

A SIMULATION OF OPTIMUM POWER REQUIREMENTS OF SELECTED GRAIN THRESHERS

Ndirika V.I.O.¹

Abstract

A power requirement model was simulated at three factor interaction of process variables in order to select a combination of optimum crop and machine variables (crop moisture content, feed rate, cylinder speed) that will yield minimum grain losses for millet and sorghum threshers. The viability of the model was demonstrated in selecting minimum grain loss for various combinations of process variables and power requirement. Result obtained from the simulations revealed that a minimum grain loss of 0.09% was obtained for millet thresher and 0.35% for the sorghum thresher at 9% grain moisture content, 5m/s cylinder speed, and feed rate of 0.03 kg/s. The power requirements obtained at these levels were 2.5kW and 4.6kW for millet and sorghum threshers, respectively. This compares well with actual measurements using the same values of the parameters with a minimum grain loss of 0.10% for millet and 0.46% for sorghum threshers, at 2.45kW and 4.5kW power requirements for millet and sorghum threshers respectively.

1. Introduction

One of the purposes of modelling a physical system is to be able to better understand the fundamental mechanisms of that system and to establish optimum conditions for the construction and operation of the system for improved efficiency. Optimum conditions are those that produce the most favourable or most beneficial result from a system (Gajda and Biles, 1979). The interest in application of modern optimization technique is primarily due to development of modern computers that help in achieving greater efficiencies by making it easier to develop software packages that can optimize a physical system.

Results of widely used techniques have previously been presented by Levi and Vol (1966); Biles and Swain (1980). From their work, the schemes by which optimization techniques can be classified are: number of independent variables; derivative or numerical methods and constrained or unconstrained problem. These considerations give rise to several different approaches to optimization.

Obtaining optimum parameters in a threshing process using modelling technique can provide better understanding of the fundamental relationships of the different machine and crop variables in order to identify the contribution of each variable. This can be achieved by the use of predicting equations to identify the independent variables (moisture content, feed rate and cylinder speed) in the order of their contributions to the total variation on the dependent variables such as power requirement. This information could be useful in assessing the relative importance of various factors influencing the dependent variables.

Ndirika *et al.* (1996) developed a mathematical model for predicting power requirement of a selected stationary grain thresher. The model was validated with experimental results from stationary grain thresher. From the results, it was found that the model correlates well with

¹Department of Agric. Engineering, Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria

experimental data. However, there is still the need to optimize the model in order to obtain optimum values of the independent variables at minimum grain loss for millet and sorghum threshers.

The specific objective of this study was to obtain the power requirement for optimum model parameters that can yield minimum grain losses for millet and sorghum threshers using a minimization technique.

2. Materials and methods

The cylinder-concave arrangement of spike tooth thresher under consideration is presented in Figure 1. The model used for this study was that developed by Ndirika *et al.* (1996) for predicting power requirement of stationary spike tooth grain threshers of a throw-in feed system.

2.1 Brief model description

The determination of power requirement (P) in the model is based on the concept of Buckingham's Pi theorem (Ndirika, *et al.* 1996) as given by Equation 1:

$$P = K_f F_r V_b^2 + K_h [(V_b F_r)^3 (1 - \beta) / \rho_d L_c^2]^{1/2} + 2\pi M_c \gamma N (g' + 2V_b^2/D) / 60 \quad (1)$$

Where;

K_h	=	Energy constant
K_f	=	Friction power constant
ρ_d	=	Dry bulk density of crop, kgm^{-3}
N	=	Cylinder speed, rpm
γ	=	Radius of the driven pulley of the cylinder, m
V_b	=	Peripheral velocity of the beaters, ms^{-1}
D	=	Effective diameter of the cylinder, m
L_c	=	Concave length, m
g	=	Acceleration due to gravity, ms^{-2}
β	=	Moisture content of crop
F_r	=	Feed rate, kgs^{-1}
M_c	=	Mass of threshing cylinder, kg

The constants K_f and K_h in Equation 1 and K_T (threshing constant) and K_d (damage constant) in Equation 2 were determined by the use of least squares method using data from available literature (Gurama, 1977; Wagami, 1979). The values of the constants used in computing the power requirement and total grain loss, TGL (Equation 2) for millet and sorghum are presented in Table 1.

$$TGL = \exp[-1.5K_T \rho_d D V_b L_c / (1-\beta) F_r] + \exp[-0.46K_d \rho_d D V_b L_c / (1-\beta) F_r] \quad (2)$$

Table 1: Values of constants

S/No	Constant	Value
1	K_T	0.0021
2	K_f	0.06
3	K_h	0.36
4	K_d	0.00794

2.2 Formulation of Optimization Function

The method used in the optimization is based on the procedure presented by Smith *et al.* (1970) and this has the following two characteristics:

- i. an objective function stating the quantity to be minimized or maximized and its functional dependence from design variables; and
- ii. constraints on the design variables under which an optimum is to be searched, expressed mathematically as in Equation 3 (Ndirika, 1997):

$$\text{Optimize } Y_o = g_o (X_1, X_2, \dots, X_n) \quad (3)$$

subject to: $a_o < X_i < b_i$; and $i = 1, 2, 3, \dots, n$

Where;

- Y_o = objective function
- g_o = some relationship between Y_o and X :
- X_i = design variables
- a_o, b_i = lower and upper bounds respectively.

