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Development and Validation of Threshing Efficiency Mathematical and Optimization Model for Spike-Tooth Cereal Threshers

Muna, N. H.[1], Muhammed, U.S.[2], El-Okene, A.M.[3] and Isiaka, M.[4]
Department of Agricultural Engineering Ahmadu Bello University, P.M.B. 1044, Zaria, Nigeria

Abstract:- A threshing efficiency mathematical and optimization model was developed for spike tooth mechanical cereal threshers. The machine parameters used were: Velocity of peripheral cylinder, Concave clearance, Threshing cylinder length, Height of threshing chamber, Mass of beaters and Number of beaters. The crop parameters used were: Mass and Moisture content of crop. Dimensional analysis and predictive validation methods were used to develop and validate the model respectively. The Mean Squared Deviation (MSD) and Coefficient of Determination (R^2) of plots of predicted against measured mean threshing efficiency were used as the criteria for validating the model. The model gave a good fit when the threshing speed was in the range 14.3 to 20 m/s, feed rate was in the range 6 to 12 kg/min and moisture content was in the range 10.6 to 15.8 % wb. The MSD were less than 1% and the R-square values were greater than 0.8. Hence it was considered valid for predicting the threshing efficiency of spike tooth mechanical cereal threshers at various speeds, feed rates and crop moisture contents.

Keywords:- Cereal, Efficiency, Spike-tooth , Thresher, Threshing, Model, Validation

I. INTRODUCTION

Mechanical threshing was first invented in 1786 by a Scottish mechanical engineer Andrew Meikle for use in agriculture. It involved the detachment of grain kernels from the heads, cobs or pods depending on the crop type. It takes away the drudgery involved in the slow and laborious process of manual threshing and cleaning. Since the invention of this machine, researchers all over the world have made significant efforts to develop mathematical models to predict and optimize its threshing performance using different crop, machine and operational characteristics. For this study a threshing efficiency mathematical and optimization model was developed to predict the threshing efficiency of spike tooth mechanical cereal threshers. The model will also be useful in establishing optimum conditions for the construction, operation and management of these machines and provide understanding of the fundamentals of its operation at different crop situations.

II. RESEARCH AND DEVELOPMENT EFFORTS ON THRESHING AND SEPARATION MODEL

Threshing and separation process is divided into the following sections:

(a) Detachment of the grains from the ears by which the grains becomes free in the threshing space.
(b) Segregation of free grains kernels through the straw mat to the concave/grate surface.
(c) Passing of free grains kernels through the concave opening.(Huynh *et al*., 1982, Miu, 1994, 1995)

(Wacker, 1985; Gasparetto *et al.*, 1989; Miu, 2002) developed a universal mathematical model for grain threshing and separation. The distribution frequency of un-threshed grain percentage into the threshing space is a continuous variable. At the end of the threshing space (e.g x=L for axial unit), the un-threshed grain becomes threshing loss, V_t (%).

$$V_t = S_n(L) = e^{-\lambda L} \quad \text{(1)}$$

Where,
V_t = Threshing loss (%)
S_n = Percentage of un-threshed grain
L = Length of the threshing space (m)
λ = Space increments between respective successive event changes (m^{-1})

Enaburekan (1994) developed mathematical and optimization models for the threshing process in a stationary grain thresher using wheat and sorghum. He developed amongst others the following threshing efficiency model:

$$E_t = 1 - e^{-3K_T \rho (1-\alpha) VWDL / 2QC} \quad \text{(2)}$$

Where,

E_t = threshing efficiency (%)
K_T = threshing constant
ρ = crop bulk density (kgm^{-3})
$\alpha =$ crop moisture content (%, dry basis)
V = velocity of threshing cylinder (m/s)
W = width of thresher (m)
D = effective cylinder diameter (m)
L = concave length (m)
Q =crop mass feed rate (kg/s)
C= concave clearance (m)

