An improved IAR sorghum thresher

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Abstract: Nigeria is the one of the major sorghum producing countries in the world with annual yield over Six million tons, however, threshing and cleaning of sorghum have remain serious problems to farmers due to high drudgery involve in traditional method. This shows that a little mechanization exist in post- harvest operation of such crop and affect the production. To address such problems, IAR sorghum thresher was developed at the Institute for Agricultural Research (IAR) Samaru, Zaria. Complete randomize design was used as the experimental design with three replications. The effect of the independent variable on the dependent variables was determined using ANOVA. The results showed that the moisture content is highly significance on the threshing and cleaning efficiency while their interaction was not significance at the same probability level (0.05). It was also observed that moisture content, feed rate and speed are highly significance on the throughput capacity, mechanical grain damage and scatter losses. Similarly all their interaction between the factor show similar effect.

Keywords: development, IAR, sorghum thresher

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1 Introduction

Threshing and cleaning operation is a necessary step before processing of grains into flour for domestic or industrial use. In addition annual yield evaluations by farmers are only possible after threshing operations. The by- product of threshing such as chopped straws and chaff could be accumulated in stack and be saved for future use as animal feed.

Sorghum is produced in large quantity in Nigeria up to about 6.851 million tons per year (NAERLS, 2012). It is the second largest cereal crop cultivated after maize in Nigeria (FAO, 1994), and has a great market potential for domestic and industrial uses. Sorghum can produce yield in areas where other crops may fail, because of its draught resistance qualities. It is the crop of choice for dry region and areas with unreliable rainfall. Nigeria is one of the major sorghum producing countries in the world ranking as the second largest sorghum producer in the world (USAID, 2006). Sorghums are of different varieties. Akinsoye, (1993) reported that the commonest types of sorghum varieties in Nigeria are: “Kaura”, “Farfara” and “Mori” which are grown almost across northern part of the country.

Despite the food and nutritional value of sorghum, it attracts large international and domestic demand. However, it`s threshing and cleaning have remained serious problems to the farmers (Joshi, 1981). The main problem associated with the threshing and cleaning of sorghum in Nigeria is the use of traditional methods of seed separation from stalk which are uneconomical, time consuming, injurious to the finger and fatigue associated(Mishra and .Desta, 1990). Manual threshing of sorghum is classified as heavy work load in terms of energy expenditure (Ali, 1986). Not only are these threshing techniques time and human energy consuming but also damaging to the crops kernels. The time required for threshing depends on variety, moisture content of the grain, and the method of threshing. It has been recorded

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that about 35 laborers are required to thresh about 300-400 kg/h of sorghum manually (Mishra and Desta, 1990). However, despite this drudgery and high labour intensive traditional method of sorghum threshing is widely used and account for more than 80% of the grown sorghum crop in Nigeria (FAO, 2006). Therefore these problems and others indicate the needs for the development of simple sorghum threshers that will reduce the farmers' difficulties encountered using the traditional method. The Institute for Agricultural Research (IAR) has developed a prototype sorghum thresher aimed at solving these difficulties. But yet the problems persist or exist. The main limitation of the existing IAR prototype sorghum thresher was low operating performance thus lead to low acceptability. Therefore this research work is aimed at improving its throughput capacity, mechanical grain damage and scatter losses to acceptable levels by the farmers.

2 Material and methods

2.1 Design consideration

The components of the thresher such as size of pegs were changed from round iron steel 20 to 12 mm while space between the stationary and rotational pegs of beaters and cylinder cover was reduce from 60 and 30 to 50 mm and 10 mm respectively . The number of pegs around the cylinder was increased from 4 to 6 thereby reducing the threshing time and increase throughput capacity (FAO, 1994). 5 mm was used as concave opening to ensure free passing of threshed grain to cleaning unit which aid to the increase of throughput capacity and reducing mechanical grain damage. The dimension of the hopper was chose based on the power from the prime mover as stated by Jain and Grace (2003).

2.2 Material selection

Materials of various components of the thresher were selected based strength, availability, durability and costs. Mild steel metal sheet 18 gauges was selected for the construction of feed hopper and top cylinder cover while Mild steel sheet 16 gauge was used for threshing cylinder. The shafts were made of mild steel iron (C1040). Mild steel iron rod was selected to construct spike tooth. A square mild steel bar was used to construct a concave grade. See Figure 1.

a: Rear view

b: Side view

c: Front view

Figure 1 Testing prototype

2.3 Determination of size of components

2.3.1 Estimation of concave radius, r_c

The radius of curvature r_c, was determined using the following Equation 1: given by Dangora, (2006)

$$r_c = r_d + h_p + C_c \quad (1)$$

Where:

r_c = radius of concave, mm

r_d = radius of cylinder drum, mm

h_p = peg height above the drum, mm

C_c = concave clearance, mm.

