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Effect of Drum Diameter and Peripheral Speed on the Performance of a Sorghum Thresher

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Abstract: *Sorghum is an important crop for Kenya's food security. Kenya produced 140000 tons of sorghum in 2016 but suffered post-harvest losses of about 5000 tons during threshing. A prototype sorghum thresher was therefore fabricated to address this problem and effect of drum diameter and drum peripheral speed on the thresher performance studied. The performance tests were conducted at three levels of peripheral drum speeds (8 m s^{-1}, 10 m $s^{-1}$and 12 m s^{-1}) and three levels of drum diameter (200 mm, 300 mm and 400 mm) using a Randomized Block Design with three replications in each treatment. The results indicated that increasing drum diameter, increased threshing efficiency as well as percentage mechanical grain damaged. The throughput per unit power consumption increased with increase in speed and drum diameter. The lowest grain mechanical damage of 1.68 % was achieved at 8.0 m s^{-1} and drum diameter 200 mm. Higher threshing efficiencies were achieved with threshing drum diameter 300 mm than the 200 mm or 300 mm drums. Maximum threshing efficiency of 97.48 % was achieved using the 400 mm diameter threshing drum. The highest throughput per unit power consumption of 1568 [kg/h/ kWh^{-1}] using 300 mm diameter threshing drum at 10 m s^{-1}. The analysis of variance showed that drum diameter and drum peripheral speed significantly affected threshing efficiency, grain mechanical damage and throughput per unit power consumption at 5 % level of confidence.*

Keywords: *diameter, efficiency, sorghum, speed, throughput*

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I. Introduction

Grain sorghum (*Sorghum bicolor* (L.) *Moench*) is the world's fifth most important cereal crop after maize, rice, wheat and barley and second most important in Africa after maize. It is the dietary staple of more than 500 million people in more than 30 countries [1]. In Kenya, sorghum growing areas are mainly the drought-prone marginal agricultural areas. Kenya's sorghum production in 2016 was 140,000 tonnes [2]. Industrially, the grain is used to manufacture wax, starch, syrup, alcohol and edible oils [3]. As food, the grain is used in making fermented and non fermented porridge, *ugali*, *pilau*, traditional dishes where it is mixed with legumes. The grain has high levels of iron and zinc, hence may be used to reduce micronutrient malnutrition [4].

Threshing is the process of separating the grain from the seed panicles [5]. The process involves the loosening the edible part of cereal grain from the scaly chaff that surrounds it [6], through the application of tensile, compressive, bending and twisting forces on the grain heads [7]. Sorghum threshing in Kenya is mainly done manually. Some of the methods used include pounding in mortar with pestle, beating with clubs on the floor, beating gently with clubs in jute bags and treading under the hooves of animals [8]. These methods are inefficient, labour intensive and are characterized by high grain breakages of up to 3.5% (4900 tons) [9]. In addition, they are slow and energy consuming and often leads to low quality product due to the presence of impurities.

The traditional techniques of hand threshing cause excessive postharvest grain losses. FAO [10] reported that sorghum post-harvest losses in Kenya amount to 15% of the total production with 24% (5040 tons) occurring during the threshing and cleaning stages. This implies the need for technically efficient threshing practices.

Various configurations exist for sorghum threshing units. There has been limited study on which type of threshing unit configuration would give maximum throughput per unit power consumption, maximum threshing efficiency and minimum grain mechanical damage in a sorghum thresher. Moreover, little work has been done on the effect of drum diameter on thresher performance. Hence a gap of knowledge exists in this area requiring an in-depth study.

II. Materials And Methods

2.1 Description of the Sorghum Thresher

The sorghum thresher was fabricated as shown in Fig. 1 and research experiments carried out at the Agricultural Technology Development Centre (Nakuru) located at latitude 0^0 21' 22.2" S. longitude 36.08^0 E.

Fig. 1 *Prototype thresher*

2.2 Threshing Unit

The threshing unit of the sorghum thresher consisted of a peg tooth threshing drum and perforated concave. The threshing drum consisted of galvanized cylindrical metal pipe 645 mm long through which a 25.4 mm shaft passed. The drum had an effective diameter of 400 mm. Fourteen pegs of side 10 mm by 15 mm were welded in a staggered helical manner on the drum (Fig. 2). The concave was 250 mm wide and 640 mm long.

Fig. 2: *Threshing drum and concave*

A concave clearance of 18 mm [12] was used in the design of the thresher and the same cylinder-concave clearance was maintained throughout the performance evaluation of the thresher.

2.3 Transmission System

At the end of the drum shaft a double groove V belt pulley was mounted on the shaft driven by a three phase 2.20 kW electric motor. The pulleys had diameters of 101.60 mm and 254 mm for the motor and drum respectively and were made from cast iron.

