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Computer applications for selecting operating parameters in a stationary grain crop thresher

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In this study, various operating parameter influencing performance of a stationary grain crop threshers were established. These parameters were deduced from the established analytical models describing the underlying principles for the crop characteristics and machine variables as factors influencing the overall machine performance of a stationary multi-crop thresher by Olaoye (2004). A computer program written in Visual Basic was used to select optimum operating performance of the threshing process in a stationary tooth - peg grain crop thresher. An IITA - popularized stationary multi- crop thresher was used to test the practical feasibility of the computer based output of the threshing process. A split - split - unit statistical design was used for data collection. The data collected were analysed using the GENSTAT 5 statistical package with its computer program. The results showed that graphs of data from measured thresher performance indices against the predicted data for all the established models indicated high correlation between the models and the measured data at $p \leq 5$ % significance level. The minimum energy requirements for detachment of sorghum and rice were observed at the threshing cylinder speed of 500 rpm (10.5 m/s) and 615 (13.0 m/s) rpm, respectively. The combination of the threshing cylinder speed of 500 rpm (10.5 m/s) and 615 rpm (13.0 m/s) at crop moisture content of 12.8 % and 16.2 % indicated optimum threshing conditions for sorghum and rice, respectively.

Key words: threshing, grain crops, computer modelling, stationary grain crop thresher, tooth

Introduction

Threshing of grain crop is a unit operation that requires attainment of sets of processing condition that must be attained for effective threshing action to be accomplished in a manual or mechanical operation. Stationary grain crop threshers refer mainly to mechanical thresher that uses threshing cylinders in a localized position. This type of thresher is classified into two distinct groups

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based on the method of feeding the crop into the thresher. The two classes are hold - on and throughput types.

Inappropriate threshing conditions in a manual threshing process reduces the grain output with respect to excessive and high energy input. In a mechanical threshing process the effect of the inappropriate operating conditions does not only affect the effective recovery of the grains from the other plant materials but it also leads to high grain loss. Grains loss is measured in term of the damage to the grain kernel, loss to the mechanical elements and non germinability of the seeds. Threshing operation is the removal of grains from the plant residues. It could be done through the process of repeated pounding and dragging of the plant over a surface or through an aperture. Threshing operation is considered as one of the foremost important post harvest operation in grain production (Olaoye, 2004).

Proper adjustment of the operating conditions in a mechanical thresher has been determined by various researchers as the most critical success factors in grain threshing. The key variables of interest are generally classified as the machine parameters, crop characteristics and influencing environmental or processing conditions (Olaoye, 2004). Olaoye and Oni (2001) investigated crops characteristics of some common grain crops within the middle belt of Nigeria. The results of the investigation revealed that specific presentation of the grain size, geometrical dimensions of the grains and grain mechanical properties are the key parameters that can enhance successful separation of the grains free of plant residues. Many researchers had concluded that the variation of cylinder peripheral speed, effective concave clearance, and fan speed are the major machine variables that can influence threshing performance (Singh and Singh, 1981; Joshi, 1981; Ghaly, 1985 and Behera *et al*., 1990). The fundamental and influencing environmental processing conditions with direct bearing on the effective performance of threshing systems are moisture content and feed rate (Olaoye, 2004). These are extrinsic factors and they are established on the plant or machine variable through the interactions of the effect of the environment, crop characteristics and machine variables.

According to Olaoye (2002) some crop parameters and machine variables are known to influence the performance of threshers. Each or combination of these parameters has influencing effects on the threshability and grain damage. He noted that the influence of both threshability and grain damage translate to measurable grain losses if not properly managed. Desta and Mishra (1990) developed and conducted performance evaluation of a sorghum thresher. A combination of feed rate at 3 levels (6, 8, 10 kg/min), cylinder-concave clearance at 2 levels (7 and 11 mm) and cylinder speed at 3 levels (300 rpm (17.5 m/s), 400 rpm (10.1 m/s); 500 rpm (12.6 m/s)) were investigated. The results of the performance analysis showed that threshing efficiency increased with an increase in cylinder speed for all feed rates and cylinder concave clearances. The threshing efficiency was found in the range of 98.3 to 99.9%. At the recommended speed of 400 rpm (10.1 m/s) the power required for operating the thresher was 4.95 kW and the maximum output of the thresher was 162.7 kg/h. Saeed *et al.* (1995) tested and evaluated a hold on paddy thresher. The field performance and economics of the machine was evaluated. A hold - on type Korea thresher (model NJ 810) was used for the study. The field performance of the machine was then measured by varying thresher cylinder speeds and crop feed rates at 3 levels of threshing cylinder speed (450 rpm (15.5 m/s), 500 rpm (17.3 m/s), 550 rpm (19.0 m/s)) and crop feed rate at 3 levels (Low (44 kg/h) medium (720 kg/h), high (1,163 kg/h)). The results obtained from the investigation showed that the grain damage in term of breakage was in the range of 0.4 to 1.2%. The percentage of the grain damage increased with the increase in cylinder speed for all feed rates. Grain damage was 0.4% for optimum operating condition. The threshing efficiency increased with increasing feed rate. The results of the comparison of mechanical threshing with manual threshing in term of grain losses clearly indicated 2.64% total loss from mechanical thresher as compared to 7.95% for manual threshing. To minimize losses in a mechanical thresher, performance of the threshing machine must be evaluated using machine, crop and processing variables. The crop and machine variables are relevant to the performance evaluation of mechanical threshers. Olaoye (2004) observed that mechanical threshing of crops become most advantageous at the instance of improved farming practices, use of high yielding varieties, multiple cropping system and expanded use of irrigation water. He noted that with such systems of cultural practices large quantities of crop will mature and must be harvested with relative benefits of mechanical processing equipment. The requirement for modeling the performance of grain crop thresher is to establish known and expected machines and crop characteristics that may have direct influence on the processing technique of the crop and the final quality and state of the crop product. The computer modeling technique will assist to simulate the thresher performance at different levels of threshing machines variable and crop conditions. The computer models could be a decision making tool to allow repeated testing of different machine parameters and crop variables. The main objective of this study was to use computer models describing threshing actions to establish the appropriate operating parameters and performance of a stationary grain crop thresher.