2.3.2 Calculating torque on the shaft

The torque required to thresh the sorghum was obtained as given by (Khurmi and Gupta, 2007) below Equation 2:

$$T = Fr \quad (2)$$

Where:

T = torque on the shaft, kNm

F = force require to detach the sorghum grain, kN

r = radius of the cylinder, m

2.4 Determination of power requirement

2.4.1 Power required operating the fan

This was calculated by the following Equation 3 (Korpella, 2011)

$$P_f = \frac{\rho Q g H}{\eta} \quad (3)$$

P_f = Power to be consume by the fan, kW

ρ = Mass density of air, 1.16 kg/m^3

Q = Volume flow rate, 0.671 m^3/s

g = Acceleration due to gravity, 9.81 m/s^2

H = Dynamic head, m

From Bernoulli's principle (Schobeiri, 2010), Equation 4:

$$H = \frac{v^2}{2g} \quad (4)$$

V = fluid velocity (3.73 m/s)

2.4.2 Power required to turn the unloaded cylinder

The power required to turn the unloaded cylinder was calculated by Equation 5 used by Olaoye et al, (2011).

$$P_1 = \frac{2\pi \times Nr \times Mc}{60 \times 75}\left(g + \frac{Vt^2}{r}\right) \quad (5)$$

N = speed of the threshing cylinder, 800 r/min)

Mc = Mass of threshing cylinder,13.79 kg

r = radius of cylinder,110 mm

V_t = peripheral velocity of the threshing mechanism,9.21 m/s

2.4.3 Power requirement due to air resistance

This was calculated by the following Equation 6 (Ndrika, 1997)

$$P_2 = k_f \, x \, F_r \, x \, V_t^2 \quad (6)$$

Where:

k_f = is a constant which is equal to 0.06 (Ndrika, 1997)

F_r = feed rate, 240 kg/h, V_t = as defined earlier

2.4.4 Power required to detach grain

It was calculated by the following Equation 7 (Olaoyeet al., 2011)

$$P_3 = \frac{3}{2} k_e \left(\frac{V_s^{\frac{3}{2}} f_r^{\frac{3}{2}}}{\rho \omega^2 L_c}\right) \quad (7)$$

Where:

K_e = A constant (grain size characteristics).

It is 1.42 for millet and 0.26 for sorghum, (Ndirika, 1997)

Lc = concave length,230 mm

Vs = Speed of the grain crop which is approximately equal to the peripheral velocity of the threshing mechanism in,9.21 m/s

fr = feed rate,240 kg/h

ρ_w = Bulk density (Wet basis)

Millet ρ_w= 82.83 kg/m^3 for millet at 12% moisture content

Sorghum ρ_w= 30.92 for sorghum at 12% moisture content (Ndirika, 1997)

2.4.5 Power required by shaking mechanism

The power was calculated using the Equation 8 given by Joshi (1981)

$$P_4 = \left(\frac{Ws \times N \times 2y}{4500}\right) + \left(\frac{2u \times Ws \times N \times 2x}{4500}\right) \quad (8)$$

Where:

Ws = Weight of sieve component along with threshed material,0.4 kN

u = Coefficient of friction of the moving component,0.25

x and y are horizontal and vertical displacement of the sieve,7 mm

2.4.6 Total power requirement of the thresher

$$P = P_1 + P_2 + P_3 + P_4 + P_f$$

Considering transmission and other losses a factor of safety of 1.2 was assumed.

Therefore the design power was P x 1.2

2.5 Estimation of belt tension

The belt tension was determined by the following Equation 9:

$$T = (S_1 - S_2)\, r \quad (9)$$

Where:

S_1 = tension on tight side, kN

S_2 = tension on slide side, kN

r = radius of pulley, m

T = torque on shaft, kNm

Similarly, $\frac{S_1}{S_2} = e^{\mu\theta Cosec\beta}$

Where:

μ = coefficient of friction between the pulley and the belt

θ = angle of contact between of the belt on pulley

β = ½ (angle of V- groove of the pulley)

Total belt tension $S_1 + S_2$

2.6 Shaft design

2.6.1 Condition on allowable maximum stress

The maximum allowable shearing stress using the ASME code (1948) was used to obtain the allowable shearing stress (S_s= 90.3MN/m^2).