2.4 The Frame Assembly

The frame provides support for the threshing unit. A frame was fabricated of iron hollow section 39 mm by 25 mm. Its overall dimension was 740 mm long, 250 mm wide and 450 mm high. The bottom of the frame was about 160 mm from the ground surface.

2.5 Feeding Mechanism

The throw-in type feeding hopper was made from mild steel sheet gauge 18 and tilted to achieve easy feeding of sorghum heads to the threshing unit. The hopper was trapezoidal in shape and fed the sorghum by gravity flow. From the design consideration, the height of hopper from the ground level was chosen as 1400 mm. The hopper was designed with dimensions 600 mm by 200 mm at the top and 450 mm by 200 at the bottom with perpendicular distance of 400 mm.

A rectangular opening of length 290 mm and width 200 mm MS sheet was provided to collect the grain at bottom of concave assembly inclined at 35° to cylinder axis. The opening was about 200 mm from ground surface.

2.6 Instrumentation and Test Materials

A digital stopwatch was used for measurement of time during the performance evaluation of the machine. A digital tachometer (*DT* 6236B) was used to determine the peripheral speed of the cylinder and electronic balance of sensitivity of 0.01 kilogram was used in weight measurements. An indigenous variety of sorghum grown in Migori County, Kenya, was used for evaluation.

2.7 Test at No load

The machine was installed on level hard surface and operated at different cylinder speeds and drum diameters for 10 minutes. The machine power consumption under no-load condition was noted. A wattmeter was connected to prime mover circuit to measure power consumption at no load condition.

2.8 Test at Load

Sorghum heads harvested at a moisture content of about 20 % were sun dried until the moisture was convenient for threshing.

The performance of the thresher was determined as follows:

a. Threshing efficiency was calculated from [12]:

$$\eta_{th} = \left(1 - \frac{m_u}{m_u + m_t}\right) \qquad (1)$$

Grain M_t = Mass of threshed grain (kg)
M_u = Mass of unthreshed grains (kg)

b. Grain mechanical damage was determined as the ratio of weight of the actual damaged grains to the weight of a sample taken[13]:

$$G_d = \frac{M_d}{M_t} \qquad (2)$$

c. Throughput per unit power consumption was calculated using (3) according to [12]

$$E_P = \frac{f}{p} \qquad (3)$$

Where:
f = Feed rate (kg/h)
p = Electric power consumed (kWh)
t = time of test run (s)

Sorghum was threshed using drums of diameter 200 mm, 300 mm and 400 (Fig. 3) mm at three levels of drum peripheral speed (8.0 m s^{-1}, 10.0 m s^{-1} and 12.0 m s^{-1}). Each experiment was replicated three times with the percentage damaged grain, threshing efficiency and throughput per unit power consumption being calculated for each experiment.

Fig. 3: *Threshing drums of different diameters*

Sorghum was threshed at drum peripheral speeds of 8.0 m s^{-1}, 10.0 m s^{-1} and 12.0 m s^{-1} respectively each at three levels of drum diameter (200 mm, 300 mm and 400 mm). Each experiment was replicated three times. The percentage grain damaged, threshing efficiency and throughput per unit power consumed were calculated for each experiment.

2.9 Data Analysis

Randomized Block Design (RBD) was employed on the treatment factor replicated three times. The collected data was subjected to analysis of variance (ANOVA). Significance of the mean difference was tested by LSD and significance was accepted at 5% level.

III. Results And Discussion

Performance of the thresher was evaluated at fixed concave clearance of 18 mm at three levels of drum speeds (8 m s^{-1}, 10 m s^{-1} and 12 m s^{-1}) using three different threshing drums diameters (200 mm, 300 mm and 400 mm) (Fig. 4). The performance indicators used were threshing efficiency, throughput per unit power consumption and grain mechanical damage.

Fig 4: *Threshing operation using the prototype thresher*

Table 1 gives a summary of the results of the performance tests.

TABLE 1: Summary of the results of threshing performance

Diameter (mm)	Speed (m/s)	Threshing efficiency (%)	Grain damage (%)	Throughput /power consumed [(kg/h)/kWh]
200	**8**	96.78	1.68	1522.63
200	**10**	97.15	1.90	1530.87
200	**12**	97.36	2.21	1523.56
300	**8**	96.92	1.72	1568.04
300	**10**	97.23	2.04	1565.20
300	**12**	97.46	2.33	1552.78
400	**8**	96.97	1.79	1536.96
400	**10**	97.27	2.21	1543.51
400	**12**	97.48	2.39	1531.45

3.1 Threshing Efficiency

Fig. 5 shows the effect of variation of drum diameter on threshing efficiency. It was observed that increasing drum diameter from 200 mm to 400 mm increased threshing efficiency from 96.78 % to 96.97 %, from 97.15 % to 97.27 % and from 97.36 % to 97.48 % at drum speeds 8 m s^{-1}, 10 m s^{-1} and 12 m s^{-1} respectively.