Materials and methods

Programme structure and development

The general principle of operation and evaluation of a stationary crop thresher using analytical models as developed by Olaoye (2004) was adopted in the programme structure development. Olaoye (2004) developed analytical models describing the underlying principles for crop characteristics and machine variables as factors influencing the overall machine performance of a stationary multicrop thresher.

The crop and machine variables that are relevant to the performance evaluation of mechanical threshers were identified as cylinder speed, concave clearance, type of threshing mechanism, cylinder diameter moisture content of crop, type of crop material and feed rate. The general threshing models as developed by Olaoye (2004) were adopted for the programme structure and development. The specific models for the programme design include the general threshing model, crop dwell time, power required for threshing operation, threshing efficiency grain damage and separation efficiency.

Programme design and implementation

The general threshing model for stationary thresher is presented as Equation 1.

$$T = 1 - e - \left[\frac{t_c}{k_m \left(\frac{\sigma}{G + \frac{2\ddot{v}_s^{\,2}}{D}} \right)^{\frac{1}{2}}} \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where: e = exponential

t_c = Dwell time (s)

k_m = constant =2.448

σ = mass thickness of unwanted plant material

G = Acceleration due to gravity

$\bar{v}_s$ = Speed of the grain crop. (m/s)

D = cylinder diameter (mm)

The crop dwell time measures the time the crop spent in the threshing zone before finally discharged at the outlet (Olaoye, 1997).

$$t_c = \frac{L_c}{V_c}\text{ , but } V_c = K_b Vt$$

$$t_c = \frac{1}{K_b} \circ \frac{L_c}{V_t} \text{ .... (2)}$$

Where: t_c = dwell time of grain crop in the threshing zone(s)
L_c = concave length of the threshing cylinder (mm)
V_c = maximum velocity of crop after impact (m/s)
V_t = peripheral velocity of the threshing mechanism

Olaoye (2004) also deduced that the Mean rate of threshing kernels is given as

$$\lambda = k_c \frac{C^3(1 - M_{cwb})}{\sigma_{max} V_T W} \text{ .... (3)}$$

Where: λ = mean rate of threshing kernels.
V_T = peripheral speed of the cylinder(m/s)
M_{cwb} = moisture content (wet basis) of the crop (%)
W = width of the threshing cylinder =D (mm)
σ_{max} = maximum distance between the threshing drum and the concave.
C = concave clearance.
K_c = constant associated with duration of grain crop within the overall length of the concave.

According to Olaoye, (2004) the energy required to detach grain from the panicle is presented as follows:

$$E_d = \frac{k_e V_s^{\frac{1}{2}} fr^{\frac{3}{2}}}{\rho w^2} \text{ .... (4)}$$

Where: k_e is a constant (grain size characteristics)
fr = feed rate (kg/h)

All other parameters as previously defined. The power required to detach the grain from the panicle is obtained as

$$P_d = k_s \left[\frac{k_e V_s^{\frac{1}{2}} fr^{\frac{3}{2}}}{\rho w^2}\right] \frac{V_T}{L_c} \text{ .... (5)}$$

Where: $k_r = k_s k_e$; k_r is a constant that is influenced by the resistance of the crop material to the machine component.
L_c = concave length (mm)

Relating the power output from the cylinder in terms of the detached grain and the power input through the impact from the beater bars, the power required to detach grain crop is

$$P_d = \frac{3k_e}{2}\left[\frac{V_s^{\frac{3}{2}} fr^{\frac{3}{2}}}{\rho w^2 L_c}\right] \qquad (6)$$

