were 0.925 and 75.237 (quadratic), 0.938 and 181.915 (simple linear) as well as 0.836 and 65.521 (exponential model). Although the quadratic model returned minimum estimation variance and highest Durbin-Watson statistics, the simple linear model remained the most parsimonious based on the earlier mentioned statistics. The concave clearance-seed loss relationships can best be predicted by quadratic model (Table 2). This is based on the highest adjusted coefficient of determination (0.947), D-W statistics (0.567) and minimum variance (0.557) obtained for the model. From these results, it can be established that concave clearance and soybean machine output can be predicted using different models.

Cylinder Speed - Thresher Output Models

High adjusted coefficients of determinations (R^2) were obtained for the best model of cylinder speed - threshing efficiency model.

These were 0.9997 for the *xy* inverse and 0.9998 for quadratic 0.993 for exponential model with estimation variance of 0.00047 (quadratic), 0.000 for inverse xy and 0.000191 (exponential model -Table 3). The quadratic model however gave the most parsimonious model of the relationship based on the statistics. The cylinder speed - percentage unthreshed relationship can be modeled using simple linear, quadratic and exponential model with the adjusted coefficient of determination of 0.9998, 0.9998 and 0.9969 respectively .The estimation variance of the model were 0.00062(linear model), 0.000497 (quadratic) and 0.0081 (exponential model) while the Durbin Watson statistics were 0.471, 0.570 and 0.2911 for simple linear quadratic and exponential model respectively. Based on these results, the quadratic model gave the most precise estimates of the relationship (Table 3). the adjusted coefficient of determination (R^2) for the cylinder speed-cleaning efficiency models (linear, exponential and quadratic), were 0.0.9897, 0.989 and 0.9915 while the estimation variance were 0.0502 (linear model) 0.056 (exponential model) and 0.0416 (quadratic model - Table 3).

The Durbin - Watson statistics of the models were 0.570, 0.5671 and 0.467 for power, quadratic and exponential models. Based on these model statistics, the quadratic model proved to be the most parsimonious model of the cylinder speed - cleaning efficiency relationship .The cylinder speed - percentage mechanical damage relationship can be modeled using simple linear, quadratic and power model (Table 3).

These models have adjusted coefficient of Determination of 0.9769 (simple linear), 0.9883 (quadratic) and 0.982 (power model) as well as estimation variance of 0.0264, 0.0134 and 0.00029 for simple linear, quadratic and power model respectively. The power model based on these model statistic can be adjudged to be the best model for the relationship (Table 3) .The cylinder speed - Blown seed relationship models have adjusted coefficient of determination (R^2) of 0.9356, 0.983 and 0.9828 for exponential , power and logarithm model .The estimation is therefore the most precise model for the relationship

Moisture Content - Thresher Output Models.

The Moisture content (mc)-threshing efficiency model gave the adjusted coefficient of determination (R^2) of 0.998, 0.997 and 0.999 for *xy*-inverse, exponential and quadratic models (Table 4). Their estimation variances were respectively 0.000 (*xy*-inverse), 0.001 (exponential) and 0.0002 (quadratic) while Durbin-Watson Statistics were 0.366, 0.324 and 0.731 in the same order (Table 4). Based on these statistics (adjusted R^2, estimation variance, Durbin-Watson and F-statistics), the quadratic model was therefore the most suitable model for the relationship. For the mc-percentage unthreshed relationship, the quadratic model was also the most preferred for the relationship because it had the highest adjusted R^2 (0.963) when compared to 0.761 (for simple linear) and 0.7596 (for exponential model). In addition, the quadratic model had minimum estimation variance (0.0093) as against 0.0606 (simple linear) and 0.0563 (exponential model) as well as highest Durbin-Watson statistics of 0.693 (Table 4). The adjusted R^2 for the mc-cleaning efficiency relationship were 0.984, 0.988 and 0.983 for linear, quadratic and exponential model. The estimation variances for the models were 0.005 (simple linear), 0.0036 (quadratic) and 0.005 (exponential model) while the Durbin-Watson statistics were 0.4692 (simple linear), 0.5699 (quadratic) and 0.4562 (exponential model). The quadratic model could thus be adjudged the best model for the relationship.