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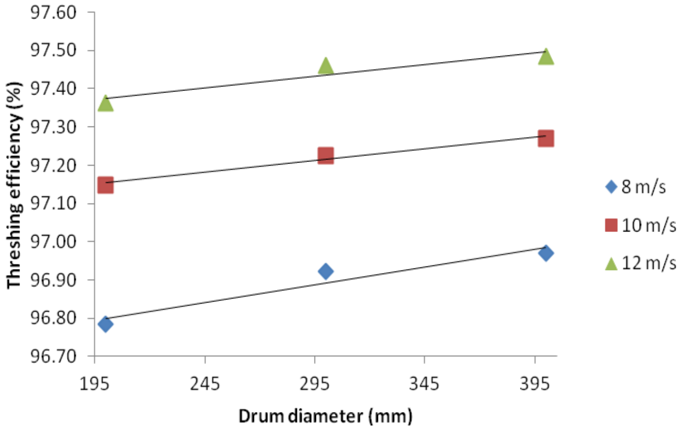

Fig. 5: Effect of drum speed on threshing efficiency

Peripheral speed of 12.0 m s^{-1} yielded the highest threshing efficiency recorded of 97.48 % with the 400 mm diameter threshing drum. The lowest value of threshing efficiency of 96.78 % was recorded with 200 mm diameter threshing drum at 8.0 m s^{-1} peripheral speed.

As the speed increases there is increase in impact with the sorghum head. Larger diameter threshing drums have longer pegs which cause more impact with the sorghum heads leading to more grains being

detached with each impact thus increasing threshing efficiency
Significance of drum diameter and drum peripheral speed in influencing overall threshing performance were determined by carrying out an analysis of variance (ANOVA) at 0.5 ($\alpha = 0.5$) level of significance on the three output parameters. The results are given in Table 2. It was found that the effect of drum diameter and drum peripheral speed were all significant on threshing efficiency ($P<0.05$). The interaction between speed and diameter was also found to be significant on threshing efficiency. Comparison among treatment means using Fischer's least significant difference (LSD) showed that for all drum diameters, the threshing efficiency was significantly different throughout. However the drum peripheral speed of 8 m s^{-1} was found to be significantly different from other two speeds of 10 m s^{-1} and 12 m s^{-1}.

TABLE 2: Analysis of Variance of the thresher performance

Source of variation	Degrees of freedom	F- value		
		Threshing Efficiency (%)	Grain mechanical damage (%)	Throughput pr unit power consumption [(kg/h)/kWh]
Replications	2			
Drum diameter (D)	2	13466.062376**	35118.7508**	37.8421*
Drum peripheral speed (S)	2	184751.570866**	314275.9663**	11.8284*
DxS	8	176.155453**	1694.0954**	0.7942^{ns}
Error	80			

** very significant * significant ns - not significant

3.2

3.3 Grain Mechanical Damage

Fig. 6 indicates that as the drum diameter was increased from 200 mm to 400 mm, the grain mechanical damage increased from 1.68 % to 1.79 %, 1.90 % to 2.21 % and 2.21 % to 2.39 % respectively for the 200 mm, 300 mm and 400 mm drum diameters. At any given speed increase in drum diameter resulted in more grain damage being realized.

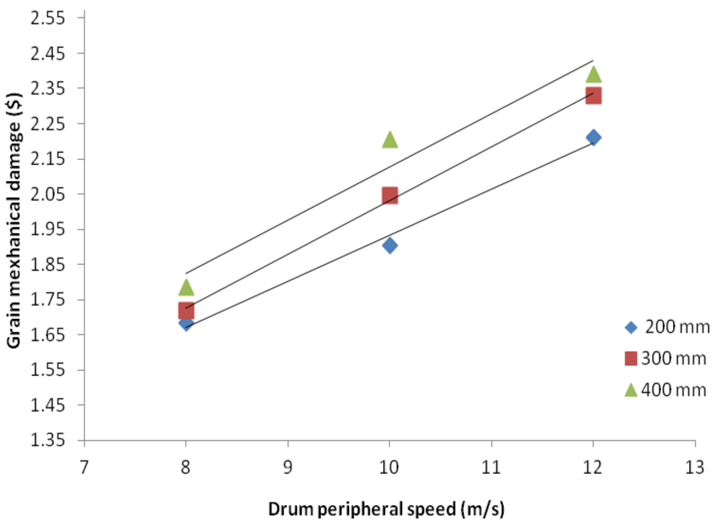

Fig. 6 *Grain damage versus peripheral drum speed at different levels of drum diameter*

At higher drum speeds the percentage of broken grains significantly increased since the peripheral speed at the tip of peg is increased leading to more impact on the grains. This impact increases with drum diameter because of increased surface area of pegs as drum diameter increases.