The power required to overcome frictional force during threshing operation is

$$p_f = \frac{2}{3} Nf \left[\frac{\sigma_{max}}{C}\right]^n .\pi DL_c \qquad (7)$$

The power required to turn the unloaded cylinder is

$$p_u = \frac{2\pi NrMc}{60 \times 75}\left[g + \frac{V_T^2}{r}\right] \qquad (8)$$

Total power required from threshing operation is evaluated as:

$$P = \frac{3k_e}{2}\left[\frac{V_s^{\frac{3}{2}} fr^{\frac{3}{2}}}{\rho w^2 L_c}\right] + \frac{2}{3} uF \left[\frac{\sigma_{max}}{C}\right]^n \pi DL_c + \frac{2\pi NrMC}{60 \times 75}\left[g + \frac{V_T^2}{r}\right] \qquad (9)$$

Where: N = speed of the threshing cylinder (rpm)
n = Power factor
uF = Factor depending on power to overcome friction
MC = Mass threshing cylinder
r = effective radius

The damage incurred during threshing is related to the dwell time, separating process, factors related to the grains crop conditions and the characteristics of the crop (Olaoye, 2004). Energy absorbed by the grain can be evaluated, thus giving an indication of the (maximum) energy that will cause the damage of the crop.

$$E = \frac{1}{2}\frac{\rho_{db} V V_T^2}{g(1 - M_{cwb})}(1 - k_s)^2 (1 - e^2) \qquad (10)$$

Where: e = coefficient of restitution by crop material
V = volume occupied by the grain crop in the threshing zone

All other notations remain as previously defined. Details of the Analysis of the threshing models are presented in Olaoye (2004).

Fig. 1 showed the major components and arrangement of a specific type of threshing unit that was used for the simulation of threshing process. The machine characteristics, crop parameters and performance indices for operating peg tooth thresher at optimum operating conditions are presented in Table 1. These parameters were used during the computer evaluation of the performance of the thresher.

Computer programming

A computer program was developed written in VISUAL BASIC to generate predicted values for the threshing performance models of a thresher handling sorghum and rice. The established mathematical models describing the relationship among the parameters and variables affecting threshing process were presented in 2.1. These equations were used in the development of the computer programme. The machine set up during computer evaluation of the performance of the thresher was presented in Fig. 2 and 3

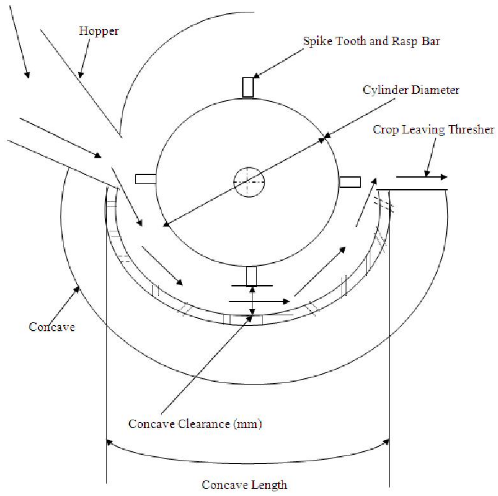

Fig. 1. Cylinder concave arrangement of a combined spike tooth and rasp bar thresher mechanism.

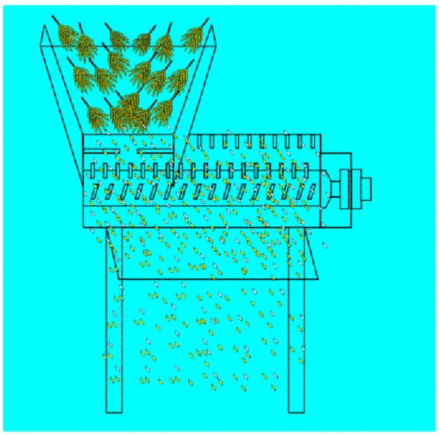

Fig. 2. Machine setup showing damages due to inappropriate threshing conditions.

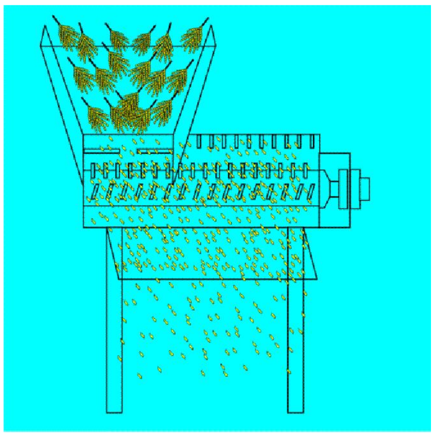

Fig. 3. Machine setup showing grain discharge during threshing at appropriate conditions.