Table 3. Summary of Concave - Soybean variables Relationships and their Statistics.

Dependent variables	Models	F-statistics	Adjusted R^2	Variance (estimates)	D-wattson Statistics
Threshing Efficiency	$Y = \frac{x}{x(-0.186 + 0.0152x)}$	12169.300**	0.999	0.00	1.548
	$Y = 135.193 - 1.388x + 0.00844x^2$	3403.24**	0.9985	0.024	1.051
	$Y = 108.625\ell^{-0.0045x}$	365.440**	0.969	0.433	0.285
Percentage unthreshed	$Y = 39.796 - 0.380x$	317.530**	0.963	0.518	0.283
	$Y = 10.573 + 0.618x - 0.008x^2$	3019.485**	0.998	0.028	0.974
	$Y = 107.119 - 22.081\ln x$	165.710**	0.932	0.962	0.276
Cleaning Efficiency	$Y = \frac{x}{(-0.131 + 0.0108x)}$	111.453**	0.902	0	0.486
	$Y = 92.186 + \frac{116.366}{x}$	109.954**	0.901	0.012	0.482
	$Y = 100.526 - 0.182x + 0.0012x^2$	62.391**	0.911	0.011	0.584
Pod Damage	$Y = 36.531 - 0.465x$	1108.358**	0.989	0.222	0.554
	$Y = 33.667 - 0.367x - 0.00082x^2$	514.862**	0.988	0.239	0.561
	$Y = 35.519 - 0.202x$	71.154**	0.854	0.652	0.405
Blown seed	$Y = 10.928 + 0.638x - 0.007x^2$	75.237**	0.925	0.334	0.585
	$Y = 39.775\ell^{-0.0089x}$	65.521**	0.826	0.752	0.381
	$Y = 63.694 - 0.324x$	181.915**	0.938	0.657	0.493
Seed Loss	$Y = 47.525 + 0.228x - 0.0046x^2$	108.764**	0.947	0.557	0.567
	$Y = 68.872\ell^{-0.0074x}$	164.017**	0.925	0.864	0.462

Table 4. Summary of Moisture - Soybean variables Relationships and their Statistics.

Dependent variables	Models	F-statistics	Adjusted R^2	Variance (estimates)	D-wattson Statistics
Threshing Efficiency	$Y = \frac{1}{x(0.0652 - 0.0004x)}$	0.998	7595.862**	0.000	0.366
	$Y = 15.277\ell^{0.0072x}$	0.997	3922.155**	0.001	0.324
	$Y = 15.481 + 0.073x + 0.0081x^2$	0.999	10135.213**	0.0002	0.731
Percentage unthreshed	$Y = 7.349 + 0.0914x$	0.761	39.185**	0.0606	0.3097
	$Y = 8.943 - 0.19x + 0.0108x^2$	0.963	158.668**	0.0093	0.693
	$Y = 7.433\ell^{0.0105}$	0.7596	40.799**	0.0563	0.312
Cleaning Efficiency	$Y = 24.668 - 0.109x$	0.984	717.946**	0.005	0.4692
	$Y = 24.4 - 0.0618x - 0.0108x^2$	0.988	476.899**	0.0036	0.5699
	$Y = 24.708\ell^{-0.0047x}$	0.983	657.392**	0.005	0.4562
Pod Damage	$Y = 43.5117 + 0.0453x$	0.433	10.178**	0.057	0.508
	$Y = 44.217 - 0.079x + 0.005x^2$	0.488	6.709**	0.052	0.565
	$Y = \frac{1}{x(0.023 - 0.000023x)}$	0.478	10.054**	0.000	0.509
Blown seed	$Y = \frac{1}{(0.0104 + 0.000016x)}$	0.912	125.498	0.000	0.503
	$Y = 96.1104 - 0.1445x$	0.9119	125..230	0.047	0.507
	$Y = 95.461 - 0.0298x - 0.004412x^2$	0.921	70.729	0.043	0.565
Seed Loss	$Y = 84.847 - 0.1227x$	0.983	711.051**	0.006	0.275
	$Y = 84.311 - 0.028x - 0.0036x^2$	0.9996	16449.300**	0.00013	1.616
	$Y = 84.862\ell^{-0.0015x}$	0.9826	678.650**	0.006	0.275