Miu (1995) developed a universal mathematical model of grain threshing and separation and was applied to tangential feeding (Miu *et al.*, 2008). The probability that grains will reach the separation surface is the same over the separation length as the probability of free grain passage through the openings of separation surface (Huynh *et al*., 1982; Mailander, 1984; Miu, 1994, 1995; Miu *et al.*, 2008; Kutzback and Quick, 1999). The probabilistic laws that respectively describe the above mentioned events were identified as follows:

(a) $$F_x(x) = e^{-\lambda x} \quad \ldots\ldots(3)$$

(b) $$F_f(x) = \frac{\lambda}{\lambda-\beta}\left(e^{-\beta x} - e^{-\lambda x}\right) \quad \ldots\ldots(4)$$

(c) $$F_S(x) = \frac{1}{\lambda-\beta}\left[\lambda\left(1-e^{-\beta x}\right) - \beta\left(1-e^{-\lambda x}\right)\right] \quad \ldots\ldots (5)$$

Where,
$F_x\ (x)$ = un-threshed fraction over the threshing length, x.
$F_f(x)$ = free grain fraction
$F_s\ (x)$ = cumulative separated grain, fraction
λ and β are probability density function, in decimals, as defined on the threshing space length (x). They represent space increments between respective successive event changes.
$\lambda, \beta =$ specific threshing and separation rates respectively (m^{-1}).

Ndirika (1997) developed mathematical and optimization models for the threshing process in a stationary grain thresher using millet and sorghum. He developed amongst other things the following threshing model:

$$T_e = 1 - e^{\frac{-1.5 K_t \rho_d D V_b L_c}{(1-\beta) F_r}} \quad \ldots\ldots (6)$$

Where,
T_e = threshing efficiency parameter (%)
K_t = threshing constant
ρ = bulk density (kg/m^3)
V_b = cylinder velocity (m/s)
L_c= concave length (m)
F_r = feed rate (kg/s)
D = cylinder diameter (m)
β = moisture content (%, dry basis)

Huynh *et al*., 1982 stated that the rate of detachment of grains from their bindings is proportional to both the specific energy input to the crop and transmissibility of the energy across the length of the crop mat. The mathematical expression is given by:

$$\lambda = K_T\,(\rho V_2^{\,2} wD)/(Qc) \quad \ldots\ldots (7)$$

Where,
D = drum diameter
c = concave clearance
ρ = bulk density of crop
V_2= peripheral velocity of rasp bar

w = width of thresher
Q = mass feed rate of crop
K_T= threshing factor

Gregory (1988) stated that rate of threshing decreases as the probability of hitting unthreshed grain decreases. The mathematical expression is given by:

$$\frac{dU}{dN_i} = -\frac{E_1}{E_2 N_b} U_m \quad \text{……………..……………..…..…..…..... (8)}$$

Where,
U_m = unthreshed grain mass
N_i = number of impacts
E_1= energy needed per area of impact to detach grain
N_b= number of bars
U = threshed grain mass
E_2 = minimum energy to cause damage

Osueke (2011) adopted Huynh *et al*., 1982 model and developed a simulation and optimization model of performance of a cereal thresher. The mathematical expression is given by:

$$Efficiency = 1 - e^{-0.5 K_T [(\rho(1-\alpha) vwDL)/(Qc)}} \quad \text{……..…...…..….... (9)}$$

Where,
α = moisture content
L = concave length
D = drum diameter
c = concave clearance
ρ = bulk density of crop
v= peripheral velocity of rasp bar
w = width of thresher
Q = mass feed rate of crop
K_T= threshing factor

The above models did not include the mass of beaters and the number of beaters in their machine characteristics hence the need for development of this model.