The performance modeling equations and the modeling thresher shown in Figs 2 and 3 are the representative version of the threshing process. During the process of the simulation, the display of Fig. 2 at the run of the program indicates the presence of white grain particles at the discharge outlet together with the other grain particles showed that the sets of either chosen crop conditions or the machine parameters adversely affect the machine performance. The display of Fig. 3 indicates the sets of chosen crops and machine parameters that represented thresher performance generated at or near optimum conditions. The simulation process follows the steps highlighted in the flow chart in Fig 4. The source code is with the authors.

The main form for the simulation of the threshing performance is shown in Fig 5. The validation of the simulation process and the predicted values of the models developed were determined to obtain how the results obtained from the simulated thresher compare with the observed performance. Fig. 6 presents a typical form for the computation of the simulation process by using one of the threshing models as presented in section 2.1.

Computer applications, testing and model validation

The program was designed to assess the effects of machine variables and crop parameters on the performance of a stationary grain crops thresher. The major indices that were used in the programme include energy required to detached grain, grain operation and threshing operation and threshing efficiency. The values presented in Table 1 were used to evaluate the machine operation. The variables associated with the computations were displayed and the results are stored in the data base provided. The results from the performance evaluation of the thresher can be used to establish ranges for computations and to classify the performance indices so as to be able to know the optimum operating conditions for various crops.

To test and validate the data generated from the computer simulation, data were also generated from the IITA popularized multi crop thresher for the validation of the performance models. Rice and sorghum crops were collected and specific weights were measured using a meter balance with 0.01g calibrations. The dwell time measurement was taken using the method described by Olaoye (2004). An automatic controlled stop watch was used for the measurement of time taken for the threshing of grain crop inside the threshing drum. The clock was an integral part of an optical sensor using (photo diode). A PND Gelger Tachometer was used to determine the speed of the rotating cylinder of the thresher. Grain loss was evaluated in term of fraction of damaged grains and fraction of unthreshed head in percentages following the definition in (NSAE/NCAM/SON, 1995) as presented in equations 11 and 12.

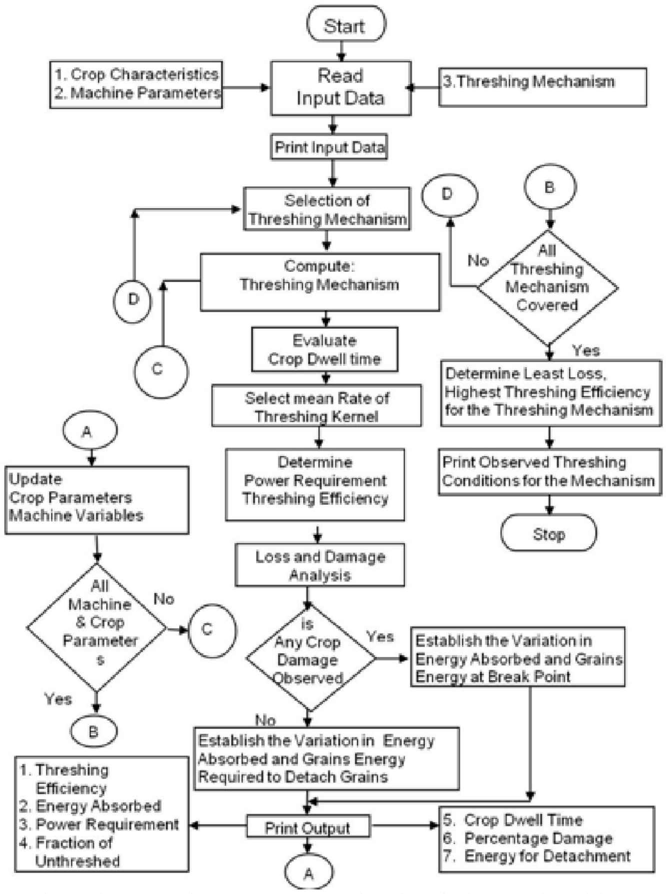

Fig. 4. Flow chart for the program for the simulation of threshing process.

Grain loss evaluation

Grain loss was evaluated in term of fraction of damaged grains (%) and fraction of unthreshed head (%). Fraction of damaged grains and fraction of unthreshed head was evaluated using the definition in (NSAE/NCAM/SON, 1995) as presented in equations 11 and 12.

$$F_{dg} = \frac{Q_b}{Q_T} x\,100 \quad \text{..} (11)$$

$$F_{ug} = \frac{U_T}{Q_T} \; x \;\; 100 \quad \text{..} (12)$$

Where: F_{dg} = fraction of damaged grain,
F_{ug} = fraction of unthreshed grain
Q_b = quantity of broken grain in sample (g)
Q_T = Total grains in sample (g),
U_T = Total unthreshed heads in sample (g)