For this study, the objective function considered was the minimization of grain loss. A measure of *TGL* was obtained using the total grain loss relation developed by Ndirika, *et al.* (2000):

The design variables used in the optimization are feed rate (F_r), cylinder velocity (V_b) and moisture content (β). The lower and the upper limits of the design variables which are incorporated as constraints for the different moisture levels are as follows:

For the millet thresher,

- i. $0.03 \leq F_r \leq 0.07$
- ii. $3.40 \leq V_b \leq 5.0$
- iii. Moisture content levels: 9, 12 and 14%

For the sorghum thresher,

A simulation of optimum power requirement for selected grain threshers

- i. $0.03 \leq F_r \leq 0.07$
- ii. $4.0 \leq V_b \leq 5.12$
- iii. Moisture content levels: 9, 12 and 14%

The optimum values were computed using the computer programming flowchart presented in Figure 2. A maximum grain loss of 5% was selected in the optimization process. Experimental data for the millet and sorghum threshers were used for the computations using 3 factor levels of variable combination. The cylinder and concave data for millet and sorghum threshers used for the optimization are contained in Table 2, while the operating conditions for these threshers are presented in Table 3.

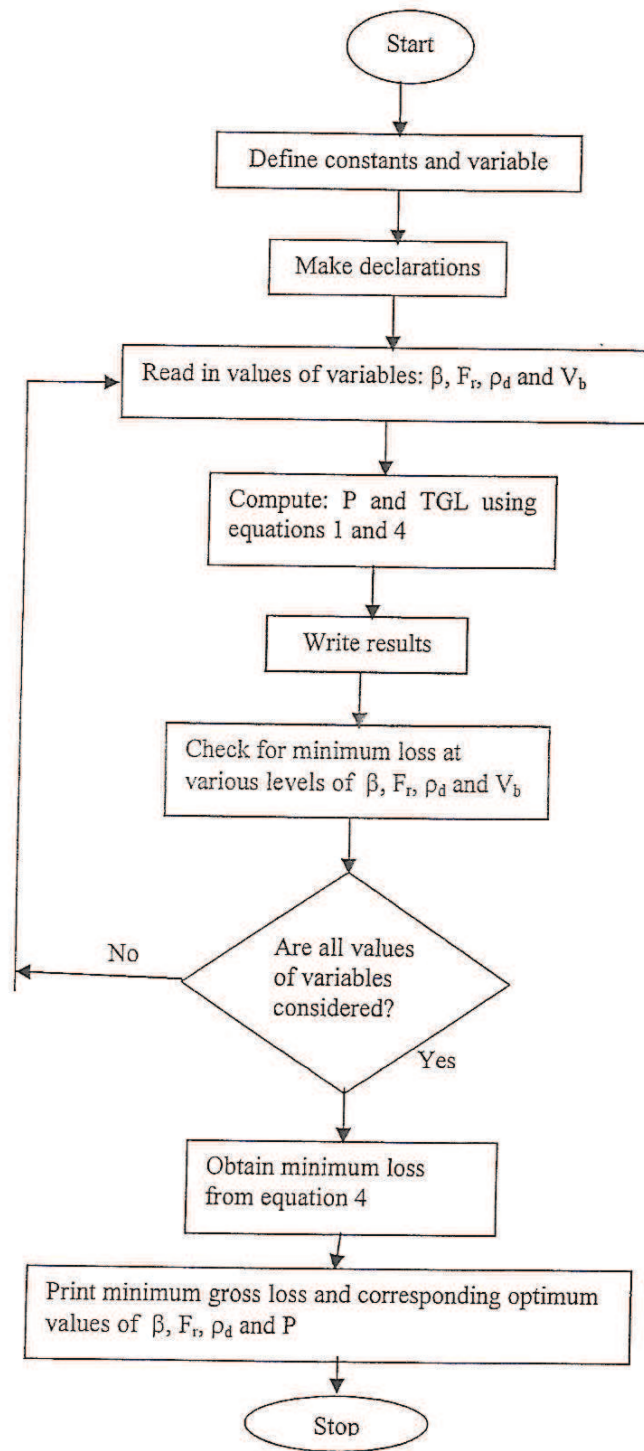


Figure 2: Flow chart for optimization simulation programme for millet and sorghum threshers