III. THRESHING EFFICIENCY MODEL DEVELOPMENT

Threshing efficiency evaluates the percentage of grains detached from the crop per second by the beaters of the threshing mechanism. Since the crop was moving up and down within the threshing chamber, the mechanical energy was the sum of kinetic and potential energies. Both energies are inversely proportional to one another. The threshing cylinder, beaters, sieves and wall of the threshing chamber had smooth surfaces, hence friction was assumed to be negligible. Therefore, transfer of energy from the beaters to the crop was entirely by direct impact. Threshing occur when the kinetic energy transferred by the beaters to the crop per second overcomes the gravitational potential energy of the free falling crop fed through the hopper per second; hence causing the crop to move from bottom to top of the threshing chamber and forward as it is threshed. Meanwhile stalling of the thresher occurs when the gravitational potential energy of the crop overcomes the kinetic energy transferred by the beaters. The variables of importance assumed to influence the rate of detachment of grains per second were identified as follows: Kinetic energy transferred by a beater per second *K.E,* (0.5 $M_b V_c^2$), (kgm^2/s^2), Potential energy of the crop fed per second, *P.E,* ($M_f$gh), (kgm^2/s^2), Concave clearance, C_c (m), Length of threshing cylinder, L_c (m), Number of beaters, N_b (dimensionless), Dueling time of crop within the threshing chamber, t (*s*), and Moisture content of the millet or soybean crop, M_c (% wb), (dimensionless). The threshing efficiency function variables and their dimensions are shown on table I.

TableI: Threshing efficiency function variables and their corresponding dimensions

Variable	Symbol	S.I Unit	Dimension [M][L][T]
Rate of detachment of grains	λ_T	s^{-1}	T^{-1}
Kinetic Energy transferred by a beater per sec.	*K.E*	kgm^2/s^2	ML^{2}T^{-2}
Potential Energy of the crop fed per second	*P.E*	kgm^2/s^2	ML^{2}T^{-2}
Concave clearance	C_c	m	L

Length of threshing cylinder	L_c	m	L
Dueling time of crop in the threshing chamber	t	s	T
Moisture content of crop	M_c	-	1
Number of beaters	N_b	-	1

According to Buckingham's π-theorem:

If $\lambda = F(A_1, A_2, ..., A_n)$ ……………….…………….…. (10)

Then $\lambda = f(\pi_1, \pi_2, ..., \pi_{r<n})$…………………………...….(11)

Where:

λ = dependent variable.

$A_1, A_2, ..., A_n$= independent variables.

$\pi_1, \pi_2, ..., \pi_{r<n}$= non dimensional groups of A_i's.

F, f = functional relationships of A_n's and π_r's respectively.

Thus:

$\lambda_T = F(K.E, P.E, L_c, C_c, N_b, M_c, t)$ …………….....… (12)

By inspection, a complete dimensionally independent subset was formed from equation (12)

Thus:

$\lambda_T t\ (P.E, C_c, M_c) = (K.E, L_c, N_b)$………………...……...(13)

$1(ML^2T^{-2}, L, 1) = (ML^2T^{-2}, L, 1)$ (dimensionally homogeneous)

We make the independent variables dimensionless by multiplying or dividing each one with a variable having similar dimensions as follows:

$[\lambda_T t]$ = 1 (dimensionless)…………………….………. (14)

$[\pi_1] = \frac{K.E}{P.E} = \frac{ML^2T^{-2}}{ML^2T^{-2}} = 1$ (dimensionless)……….......... (15)

$[\pi_2] = \frac{L_c}{C_c} = \frac{L}{L} = 1$ (dimensionless)……………………........(16)

$[\pi_3] = \frac{N_b}{M_c} = \frac{1}{1} = 1$ (dimensionless)…………................. (17)

Hence,

$[\lambda_T t] = [\pi_1] = [\pi_2] = [\pi_3] = 1$ (dimensionally homogeneous)

From equation (11): $\lambda = f(\pi_1, \pi_2, ..., \pi_{r<n})$

Hence,

$\lambda_T t = f(\pi_1, \pi_2, \pi_3)$…………………………………….. (18)

$\lambda_T t = K_T \frac{N_b.L_c.K.E}{M_c.C_c.P.E}$ ……………………………......... (19)

But, $K.E = 0.5\ M_b V_c^2$ and $P.E = M_f\ g\ h$

Thus:

$\lambda_T t = K_T \frac{0.5 N_b.L_c.M_b.V_c^2}{M_c.C_c.M_f.g.h}$ ……………………………... (20)

The threshing constant (K_T) was obtained as follows:

$$K_T = \frac{\lambda_T t}{\frac{0.5 N_b.L_c.M_b.V_c^2}{M_c.C_c.M_f.g.h}} = 1 \text{(Elastic collisions)............ (21)}$$

Since there was grain damage during threshing, the collision taking place within the threshing chamber was considered inelastic. Hence, the threshing constant (K_T) for SOSAT C88 Millet Variety was obtained by trial and error method. Starting with $K_T = 1$ we substitute different K values on the threshing efficiency model developed below and compare the answer with those obtained during field experiments. The threshing constant was determined to be $K_T = 0.028$.

The universal mathematical model of grain threshing and separation as developed by Miu, (1995) and applied to tangential feeding (Miu and Kutzbach, 2008) was used for developing the mathematical model for predicting the threshing efficiency of spike tooth cereal threshers.

$$F_x(x) = e^{-\lambda x} \quad \text{......................................} (22)$$

$$F_f(x) = \frac{\lambda}{\lambda - \beta}\left(e^{-\beta x} - e^{-\lambda x}\right) \quad \text{..................................} (23)$$

$$F_s(x) = \frac{1}{\lambda - \beta}\left[\lambda\left(1 - e^{-\beta x}\right) - \beta\left(1 - e^{-\lambda x}\right)\right] \quad \text{...............} (24)$$

Where:
$F_x(x)$ = unthreshed fraction
$F_f(x)$ = free grain fraction.
$F_s(x)$ = cumulative separated grain fraction.
λ and β are probability density functions in decimals for a period of time x.
Amongst the above functions, equation (22) best describes the threshing event.
Thus:

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

Where,
$F_x(x)$ = unthreshed fraction.
$\lambda x = \lambda_T t$ = dimensionless arbitrary number.

The threshing efficiency function (E_T) was developed as follows:

$$E_T = (1 - e^{-\lambda_T t}) \times 100 \quad \text{..................................} (25)$$

Substituting equation (20) into equation (25), the threshing efficiency function is given by:

$$E_T = (1 - e^{-0.5 K_T N_b L_c M_b V_c^2 / M_c C_c M_f g h}) \times 100 \quad \text{....} (26)$$

Where,
E_T = threshing efficiency (%)
K_T = threshing constant (K_T = 0.028 for millet crop)
N_b = number of beaters (38).
M_b = mass of beater (0.188 kg)
L_c = length of threshing cylinder (1.195 m)
V_c= velocity of peripheral cylinder (m/s)
M_f =total mass of crop fed (kg)
g = acceleration due to gravity (9.81m/s^2)
h = height of the threshing chamber (0.47 m)
M_c = moisture content of the crop (% wb)
C_c = concave clearance (m)

3.1 Model Verification

The objective of the model verification was to ensure that this model was correct and that it was able to perform its respective task. In the implementation of the model it was tested for errors using input data of field experiments and the errors found were fixed.

3.1.1 Verification of dimensions of threshing efficiency model

The dimensions (length (L), mass (M), and time (T)) on both sides of the equality sign of the threshing efficiency model was verified if they were the same as follows:

$$E_T = (1 - e^{-\lambda_T t}) \times 100$$

$$E_T = (1 - e^{-0.5 K_T N_b L_c M_b V_c^2 / M_c C_c M_f g h}) \times 100$$

Hence,
$[E_T] = 1$

$$[\lambda_T t] = \frac{K_T N_b.L_c.M_b.V_c^{\,2}}{M_c.C_c.M_f.g.h}$$
$$= \frac{1.1.L.M.L^2.T^{-2}}{1.L.M.L.T.^{-2}L}$$
$$= \frac{M.L^3.T^{-2}}{M.L^3.T^{-2}} = 1$$
$$[E_T] = [\lambda_T t] = 1$$