Moisture content-percentage mechanical damaged seed relationship can be modeled using linear, quadratic and *xy* inverse models. These models returned adjusted coefficient of determination (R^2) of 0.433, 0.488 and 0.478 for linear quadratic and *xy* inverse model and estimation variance of 0.057, 0.052 and 0.000 respectively. The *xy* inverse model could therefore be adjudged the most precise and concise model for the relationship. Moisture content - blown seed relationship returned adjusted coefficient of determination (R^2) of 0.912, 0.9119 and 0.921 for *x* inverse, linear and quadratic models. Their respective estimation variance are 0.000, 0.047 and 0.043 while their Durbin - Watson statistics were 0.503 (*x* inverse) 0.507 (linear) and 0.565 (quadratic).

The *x* inverse model is the most parsimonious model for the relationship based on the models statistics. The adjusted coefficient of determination (R^2) for moisture content - seed loss relationship were 0.983, 0.9996 and 0.9826 for simple linear, quadratic and exponential model (Table 4). These models have estimation variance of 0.006, 0.00013 and 0.006 with Durbin - Watson statistics of 0.275, 1.616 and 0.275. The quadratic model on the basics of the model statistics is therefore the most parsimonious model for the relationship (Table 4).

4. Discussion and Conclusion

Concave clearance, cylinder speed and moisture content are essential parts that are prominently modified to improve machine performance [13]. The association of high cleaning and threshing efficiency with low seed loss, blown seed and mechanical damaged seeds as established in the present study indicated contrasting relationships with the thresher's parameter (cylinder speed, concave clearance and moisture content). This agrees with [14] and [13] who established that high cylinder speed and concave clearance enhance optimum threshing though with different test seeds. Similarly, threshing efficiency was found to increase with the increase of cylinder by [6]. The seed damage and unthreshed seed in [6] were however much less than in the present study. [6] used 15.38m/s against the highest 83.776m/s in the present study. This confirms also, the validity of the moisture content-thresher's output models. The result (increasing threshing efficiency associated with cylinder speed and concave clearance) as established in the current study however conflicts with [15]. Damaged seed percentage was found to increase with increasing cylinder speed. The cause of disparity in the 2 studies may be hinged on the differences in the objects of the 2 studies. [15] uses sorghum as the test seed while the present study uses soybean. The presence of orthogonality in some of the threshing output parameters might not be unconnected with difference in the association between the machine and the output parameters. This conform with [6] that maintained that threshing efficiency increased with the increase of cylinder speed but decreased with the increase of feeding rate and concave clearance. Similarly, threshing equipment is said to consist of Waraparound concave and threshing rotor and that concave clearance is important in reducing grain loss and damage (Fu *et al.*, 2018).