Table 2: Cylinder and concave data for millet and sorghum threshers

S/No	Parameter	Dimension	
		Millet thresher	Sorghum thresher
1	Effective cylinder diameter, D (m)	0.350	0.50
2	Concave length, L_c (m)	0.360	0.48
3	Cylinder concave clearance (m)	0.006	0.011
4	Radius of driven pulley (m)	0.058	0.01
5	Cylinder width (m)	0.820	0.45
6	Mass of threshing cylinder, M_c (kg)	2.5	7.0

Table 3: Crop and operating conditions for millet and sorghum threshers

Parameter	Levels	
	Millet thresher	Sorghum thresher
Feed rate, F_r (kgs^{-1})	0.03, 0.05, 0.07	0.03, 0.05, 0.07
Cylinder speed, V_b (ms^{-1})	3.40, 3.85, 4.65, 5.0	4.0, 4.45, 4.49, 5.12
Moisture content, β (%)	9, 12, 14	9, 12, 14
Bulk density, ρ_d (kgm^{-3})	62.12, 82.83, 102	22.80, 30.92, 42.20
Crop variety:	<i>Ex-Borno</i>	<i>Farafara</i>
Power of prime move used (kW)	3.7	5
Acceleration due to gravity of crop, g (ms^{-2})	10	10

2.3 Experiments

Minimum grain loss (*MGL*) and power requirement obtained from the simulations were compared with those from the millet and sorghum threshers using the optimum parameters. Moisture content of millet and sorghum were determined by oven drying at a temperature of 130°C for 18 hours (ASAE, 1972). Bulk density was determined by weight – volume method, while speed was measured using a tachometer. Two wattmeters (0 - 4,800 and 0 - 12,000 W rating) were used for measuring the power requirements for the millet and sorghum threshers respectively.

Total grain loss was obtained by adding the functions of the broken grains and the unthreshed heads. The percentage of grain damage was evaluated using Equation 4 (Ndirika, 1994):

$$\text{Grain damage (\%)} = (Q_b/Q_T) \times 100 \quad (4)$$

Where;

Q_b = Quantity of broken grain in sample, kg

The percentage of unthreshed heads was evaluated using Equation 5 below:

$$\text{Unthreshed head (\%)} = U_T/Q_T \times 100 \quad (5)$$

Where;

U_T = Total unthreshed heads in sample, kg

3. Results and discussion

3.1 Millet thresher

Minimum grain loss increases with increase in crop moisture content for both simulated and measured results, but the minimum grain loss obtained from measured result was higher than that obtained from simulated for the millet threshing (Figure 3).

The optimum power requirements and corresponding grain loss as obtained from simulation and the experiment are presented in Table 4. It is observed that the moisture content has no significant effect on power requirement. The study also reveals that the minimum grain loss obtained by simulation for this thresher with the optimum parameters (moisture content, cylinder speed and feed rate) and power requirement agreed well with the measured values (Figure 3). Since all the values of minimum loss obtained at the three levels of moisture content are less than the tolerable value (5%), it then implies that threshing at those three levels is adequate.

Table 4: Optimum parameters and power requirement corresponding to minimum grain losses for millet thresher

β (%)	V_b (ms ⁻¹)	F_r (kgs ⁻¹)	P (kW)		MGL (%)	
			Simulated	Measured	Simulated	Measured
9	5.0	0.03	2.5	2.45	0.085	0.10
12	5.0	0.03	2.5	2.45	0.273	0.32
14	5.0	0.03	2.5	2.45	1.230	1.33

P = Power requirement
 MGL = Minimum grain loss
 β = Moisture content
 V_b = Cylinder speed
 F_r = Feed rate