3.1.2 Verification Of Threshing Efficiency Model Using Input Data Of Field Experiments

The combination of speed, feed rate and moisture content that were used during field experiments were also used for testing the model and the outputs compared. Considering a cylinder speed of 14.3 m/s, feed rate of 8 kg/min and moisture content of 10.6 % the mean threshing efficiency of the multicrop thresher from field experiments was 99.81 %. The threshing efficiency of the machine was predicted using the threshing efficiency model by substituting the following:
K_T = 0.028 for millet, N_b = 38, L_c = 1.195 (m), M_b = 0.188 kg, V_c= 14.3 m/s, M_c = 10.6 (% wb), C_c = 0.01 (m), M_f= 8 kg, g = 9.81 (m/s^2), h = 0.47 (m).

Thus:

$$E_T = (1 - e^{-\lambda_T t}) \times 100$$
$$-\lambda_T t = \frac{-0.5 K_T N_b.L_c.M_b.V_c^{\,2}}{M_c.C_c.M_f.g.h}$$
$$-\lambda_T t = \frac{-0.5 \times 0.028 \times 38 \times 1.195 \times 0.188 \times 14.3^2}{10.6 \times 0.01 \times 8 \times 9.81 \times 0.47} = \frac{-24.44046485}{3.9098736} = -6.250960351$$
$$E_T = (1 - e^{-6.250960351}) \times 100$$
$$E_T = (1 - 0.0019286011) \times 100$$
$$E_T = (0.998071) \times 100$$
$$E_T = 99.81\%$$

The threshing efficiency (E_T = 99.81 %) predicted by the model was the same as the measured threshing efficiency of the machine obtained during field experiments.

3.2 Model Validation

Predictive validation was used for this study. The developed model was used to predict the multicrop thresher performance with the same treatments given during field experiments. Then, the measured output data from field experiments and the predicted output data from the model were both plotted. Regression validation method and graphical comparison method for determining the "Goodness of fit of the model" were used on the plotted graphs. This method measures the discrepancy between the field experimental values and the predicted values of the model. The discrepancy and coefficient of determination (r^2) of the regression line of predicted versus measured plots was determined and used as the criteria for validating the developed model.

3.2.1 Model validation experimental treatments

The treatments of field experiments were used as treatments for the model validation experiments. The threshing efficiency model was subjected to three experimental treatments. Thus, the following treatments were considered for millet threshing:

- **i** Moisture content (M) at 5 levels: M_1 = 10.6 %, M_2 = 11.9 %, M_3 = 13.2 %, M_4 = 14.3 % and M_5 =15.8 %.
- **ii.** Cylinder speed (S) at 5 levels: S_1 = 550 rpm (12.1 m/s), S_2 = 650 rpm (14.3 m/s), S_3 = 750 rpm (16.5 m/s), S_4 = 850 rpm (18.7 m/s) and S_5 = 909 rpm (20 m/s).
- **iii** Feed rate (F) at 5 levels: F_1 = 6 kg/min, F_2 = 8 kg/min, F_3 = 10 kg/min, F_4 = 12 kg/min and F_5 = 14 kg/min

3.2.2 Model Validation Experimental Design, Experimental Layout And Data Analysis

The experimental design, experimental layout and data analysis methods used for the field experiments were also used for the model validation experiments. A randomized complete block design (RCBD) was used. SAS statistical software was used to analyze the data. The difference between the means and variables was compared using ANOVA and Duncan's multiple range tests. Summary of ANOVA for predicted and measured threshing efficiencies for SOSAT C88 millet variety is shown on table II (a, b).

3.2.3 Goodness-Of-Fit Of The Threshing Efficiency Model

Direct comparisons between the model outputs to the measured outputs using graphical method were used to make a subjective decision of goodness-of-fit of the threshing efficiency model. Graphical method was chosen because it has an advantage over theoretical methods of goodness-of-fit measurement as it readily illustrates a broad range of complex aspects of the relationship between the model data and the measured data. It also enables us to quickly locate areas with larger deviation. Wilmot (1982) suggested that Bias and Root Mean Square Error (RMSE), equations (27) and (28) were amongst the best overall measures of a model performance.