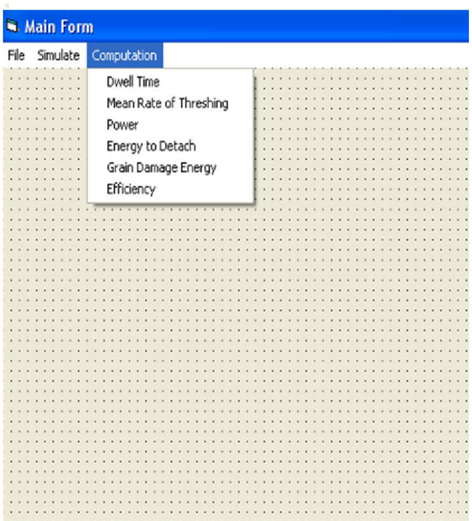

Fig. 5. Main form for the simulation of threshing performance.

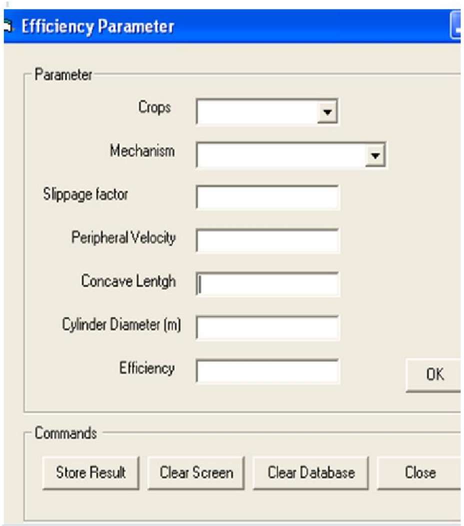

Fig. 6. Form for the determination of threshing efficiency of the simulated model.

Evaluation of threshing efficiency

Equation 13 was used for the evaluation of threshing efficiency (NSAE/NCAM/SON, 1995).

$$\eta_T = 100 - \frac{Q_u}{Q_T} x \ 100 \quad (13)$$

Where: η_T = Threshing efficiency
Q_U = Quantity of unthreshed grain in sample

The results generated by the predicting models were compared with the measured data. The comparison was to determine how well the predicting models fit and statistical significance test were used following the procedure described by Obi (1986) and Snedecor and Cochran (1980) respectively. Measured data from the IITA grain crop thresher using sorghum and rice were used to validate the performance models. The values of the associated constants and coefficients were presented in Table 2. These values were used in the simulation of the threshing processes as presented in the computer programming. The obtained results from the computer simulation were compared with the experimental investigation using IITA multicrop thresher. The computed values of the machine performance indices were represented by the results that were generated from the computer programming version of the threshing process. The graphs of measured values against predicted data for all the models were presented. The line of best fit and the coefficient of determination R^2 were used to measure how well the regression equation fits the data. The simulated results of each performance models obtained at variable cylinder speed V_F were used to compare values of each of the performance parameters obtained from experimental results.

Results and discussions

The results of the comparison of the value of grain dwell time, threshing efficiency and total grain loss due to unthreshed fraction and damaged crop were made between the predicted from computer simulation and from data that were obtained using the multicrop thresher for threshing sorghum and rice. The detailed results were presented in Tables 3 to 7. The graphical illustration of the relationship between the predicted and the measured results were presented as Figures 7 to 10. The R^2 value of goodness fit and its significance level respectively for each of the compared performance parameters were evaluated. The calculated R^2 and "t" value for each of the compared performance parameters at $P< 0.01$ and $P< 0.05$ level of significances were presented.

The validity and effectiveness of modeling equations in computer simulation is related to the appropriateness of the values of the undetermined constant that were present in the modeling equations (Isaacson, 1975 and Menasca *et al.*, 1994). The results generally revealed that the regression coefficient obtained from regression lines of various models are between 0.90 and 0.99 at 0.05 level of significance. The coefficients of determination of the modeling equations are all statistically significant at 5% level of probability, the high values of the coefficients of the determination show that the regression lines fit the data points adequately.

Table 2. Estimated values of K_e and K_s (constants and coefficients) for different grain crops and threshing mechanisms, respectively.

Types of Grain Crop	Values K_e, K_s and $K_r = K_s K_e$ for Various Threshing Mechanisms							
	Rasp Bars $K_s = 0.7$		Spike Tooth $K_s = 0.35$		Beater Bars $K_s = 0.5$		Wire Loop $K_s = 0.25$	
	K_e	$K_s K_e$	K_e	$K_s K_e$	K_e	$K_s K_e$	K_e	$K_s K_e$
Rice	0.90	0.630	0.90	0.315	0.90	0.450	0.90	0.225
Sorghum	0.26	0.182	0.26	0.091	0.26	0.130	0.26	0.065
Millet	1.42	0.994	1.42	0.497	1.42	0.710	1.42	0.355

Table 3. Threshing efficiency of an IITA multi-crop thresher for threshing of grain crops at four levels of moisture content and four levels of threshing speeds; in a split-split-unit design with crop types (C) as main unit, moisture content levels (M) as sub unit and speed of threshing (S) as sub-subunit factors with two replications.

