International Journal of Scientific & Engineering Research Volume 9, Issue 4, April-2018
ISSN 2229-5518

Optimization of Selected Parameters of Sorghum Threshing Unit

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Abstract— Manual methods of sorghum threshing in Kenya causes grain loss of up to 4% of total sorghum production. Optimization of selected machine parameters was conducted for a prototype sorghum thresher developed using engineering principles. The optimization was based on experiments conducted using Taguchi technique. The parameters: peg spacing, drum diameter and drum peripheral speeds were investigated. Taguchi L_9 orthogonal array was specifically selected for the experiments in order to maximize threshing efficiency and throughput per unit energy consumption and minimize grain mechanical damage. The results were subjected to signal to noise ratio analysis. Maximum threshing efficiency was attained with drum diameter of 400 mm, peg spacing of 50 mm and drum speed of 12 m s^{-1}. The maximum throughput per unit energy consumption was achieved using drum diameter of 400 mm, peg spacing of 50 mm, drum speed of 10 m s^{-1} whereas minimum grain damage was realized with drum diameter of 400 mm, peg spacing of 100 mm and drum speed of 8 m s^{-1}. The study therefore recommends threshing unit settings consisting of drum diameter of 400 mm, peg spacing of 50 mm and peripheral speed of 12 m s^{-1}.

Index Terms— Grain damage, Optimization, Signal to Noise Ratio, Taguchi Method, Threshing Efficiency, Throughput

1 Introduction

GRAIN sorghum (*Sorghum bicolor* (L.) *Moench*) is Kenya's second most important cereal crop after maze. Sorghum is used to manufacture wax, starch, syrup, alcohol and edible oils [1]. Losses occur during threshing due to incomplete removal of grains from heads and grain damage. A possible cause of this could be improper peg geometry on the threshing drum.

Damaged grains are prone to attack by fungi and reduce the grade and marketability of the grain [2}. The problem of tresing grain losses can be addressed by optimization of threshing parameters

Various methods have been employed by researchers to optimize the parameters affecting threshing performance. Salari *et al.* [3] optimized a chicken pea thresher using response surface methodology (RSM). Optimal settings were determined as cylinder speed of 10.63 m s^{-1}, concave clearance of 13.74 mm, feed rate of 240 kg h^{-1} and moisture content of 12% (wb).The optimum values of grain damage and threshing efficiency were 3 and 98.3 percent.

Singh *et al.* [4] optimized machine parameters of a pedal-operated paddy thresher using RSM. The machine performance was evaluated for optimal design parameters of wire loop spacing 39.1 mm, wire loop tip height 60.6 mm and threshing drum speed 339.46 m min^{-1}. The corresponding threshing capacity and efficiency were 64.6 kg h^{-1} and 96.4% respectively.

Mishra and Saha [5] optimized machine parameters of finger millet thresher using artificial neural network (ANN). The threshing capacity (32.4 kg h^{-1}) and threshing efficiency (98.41 %) were evaluated at its optimal design parameter settings: number of canvas strips on the drum periphery (8) and peripheral drum speed (7.97 m/s).

Wangete *et al.* [6] developed a groundnut sheller and reported an optimal throughput per unit energy consumption of 921.03 kg $h^{-1}kWh^{-1}$ at a shelling speed of 12.2 m s^{-1}, 1200 kg h^{-1} feed rate and 10 mm concave clearance using Taguchi Method.

Taguchi technique is an opimization method used to obtain product and process conditions which produce high-quality products [7]. The method helps to arrive at the best parameters for optimal conditions with the least number of analytical investigations at a lower cost than the corresponding full factorial experiment [8].

Said *et al.* [9] made a comparison between Taguchi method and response surface methodology (RSM) to optimize machining condition for aluminum silicon alloy. They found that Taguchi method required less number of experiments than RSM.

Youssef *et al.* [10] compared full factorial design, fractional factorial design and Taguchi design. They found that Taguchi design was able to reduce experiments from 288 trials of full factorial design to only 16 trials.

Taguchi technique uses two tools in optimization: orthogonal array and signal to noise ratio. An orthogonal array is a matrix of numbers arranged in rows and columns with every row representing a set of parameters for one run of the experiment. Signal-to-noise ratio is an average performance characteristic value for each experiment.

The Taguchi technique identifies three different forms of signal-to-noise ratio depending on objective of the research. The *nominal-the-better* arises when neither a smaller nor a larger value is desired. The *higher-the-better* is used if the system is optimized when the response is as large as possible while the

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smaller-the-better is used if the system is optimized when the response is as small as possible [11] . Regardless of the category of the quality characteristic used, a greater S/N ratio corresponds to better quality characteristics.

The objective of the present study was to determine optimum machine parameters for achieving maximum threshing capacity and efficiency and least mechanical grain damage using the Taguchi Method.