Bias = $\frac{1}{N}\sum_{i=1}^{N}\left(P_i - M_i\right)$ …………………….......... (27)

Where,

P_i and M_i = predicted and measured values of the variable of interest respectively

N = the number of observations.

RMSE = $\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(P_i - M_i\right)^2}$ ……………….…... (28)

Table IIa: Summary of ANOVA for Predicted and Measured Threshing Efficiencies for SOSAT C88 Millet Variety

Source	DF	SS Measured	SS Predicted	MS Measured	MS Predicted	F Value Measured	F Value Predicted
Replication	2	0.003	0.000	0.000	0.000		
Moisture (M)	4	812.649	232.774	203.162	58.193	46041.8**	$1.41 x10^{15}$**
Speed (S)	4	7.271	1974.167	1.818	493.542	411.93**	$1.21 x10^{16}$**
Feed rate (F)	4	16.259	860.426	4.065	215.107	921.19**	$5.21 x10^{15}$**
M × S	16	2.793	210.683	0.175	13.168	39.56**	$3.19 x10^{14}$**
M × F	16	8.705	95.136	0.544	5.946	123.30**	$1.44 x10^{14}$**
F × S	16	3.761	874.009	0.235	54.626	53.27**	$1.32 x10^{15}$**
M × S × F	64	6.600	52.514	0.103	0.821	23.37**	$1.99 x10^{13}$**
Error	248	1.094	0.000	0.004	0.000		
Total	374	859.136	4299.708				

** = Highly Significant, DF= Degree of Freedom, SS = Sum of Squares, MS = Mean Squares

Table IIb: Summary of performance indices for Predicted and Measured Threshing Efficiencies for SOSAT C88 Millet Variety

Performance Index	R^2	Coefficient of Variation	Root Mean Square Error	Mean Threshing Efficiency (%)
Measured	0.999	0.067	0.066	98.53
Predicted	1.000	$2.073 x10^{-7}$	$2.031 x10^{-7}$	98.00

The discrepancy between the measured and predicted values of the model was determined using Mean Square Deviation (MSD), Square Bias (SB) and lack of correlation weighted by the standard deviation (LCS), equations (29), (30) and (31) Kobayashi and Salam (2000). Thus:

MSD = $\frac{1}{n}\sum_{i=1}^{n}\left(P_i - M_i\right)^2$ …………………………… (29)

SB = $\left(\overline{P} - \overline{M}\right)^2$ ………………………………….….... (30)

LCS = $2 \times SD_p \times SD_m \times (1- r)$ ………………….…..........… (31)

Where,

$\overline{P}$ and $\overline{M}$ = average predicted and measured values respectively.

SD_p and SD_m = standard deviations of predicted and measured values respectively.

r = the correlation coefficient between predicted and measured values.

The model performance was quantified by calculating the Standard Error (SE) and Average Absolute Deviation (AAD), equations (32) and (33) Yusuf (2001).

Thus:

$$SE = \frac{\sqrt{\sum (y_m - y_p)^2}}{n} \quad \text{.........................} \quad (32)$$

$$AAD = \frac{\sum |y_m - y_p|}{n} \quad \text{.........................} \quad (33)$$

Where,
y_m and y_p = measured and predicted values respectively.
n = number of observed values.

The Coefficient of Efficiency was determined by equation (34) (Logates and Mc. Cabe, 1999):

$$E = 1 - \frac{\sum_{i=1}^{N} |M_i - P_i|}{\sum_{i-1}^{N} |M_i - \overline{M}|} \quad \text{.........................} \quad (34)$$

Where,
M_i = measured data
P_i = predicted data.

The Mean Squared Deviation (MSD) and Coefficient of Determination (R^2) of the regression lines of plots of predicted against measured mean threshing efficiency were used as the criteria for validating the model. Tables 3 (a, b, c) are Duncan grouping for Measured and Predicted Mean Threshing Efficiencies at various speeds, feed rates and moisture contents for SOSAT C88 Millet Variety.