The highest cylinder speed in our present study was 800rpm (equivalent to 83.776ms^{-1}) and it is much higher than the best cylinder speed ($21ms^{-1}$) recommended for sorghum (Saeidirad *et al*., 2013). This implies that cylinder speed may be dependent on the seed under study. Meanwhile, increasing the rotating speed of threshing drum (otherwise known as cylinder speed) has been recommended for improved threshing quality (Fu *et al.*, 2018). The model arrived at in the present study is a solitude model (as against multiple model) unlike the ones reported in Ajmal *et al.*, (2017). This was indeed due to existence of linearity among the thresher's variable (concave, cylinder speed and moisture content). Also, the solitude model is desirable because it gives specificity to the thresher - output model. In conclusion, the main principle in the design of threshing machine has been based on grains - panicle relationship which depends on the crop type, variety and moisture content. The present study has successfully advanced models of relationship between some thresher's components and the output variables. The practical application of the present study is the establishment of the efficiency model of the threshing machine which would enhances the adoptability of the technology by the farmers. It is therefore recommended that this study should be expanded to accommodate a universal model for threshing machine regardless of the seed types.

References

[1] Olufemi, I.O (2008). Construction and Evaluation of a Multi-Crop Thresher for Soybean. An Unpublished HND Project, Department of Agricultural Engineering, Federal College of Agriculture, Ibadan Nigeria, 59pp.

[2] FAO (2006). Upstream Implement for Combine Harvester-Thresher For Harvesting. www.fao/org/Agric/search/display.do assesed on 23rd November, 2006, 15pp.

[3] Adegbulugbe T.A (2003): Effect of Some Environmental Factors, Variety and Moisture Content on Selected Physical Properties of Cowpea (Vigna Unguiculata): 27pp.

[4] Singh, R.P, Albert F.T, Brown P.K (1987). Entomology Research on Soybean in African Soybean for the Tropics Research, Production and Utilization: 17: 122-134.

[5] Osueke, C.O. (2011). Simulation and Optimization Modeling of Performance of a Cereal Thresher. *International Journal of Engineering Technology,* 11 (3): 143-152.

[6] Zaalouk, A.K. (2009). Evaluation of Local Machine Performance for Threshing Bean. *Misra Journal of Agricultural Engineering,* 26 (4):1696-1709.

[7] Ilori T.A., Raji A,O and O. Kilanko 2013: Modelling some ergonomic parameters with machine parameter using hand powered maize Sheller. *Journal of Engineering and Technology Research* Vol. 5(3): 52-57.

[8] ASAE Standards. 2003. Moisture measurement- unground grain and seeds. S352.2. ASAE. St Joseph, Mich.: USA.

[9] Ogunsina B.S, Olaoye I.O, Opeyemi O.O and Adeboye A.O (2009): Some Nutritional Physical and Mechanical Properties of Spong Guard (Criffa Aegyptiaca) Seeds. Proceeding of 3rd International Conference of WASAE: 198pp.

[10] Ajmal U.B.1, Khan M.U., Faheem M.1, Tayyab M., Maje`ed M., Sarwar A.Khan M.R.,Shariati M.A., Shafeeque M., Mohamed A.M. 2017. Modification and Performance Evaluation of a Wheat Thresher. RJOAS, 5(65):261-270.

[11] NIS 319 (1997). Nigeria Industrial Standard for maize grain. Published by federal Ministry of Industries , Lagos, Nigeria

[12] Saheed M. A, Khan K. S and Risvi H. A (1995). Testing and evaluation of holdon paddy thresher, *Journal of Agricultural Mechanization in Asia, Africa and latin America (AMA)* 26(2): 47-51.

[13] Sinha, J.P., Dhaliwal, I. S., Sinha S. N. and Anoop D. (2009). Studies on Machine-Crop Parameters for Chickpea Seed Crop Threshing. Agricultural Engineering International: *the CIGR Ejournal. Manuscript* PM 07 026:1-9.

[14] Fu, J., Chen, Z., Han, L. and Ren, L. (2018). Review of grain Threshing theory and technology. *International Journal of Agricultural and Biological Engineering,* 11(3): 12-20.

[15] Saeidirad, M. H., Esaghzade, M., Arabhosseini, A. and Zarifneshat. S. 2013. Influence of machine-crop parameters on the threshability of sorghum. *Agric Eng Int: CIGR Journal,* 15(3): 55-59.