Moisture Content (% wb)	Threshing Efficiency (%)							
	S1		S2		S3		S4	
	Rep I	Rep II	Rep I	Rep II	Rep I	Rep II	Rep I	Rep II
	Crop Types (C1, Sorghum)							
M1	74.2	75.0	76.2	77.4	78.8	80.0	84.0	86.2
M2	76.4	78.6	80.2	82.6	84.0	84.4	88.4	90.1
M3	90.2	91.3	93.4	94.5	95.6	96.5	97.6	98.1
M4	94.5	94.6	96.4	96.3	98.0	98.0	98.6	98.7
	Crop Types (C2, Rice)							
M1	80.5	80.2	85.6	82.4	84.1	86.2	84.0	88.6
M2	81.3	82.2	84.7	83.3	86.4	85.0	87.2	86.2
M3	86.2	84.4	87.4	87.6	88.8	88.4	90.3	90.4
M4	86.6	84.8	88.1	88.2	88.6	90.4	90.4	90.8

Table 4. Un separated fraction of grain crops threshed under four levels of moisture content and four levels of threshing speeds; in a split-split-unit design with crop types (C) as main unit, moisture content levels (M) as sub unit and speed of threshing (S) as sub - subunit factors with two replications.

Moisture Content (% wb)	Fraction of Un separated Grains from Discharged Grains (%)							
	S1		S2		S3		S4	
	Rep I	Rep II	Rep I	Rep II	Rep I	Rep II	Rep I	Rep II
Crop Types (C1, Sorghum)								
M1	28.78	29.86	30.39	31.67	34.18	34.59	42.86	43.12
M2	21.45	21.57	22.15	23.89	24.10	27.27	36.41	38.79
M3	7.69	9.70	11.49	12.16	17.51	17.55	19.83	28.76
M4	31.40	35.87	37.35	38.92	41.75	44.30	53.66	46.42
Crop Types (C2, Rice)								
M1	40.76	41.50	42.35	49.39	77.43	77.48	81.82	88.48
M2	28.30	32.75	32.95	45.24	55.16	59.88	70.59	84.21
M3	12.53	16.81	25.25	33.33	41.38	53.47	57.41	63.71
M4	43.64	48.27	54.76	52.26	78.48	78.94	82.80	98.68

Table 5. Observed visible damage during threshing of grain crops threshed at four levels of moisture content and four levels of threshing speeds; in a split-split-unit design with crop types (C) as main unit, moisture content levels (M) as sub unit and speed of threshing (S) as sub - subunit factors with two replications.

Moisture Content (% wb)	Visible damage (%)							
	S1		S2		S3		S4	
	Rep I	Rep II	Rep I	Rep II	Rep I	Rep II	Rep I	Rep II
Crop Types (C1, Sorghum)								
M1	1.85	1.39	1.84	1.93	2.20	2.10	2.41	2.95
M2	2.00	2.01	1.92	2.37	2.50	2.44	2.72	2.67
M3	2.09	2.11	2.82	3.74	5.13	4.05	7.57	6.70
M4	2.18	2.21	3.98	3.92	5.23	4.80	8.08	8.46
Crop Types (C2, Rice)								
M1	1.11	1.12	1.38	1.46	1.51	1.56	1.69	1.62
M2	1.45	1.48	1.63	1.72	1.76	1.73	1.80	1.84
M3	2.10	1.79	2.24	2.28	2.94	2.93	4.64	4.77
M4	2.35	2.25	2.63	2.67	3.57	3.91	5.36	5.26

Table 6. Measured crop dwell time within threshing mechanism for threshing grain crops at four levels of moisture content and four levels of threshing speeds; in a split - split - unit design with crop types (C) as main unit, moisture content levels (M) as sub unit and speed of threshing (S) as sub - subunit factors with two replications.

Moisture Content (% wb)	Crop Dwell Time per kilogramme of Grain (s)							
	S1		S2		S3		S4	
	Rep I	Rep II	Rep I	Rep II	Rep I	Rep II	Rep I	Rep II
Crop Types (C1, Sorghum)								
M1	6.80	6.40	5.60	5.40	5.00	4.80	4.40	4.00
M2	6.00	6.00	5.00	4.80	4.40	4.00	3.80	3.80
M3	3.80	3.60	3.20	3.00	2.60	2.40	1.60	1.50
M4	4.20	4.80	4.10	3.80	3.20	3.20	2.20	2.10
Crop Types (C2, Rice)								
M1	10.00	10.20	8.40	8.20	6.40	6.80	5.40	5.20
M2	8.20	9.00	7.40	7.20	5.50	5.40	4.80	4.80
M3	6.40	6.40	4.80	4.30	3.00	3.20	2.40	2.60
M4	7.00	7.20	5.30	5.10	3.40	3.60	3.00	3.20