2 MATERIALS AND METHODS

2.1 Experimental set up

Research experiments were carried out in selected sorghum farms in Migori County. Indigenous variety of sorghum (*andiwo*) was used as test material. A digital stopwatch was used for measurement of time, digital tachometer (*DT* 6236B) to determine the speed of the drum, digital weighing balance of sensitivity 0.01 g in weight measurements and a digital wattmeter connected to the motor circuit to measure power consumption

The overall dimensions of the thresher were: length of 645 mm, width of 250 mm and height of 1040 mm. The threshing unit consists of a rotating drum and a stationary concave sieve. The threshing drum was made of galvanized cylindrical metal pipe 645 mm long through which a 25.4 mm shaft passed. Pegs were welded in a staggered helical manner on the drum. At the end of the drum shaft a double groove V belt pulley made of cast iron was mounted on the shaft driven by a three phase 2.20 kW electric motor. The concave, which had holes of diameter 10 mm, was made of perforated and rolled steel sheets with a radius of 293 mm and length of 645 mm.

2.2 Performance evaluation of the thresher

The parameters selected for conducting the optimization of the thresher were drum diameter, peg spacing and drum peripheral speed. The drum diameter of the machine was varied over three ranges 200, 300 and 400 mm. The peg spacing was also varied over three levels of 50 mm, 75 mm and 100 mm whereas drum peripheral speed levels were 8, 10 and 12 m s^{-1}.

Before the sorghum heads were released into the threshing chamber, the thresher was run empty for 15 minutes to stabilize the rotation. At each drum diameter, peg spacing and drum speed setting, sorghum heads were continuously fed to the thresher for about 20 mins. The time taken for the threshing process and the power consumption during threshing were noted. All the grains and non-grain materials at the outlets and the threshing chamber were collected.

The performance of the thresher was determined in terms of threshing efficiency, grain damage and throughput per unit power consumption as given below:

$$Threshing\ efficiency = \left(1.00 - \frac{M_u}{M_t + M_u}\right) x\ \ 100 \quad (1)$$

Where:

M_t = Mass of threshed grain
M_u = Mass of unthreshed grains

$$Mechanical\ grain\ \ damage = \frac{M_d}{M_t}\ x\,100 \quad (2)$$

Where:

M_d =Mass of damaged grains
M_t= Mass of threshed grain

$$Throughput\ \ per\ \ unit\ \ energy\ \ consumption = \frac{M_t}{p\ t} \quad (3)$$

Where:

M_t= Mass of threshed grain
p= Electric energy consumed (kWh)
t = time of test run (h)

Since it was desired to maximize the threshing efficiency and throughput per unit energy consumption, the *higher-the-better* quality characteristic was employed [12]:

$$\frac{S}{N} = -10\ \ \log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^{2}}\right] \quad (4)$$

The *smaller-the-better* quality characteristic was used to obtain minimum mechanical grain damage according to [13]:

$$\frac{S}{N} = -10\ \log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^{2}\right] \quad (5)$$

Where:

n = number of experiment replications in a trial and
y_i= ith measured output value for the trial.

Taguchi L_9 orthogonal array (Table 1) was used to optimise the factors affecting threshing performance.

Table 1: The Taguchi L_9 orthogonal array for optimization experiments

Experiment No	Control parameters		
	Drum diameter	**Peg spacing**	**Drum peripheral speed**
1	1	1	3
2	1	2	2
3	1	3	1
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	2
8	3	2	3
9	3	3	1

Experiments were conducted using the L_9 orthogonal array with 9 rows corresponding to the number of experiments as shown in Table 2.

Table 2: The optimization experimental setup

Expt No.	**Drum diameter (mm)**	**Peg spacing (mm)**	**Drum peripheral speed (m/s)**
1	200	50	**12**
2	200	75	10
3	200	100	8
4	300	50	10
5	300	75	12
6	300	100	8
7	400	50	10
8	400	75	12
9	400	100	8

5 RESULTS AND DISCUSSION

The results of the experiments are presented in Table 3 below.

Table 3: Results of optimization experiments

Expt. No.	**Drum diameter (mm)**	**Peg spacing (mm)**	**Drum peripheral speed (m s⁻¹)**	**Threshing efficiency**		**Mechanical grain damage**		**Throughput /energy consumption**	
				Mean (%)	**S/N Ratio (dB)**	**Mean (%)**	**S/N Ratio (dB)**	**Mean (kg h^{-1}) kWh^{-1}))**	**S/N Ratio (dB)**
1	**200**	**50**	**10**	94.51	59.93	5.80	-15.14	123.74	33.56
2	**200**	**75**	**8**	92.70	43.81	4.81	-13.64	97.89	31.28
3	**200**	**100**	**6**	91.00	53.46	3.00	-9.24	67.84	33.06
4	**300**	**50**	**8**	95.10	60.09	4.81	-13.45	141.91	34.54
5	**300**	**75**	**10**	95.99	58.30	4.89	-13.59	123.98	32.33
6	**300**	**100**	**6**	92.31	53.02	2.20	-6.49	75.28	33.98
7	**400**	**50**	**8**	97.01	59.67	4.30	-12.47	153.27	35.22
8	**400**	**75**	**10**	97.01	58.71	3.02	-9.30	131.52	33.13
9	**400**	**100**	**6**	93.10	53.06	1.19	-0.82	83.46	34.89