IV . RESULTS

Table III (a) shows that, the model gave a good fit when the threshing speed was in the range 14.3 to 20 m/s (B, C, D and E). At this range the MSD was 0.9 % and the maximum deviation between the measured and predicted threshing efficiencies was 1.4 %. A perfect fit was seen at a threshing speed of 17.1 m/s. The model gave a poor fit when the threshing speed was below 14.3 m/s and the difference between the measured and predicted threshing efficiencies was seen to increase continuously until it reaches a maximum of 2.7 % at a speed of 12.1 m/s.

Table III (b) shows that, the model gave a good fit when the feed rate was in the range 6 to 12 kg/min (A, B, C and D). At this range the MSD was 0.81 % and the maximum deviation between the measured and predicted threshing efficiencies was 1.1 %. A perfect fit was seen at a feed rate of 10.8 kg/min. The model gave a poor fit when the feed rate was above 12 kg/min and the difference between the measured and predicted threshing efficiencies was seen to increase continuously until it reaches a maximum of 4.5 %.

Table III (c) shows that, at various moisture contents the threshing efficiency model gave a good fit. The model gave a good fit when the moisture content was in the range 10.6 to 15.8 % wb (A, B, C, D and E). At this range the MSD was 0.92 % and the maximum deviation between the measured and predicted threshing efficiencies was 1.5 %.

Table IIIa: Duncan grouping for Measured and Predicted Mean Threshing Efficiencies at various Speeds for SOSAT C88 Millet Variety

Duncan Grouping	N	Speed (m/s)	Measured Threshing Efficiency (%)	Predicted Threshing Efficiency (%)	Deviation (%)
A	75	12.1	98.2	95.58	2.62
B	75	14.3	98.48	97.08	1.40
C	75	16.5	98.57	98.32	0.25
D	75	18.7	98.64	99.24	0.60
E	75	20.0	98.67	99.78	1.11

MSD = 0.9 % for B, C, D and E

Table IIIb: Duncan grouping for Measured and Predicted Mean Threshing Efficiencies at various Feed rates for SOSAT C88 Millet Variety

Duncan Grouping	N	Feed Rate (kg/min)	Measured Threshing Efficiency (%)	Predicted Threshing Efficiency (%)	Deviation (%)
A	75	6	98.77	99.87	1.10
B	75	8	98.70	99.72	1.02
C	75	10	98.58	99.14	0.56
D	75	12	98.38	97.55	0.83
E	75	14	98.21	93.71	4.5

MSD = 0.81 % for A, B, C and D

Table IIIc: Duncan grouping for Measured and Predicted Mean Threshing Efficiencies at various Moisture contents for SOSAT C88 Millet Variety

Duncan Grouping	N	Moisture Content (%wb)	Measured Threshing Efficiency (%)	Predicted Threshing Efficiency (%)	Deviation (%)
A	75	10.6	99.73	99.03	0.70
B	75	11.9	99.69	98.59	1.10
C	75	13.2	99.64	98.05	1.59
D	75	14.3	97.41	97.54	0.13
E	75	15.8	96.17	96.78	0.61

MSD = 0.92 % for A, B, C, D and E

Fig.1 (a, b, c) represent plots of Predicted against Measured values of Mean Threshing Efficiency for SOSAT C88 Millet Variety. The equation of regression lines and R-square values were determined. The R-square values for Fig. 1 (a, b and c) were all greater than 0.8.