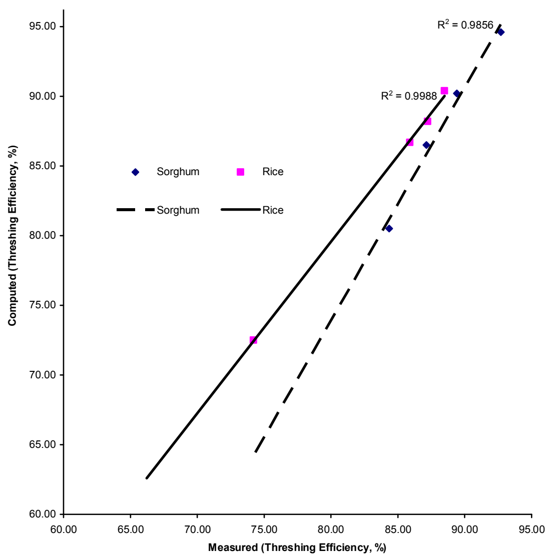

Fig. 7. Computed versus measured threshing efficiency during threshing of sorghum and rice.

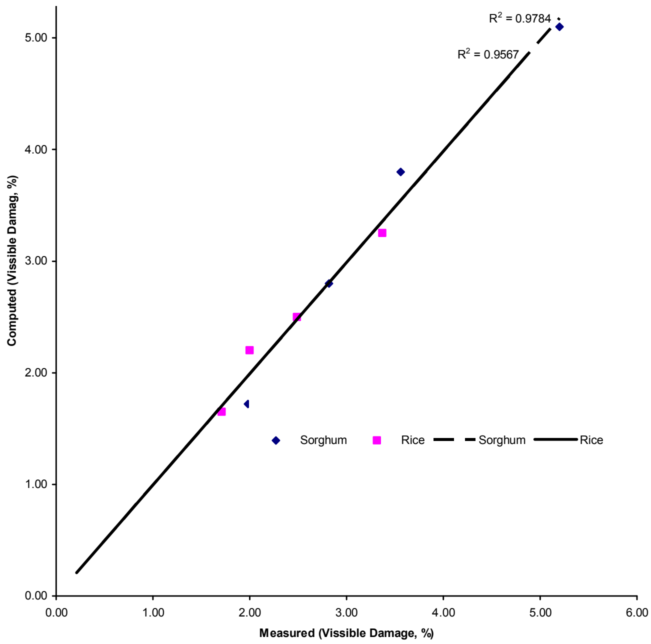

Fig. 8. Computed versus measured visible damage for threshing of sorghum and rice.

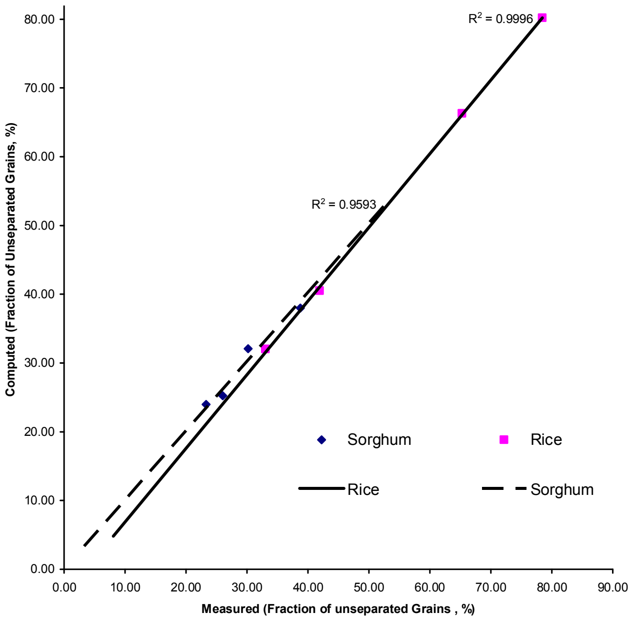

Fig. 9. Computed versus measured fraction of unseparated grains from discharged outlet for threshing of sorghum and rice.