i. Threshing efficiency

The mean S.N ratio for threshing efficiency is presented in Table 4. It was found that the greatest influence on threshing efficiency was drum speed while drum diameter had the least effect. Maximum threshing efficiency was achieved with 400 mm drum diameter, 50 mm peg spacing and 12 m s^{-1} of drum peripheral speed.

Table 4: Mean S/N values for threshing efficiency

Factors	Mean S/N ratios (dB)				
	Level 1	Level 2	Level 3	Range	Rank
Drum diameter	52.1	57.5	57.6*	5.50	3
Peg spacing	59.6*	54.3	53.3	6.34	2
Drum speed	53.3	54.3	59.6*	6.36	1

* S/N values for optimum output.

ii. Mechanical grain damage

Table 5 gives mean S/N ratios for mechanical grain damage.

Table 5: Mean S/N values for mechanical grain damage

Factors	Mean S/N ratio (dB)				
	Level 1	Level 2	Level 3	Range	Rank
Drum diameter	-12.67	-11.17	-7.52*	5.14	3
Peg spacing	-13.68	-12.17	-2.76*	10.92	1
Drum speed	-5.52*	-6.59	-12.67	7.15	2

* S/N values for optimum output

Minimum mechanical grain damage was achieved with 400 mm drum diameter, 100 mm peg spacing and 8 m s^{-1} of drum peripheral speed. The greatest influence on threshing efficiency was peg spacing while drum diameter had the least effect.

iii. Throughput per unit energy consumption

Table 6 gives mean S/N ratio for throughput per unit energy consumption.

Table 6: Mean S/N for throughput per unit energy consumption

Factors	Mean S/N Ratio (dB)				
	Level 1	Level 2	Level 3	Range	Rank
Drum diameter	32.64	32.20	34.07*	1.98	2
Peg spacing	34.43*	32.20	33.98	2.23	1
Drum speed	33.06	33.56	34.07*	1.01	3

* S/N values for optimum output.

Peg spacing was found to have the greatest effect on throughput per unit energy consumption while drum peripheral speed had the least effect. Maximum grain output per unit energy consumption was achieved with 400 mm drum diameter, 50 mm peg spacing and 12 m s^{-1} of drum peripheral speed.

iv. Optimal factor levels

Table 7 gives the combination of optimal factor levels, Based on the need for higher throughput per unit energy consumption and low mechanical grain damage, combination 3 comprising 400 mm drum diameter, 50 mm peg spacing and drum peripheral speed 10 m s^{-1} was selected as the optimal factor levels.

Table 7: Factor level combination for optimum threshing performance

Combination	Optimum Factor Combinations			Responses		
	Drum diameter (mm)	Peg spacing (mm)	Drum speed (m/s)	Threshing Efficiency (%)	Mechanical grain damage (%)	Throughput/ energy consumption (kg h^{-1}) kWh^{-1}
1	400	50	12	99	5	140
2	400	100	8	93	1	84
3	400	50	12	97	4	153

Confirmation experiment was carried out at the selected optimal setting and the results of threshing efficiemcy (98%), Mechanical grain damage (5 %) and Throughput per unit energy consumption (158 (kg h^{-1}) kWh^{-1}) were in close agreement with the output at the determined optimal factor levels for the thresher.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The effect of the control variables, drum diameter, peg spacing and drum peripheral speed, threshing efficiency, mechanical grain damage and throughput per unit energy consumption of a sorghum thresher was investigated. The significance of these control parameters on the response variables was identified using the Taguchi technique.

The following conclusions are made about the performance of the sorghum thresher.

1. Drum diameter 400 mm, 50 mm peg spacing and drum peripheral speed 12 m s^{-1} were found as the optimal factor levels:
2. Among the three control parameters, peg spacing had the greatest influence on grain mechanical damage and throughput per unit energy consumption while drum diameter had the greatest effect on threshing efficiency.
3. The results from the confirmation test runs were very close to the output at the selected optimum settings and the deviation is less than 10 percent.

6.3 Recommendation

The threshing parameters should be optimized using other optimization methods such as response surface methodology (RSM) to confirm the optimal settings.

ACKNOWLEDGMENT

This work was supported in part by a grant from AfDB.

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