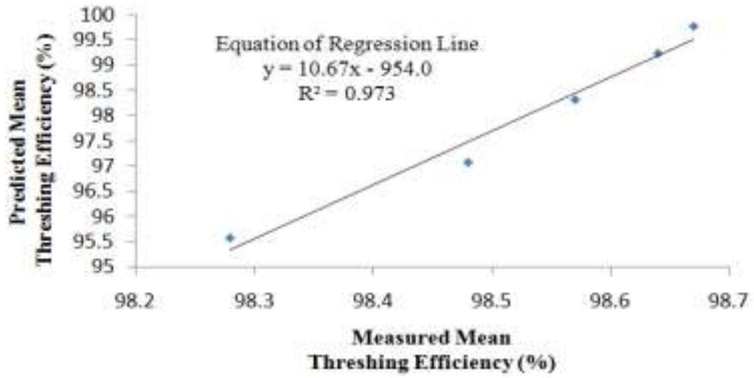

Fig.1a: Graph of Predicted against Measured Mean Threshing Efficiency at five levels of Speed for SOSAT C88 Millet Variety

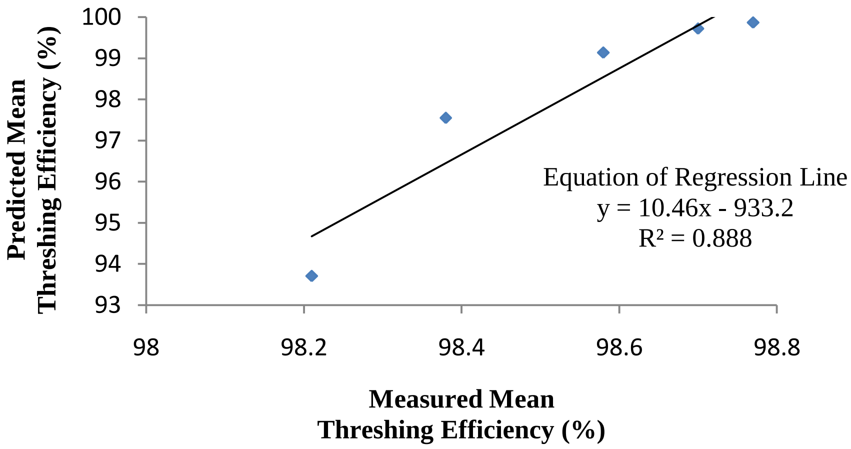

Fig.1b: Graph of Predicted against Measured Mean Threshing Efficiency at five levels of Feed Rate for SOSAT C88 Millet Variety

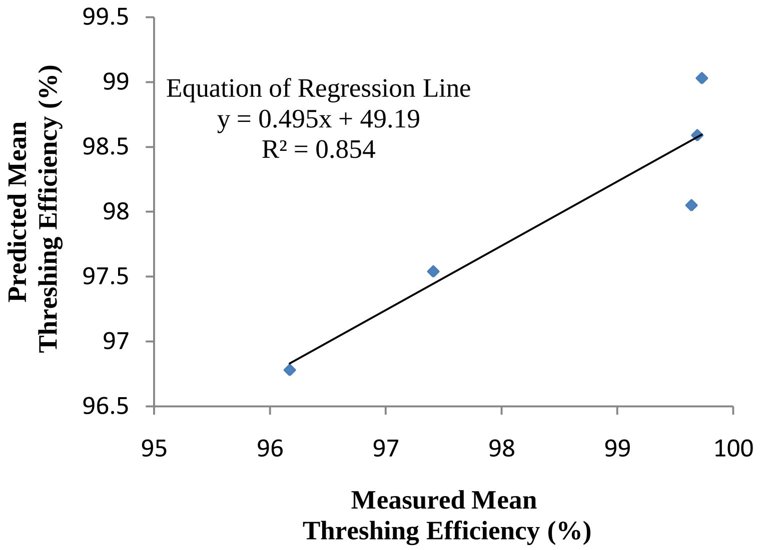

Fig.1c: Graph of Predicted against Measured Mean Threshing Efficiency at five levels of Moisture Content for SOSAT C88 Millet Variety.

V. CONCLUSION

The low percentage Mean Squared Deviation (< 1%) and high R-square values (> 0.8) shown on Tables 3 (a, b, c) and Fig.1 (a, b, c) indicates that the model is valid for predicting the threshing efficiency of spike tooth mechanical cereal threshers at various speeds, feed rates and crop moisture contents.

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