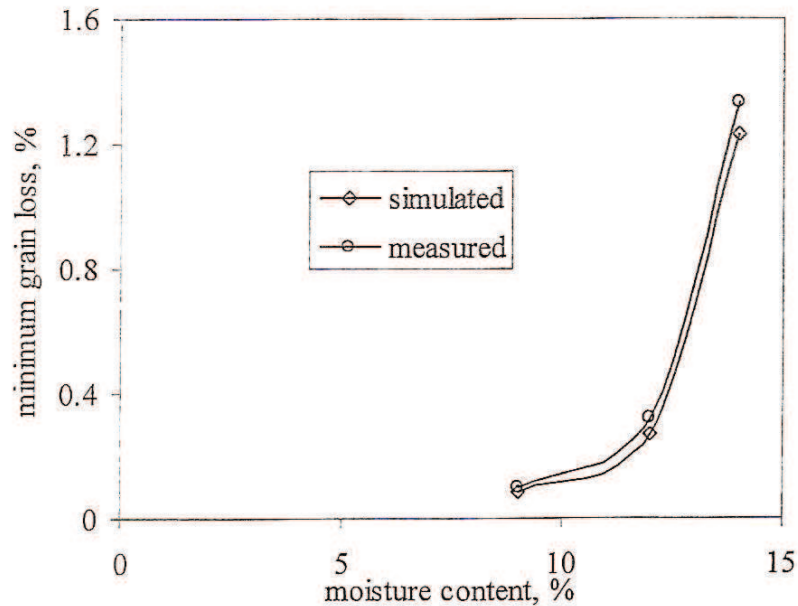


Figure 3: Variation of minimum grain loss with moisture content for millet thresher

3.2 Sorghum thresher

For the sorghum thresher also, the minimum grain loss increases with crop moisture content for both simulated and measured results. The minimum grain loss obtained with measured values was higher than that obtained with simulated at 9 and 12% moisture contents but less than simulated at 14% moisture content. This could be due to the fact that the moisture content obtained with simulated result (5.17%) was slightly above the tolerable value (5%).

The threshing operations at this moisture content might not be favourable because the crop is sensitive to high moisture content.

The optimum power requirements and corresponding grain losses obtained from simulation and experiment are presented in Table 5. From the table, the optimum feed rate, cylinder velocity and moisture content obtained were 0.03 kgs⁻¹, 5.12 ms⁻¹ and 9% respectively. The power requirement of the thresher obtained at these values was 4.6 kW. It was observed that moisture content has no effect on the power requirement, but affected only the minimum grain loss. The result also reveals that there was good agreement between simulated and measured values for both minimum grain loss (*MGL*) and power requirement as shown in Figure 4.

Table 5 Optimum parameters and power requirements corresponding to minimum grain losses for sorghum thresher

β (%)	V_b (ms ⁻¹)	F_r (kgs ⁻¹)	P (kW)		MGL (%)	
			Simulated	Measured	Simulated	Measured
9	5.12	0.03	4.6	4.5	0.35	0.46
12	5.12	0.03	4.6	4.5	1.59	1.74
14	5.12	0.03	4.6	4.5	5.17	4.95

P = Power requirement
 MGL = Minimum grain loss
 β = Moisture content
 V_b = Cylinder speed
 F_r = Feed rate

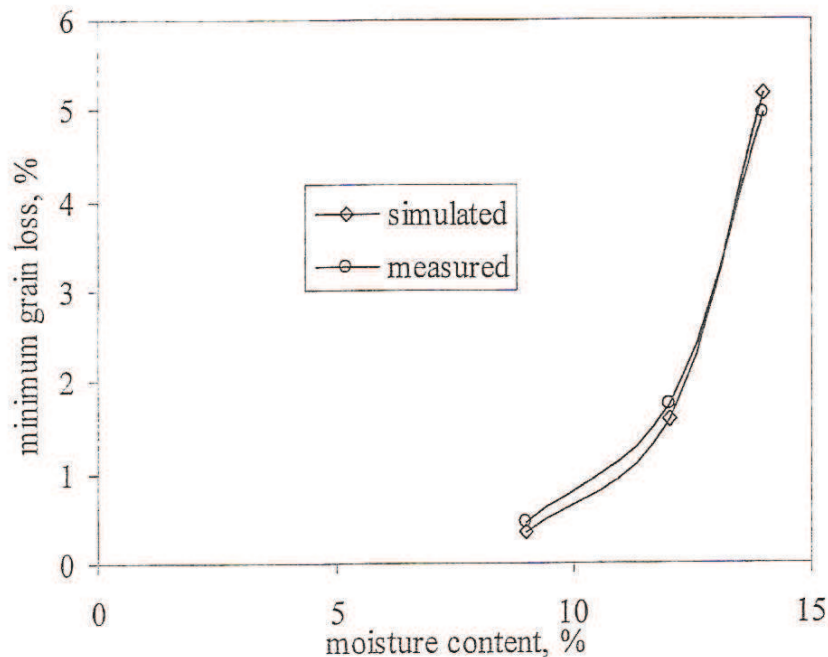


Figure 4: Variation of minimum grain loss with moisture content for sorghum thresher

4. Conclusion

The study revealed that power requirement corresponding to optimum crop and machine variables (moisture content, cylinder speed and feed rate) with minimum grain losses for millet and sorghum threshers can be achieved by simulation. The results in this study reveal that there was good agreement between simulated and measured values for both minimum grain loss (*MGL*) and power requirement. The model can therefore, be used to estimate the best crop and machine variable combinations of other grain threshers.

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