The analysis of variance of the main effects on grain mechanical damage indicate that both drum diameter and peripheral drum speed were significant ($P<0.05$) on grain damage from the sorghum thresher. Comparison among means using LSD showed that at all drum diameters and peripheral speeds, the percentage grain mechanical damage were significantly different from each other.

3.4 Throughput per Unit Power Consumption

Results in Figure 7 show that increasing drum peripheral speed from 8 to 12 m s^{-1} resulted in optimal throughput per unit power consumption of 1568.04 [(kg h^{-1}) kWh^{-1}], 1565.20 [(kg h^{-1}) kWh^{-1}] and 1552.78 [(kg h^{-1}) kWh^{-1}] at speeds of 8 m s^{-1}, 10 m s^{-1} and 12 m s^{-1} respectively.

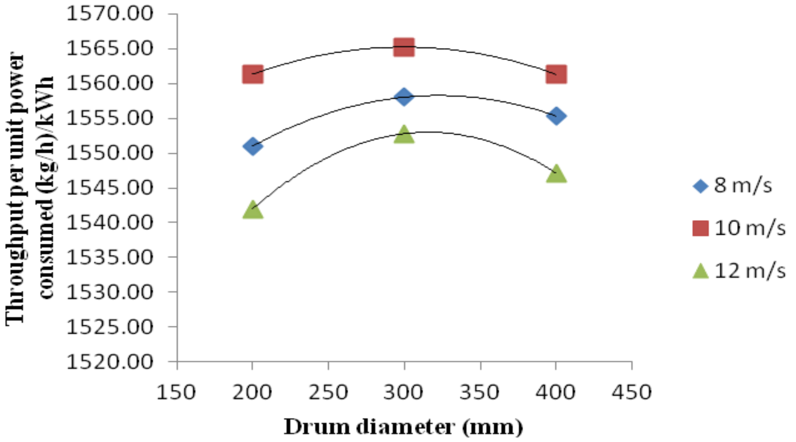

Fig.7: *Effect of drum speed on throughput per unit power consumption*

At any given speed, using threshing drum of diameter 300 mm yielded greater throughput per unit power consumption than 200 mm or 400 mm diameter drums. Also, larger diameter threshing drums have longer pegs which caused more impact with the sorghum heads leading to more grains being detached with each impact.

The forces that result in the threshing of sorghum rise with increase in drum peripheral speed. This leads to an initial increase in throughput per unit power consumption as the momentum of the pegs increase. However there is greater consumption of energy above 10 m s^{-1} leading to reduced throughput per unit power consumption.

The ANOVA of the main effects on throughput per unit power consumption shows that threshing drum diameter (D) and peripheral drum speed (S) were all significant at 5% ($P<0.05$) on throughput per unit power consumption. Comparison among means using LSD showed that at all drums diameters and peripheral speeds, the throughput per unit power consumption were significantly different. However the throughput at 12 m s^{-1} was significantly different and lower than the other two speeds of 8 m s^{-1} and 10 m s^{-1}

IV. Conclusions

Increasing drum diameter from 200 mm to 400 mm from increased threshing efficiency as well as the percentage of grain damaged. However throughput per unit power consumed increased to a maximum value using threshing drum of diameter 300 mm under for all speeds but decreased when 400 mm drum diameter was used.

It was observed that increasing drum peripheral speed from 8 m s^{-1} to 12 m s^{-1} led to increased threshing efficiency for all levels of drum diameters. Peripheral speed of 12 m s^{-1} yielded the highest threshing efficiency of 97.48 % with the 400 mm diameter threshing drum while a minimum threshing efficiency of 96.78 % was recorded with 200 mm diameter threshing drum at 8.0 m s^{-1}. Increase in drum peripheral speed increased percentage of grain mechanical damage with the lowest grain damage of 1.68 % recorded using the 200 mm drum diameter. However, threshing drum of diameter 300 mm at peripheral drum speed of 10 m s^{-1} was found efficient in using each unit of energy consumed during threshing.

Analysis of variance on the main effects found that drum peripheral speed and drum diameter were significant at 5% on threshing efficiency, grain mechanical damage and throughput per unit power consumption.

It is suggested that further research be carried out using diesel engine instead of electric motor to see if the performance of the thresher could be different.

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