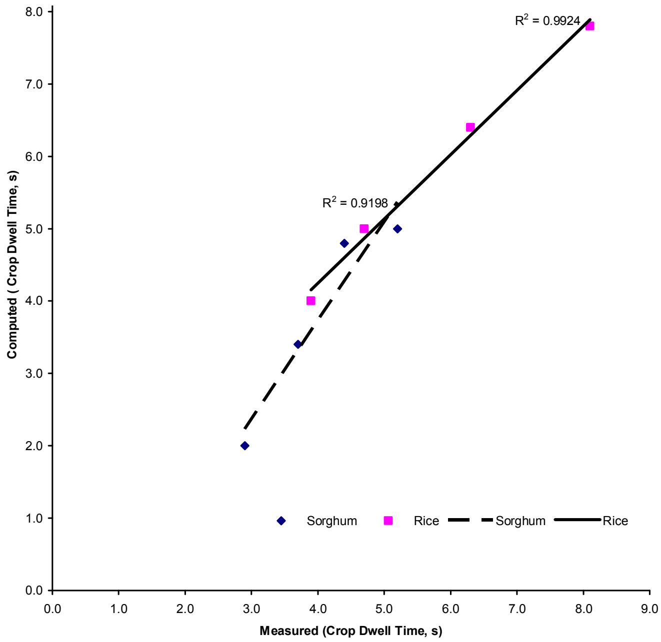

Fig. 10. Computed versus measured crop dwell time during threshing of sorghum and rice.

The modeling equations were adopted to describe the threshing processes. The output of the computer simulation using the modeling equations had shown high level of correlation with the observed results of the thresher performance with an IITA popularize thresher that was used for the validation of the simulated results. The compared results generally revealed that the regression coefficient obtained from regression lines of various models were between 0.09 and 0.99 at 0.05 level of significance. The results showed the R^2 values for the computed against predicted threshing efficiency for sorghum and rice as 0.985 and 0.998, respectively. The performance modeling equations and the modeled thresher were used dynamically to observe machine performance by following changes in the machine parameter and crop characteristics. The applications of the simulated computer programme have indicated that the models can be used as a guide for the design of multicrop thresher for optimum operating performance. The simulated programme can be used to analyse the various input combinations of crop and machine variables for optimum thresher performance.

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Table 1. Performance of different threshers for threshing grain crop under optimum operating conditions.

S/n	Type of Cylinder	Crop	Cylinder Speed	Concave Clearance	Crop Parameter	Cylinder Dimension	Performance Index	Threshing Capacity	Feed Rate	Power Source	Source
1	Raspbar	Sorghum	400 rpm (10.5 m/s)	7.0 mm	Gs = 4.33 mm G:S = 1:3 d = 0.22 g/cc ar = 33 ^{o} ai = 32 ^{o} Mc = 16.2 %	D = 480 mm L = 640 mm	T_e = 98.3 % C_e = 97.2 % Gd = 1.12 % Sl = 3.8 % G = 85.3 %	33.2 q/h	6 kg/min (360 kg/h)	4.95 kw Electric motor	Desta and Mishra (1990)
2	Tooth Peg	Chick pea	580 rpm (14.6 m/s)	30 mm	Yd = 517 kg/ha Mc = 14.2 %	D = 480 mm L = 640 mm	T_e = 93.0 % Gd = 2.2 % Ml = 9.1 %	190 kg/h	430 kg/h	5.7 lit/h Gasoline engine	Anwar and Gupta (1990)
3	Tooth Peg	Multi crop Wheat, Sorghum, & Paddy Maize	(12.8 m/s) (10.5 m/s) (16.5 m/s) (15.0 m/s)	25 mm 35-45 mm 20 mm	Mc = 20.2 % Mc = 16.2 % Mc = 15.5 % Mc = 14.6 %	D = 480 mm L = 640 mm D = 235 mm L = 830 mm	T_e = 99.0 % Gd = 2.0 % 4.0%	276 kg/h Wheat 200 kg/h Sorghum 392 kg/h Paddy	500 kg/h 450 kg/h 550 kg/h 500 kg/h	5.0 hp Electric motor	Majundar (1985), Joshi (1981)
4	Tooth Peg	G.nut	400 rpm (6.3 m/s)	25.00 mm	Mc = 12.0 %	D = 300 mm L = 1220 mm 61 pegs	C_e = 95 % Gd = 3 % Sl = 6 %	264-367 kg/h		Tractor PTO	Zafar, *et al.* (1997)
5	Tooth beater	Millet	800 rpm (9.8 m/s)	6 mm	Mc = 12.0 % ar = 13.95 ^{o} d = 798 g/cc Gs = 3.9 mm	D = 235 mm L = 830 mm	T_e = 96.8 % Gd = 1.3 % Sl = 4.5 %		385 kg/h	2.24 kw Electric motor	Ndirika (1993)

Gs = Grain Size; G:S = Grain to Straw Ratio; d = Bulk Density; ar = Angle of Repose; ai = Angle of Internal Friction; D = Cylinder Diameter; L = Cylinder Length;

T_e = Threshing Efficiency; C_e = Cleaning Efficiency; Gd = Damaged Grain; Sl = Sieve Loss; G = Germination Rate; G.nut= Groundnut; Mc = Moisture Content (wet basis);

Bl = Blower Loss; Yd = Yield; Ml = Machine loss; wb = wet basis.