2.6.2 Determination of shaft diameter

The determination of the shaft diameter was obtained from the ASME code relation Equation 10:

$$d^3 = \frac{16}{\pi S_s}\sqrt{(k_b M_b)^2 + (K_t M_t)^2} \quad (10)$$

Where:

M_b = bending moment, (Nm)

M_t = torsional moment, (Nm)

K_b = combined shock and fatigue factor applied to bending moment = 1.5

K_t = combined shock and fatigue factor applied for torsional moment = 1.0

S_s = allowable shear stress for shaft with keyway = 90.3 MN/m^2

d = shaft diameter, m

2.7 Experimental procedure and design

The operation started by putting on the prime mover. A batch of a weighed sorghum heads were fed into the machine through the hopper. After each operation, samples were collected at the grain outlet and non-grain outlets. Grains and non-grain materials were separated for all the samples and weight separately for further analysis to determine the significance of independent variables on dependent variables. A completely randomized design experiments (CRD) was used. A layout of 5 levels of cylinder speed (700 r/min, 800 r/min, 900 r/min 1000 r/min and 1100 r/min) by 2 levels of feed rates (3 kg/h and 5 kg/h) and five levels of moisture contents (11%, 12%, 13%, 14% and 15%) in three replications was used. Total of 50 treatments employed. The results obtained from the experiments were subjected to statistical package using SAS software to determine the effect of independent variables on the dependent variables.

3 Result and discussion

3.1 Effect of independent variables on the threshing efficiency

Table 1 shows the analysis of variance of an independent variable on threshing efficiency. From the table moisture content and replication are highly significant on the threshing efficiency while feed rate and speed are not significance at 5%. However, the interaction between those factors such as moisture content and feed rate, moisture content and speed, feed rate and speed are not significance at 5%. The same for interaction of the three factors moisture content, feed rate and speed are not significance at 5%. When the mean was subjected to Duncan range test for moisture content m_1 has the highest effect on the threshing efficiency while m_2 has the least.m_3, m_5, m_4 and m_2 are not significance. When the mean of feed rate was compared it was found that f_1 and f_2 are statistically similar i.e having the same effect on the threshing efficiency. Similarly for speeds no significance difference between their mean.

Table 1 ANOVA show the effect of independent variables on threshing efficiency

Source	DF	Anova SS	Mean Square	F Value	Pr > F
replication	2	56604.6356	28302.3178	291.47	<.0001**
moisture	4	10263.1938	2565.7984	26.42	<.0001**
feedrate	1	138.3552	138.3552	1.42	0.2355 NS
speed	4	222.8732	55.7183	0.57	0.6823 NS
moisture*feedrate	4	210.9633	52.7408	0.54	0.7044 NS
moisture*speed	16	561.9516	35.1219	0.36	0.9879 NS
feedrate*speed	4	110.4068	27.6017	0.28	0.8876 NS
moisture*feedrate*speed	16	562.7674	35.1729	0.36	0.9878 NS
error	98	9516.1481	97.1035		
Corrected total	149	78191.2954			

3.2 Effect of independent variables on cleaning efficiency

Table 2 shows the effect of independent variables on the cleaning efficiency. It can be understood that replication and moisture content are highly significance on the cleaning efficiency. The other factors (feed rate and speed) are not significance on the cleaning efficiency although their interaction shows similar scenario. The interaction between the two and three factors indicated that are not significance at 5% for different combination. Other Tables showed that m_1 are statistically significance with m_5, m_3, m_4 and m_2 while speed and feed rate have no significance different between their means.

Table 2 ANOVA showed the effect of the independent Variables on cleaning efficiency

Source	DF	Anova SS	Mean Square	F Value	Pr > F
replication	2	57005.3937	28502.6968	342.99	<.0001**
moisture	4	6286.4789	1571.6197	18.91	<.0001**
feedrate	1	12.3209	12.3209	0.15	0.7010 NS
speed	4	80.5911	20.1478	0.24	0.9136 NS
moisture*feedrate	4	58.3072	14.5768	0.18	0.9506 NS
moisture*speed	16	582.3819	36.3988	0.44	0.9683 NS
feedrate*speed	4	178.9512	44.7378	0.54	0.7079 NS
moist*feedrt*speed	16	808.7226	50.5451	0.61	0.8704 NS
error	98	8143.7503	83.0994		
Corrected total	149	73156.8982			

3.3 Effect of independent variable on throughput capacity

Table 3 presented the ANOVA result of moisture content, speed and feed rate on throughput capacity. The result indicate that there is highly significance difference for replication, moisture content, feed rate and speed at 0.05 probability level. Similarly the interactions between the factors (moisture content and feed rate and feed rate and speed) are highly significance at 0.05 while moisture content and speed are significance at 0.05. However, the interaction between the three factors shows highly significance on throughput capacity at 0.05. When the Duncan range test was carried out the result show that m_1, m_3, and $m_5$have no significance difference between their means thus, have similar effect likewise m_4 and $m_2$have similar effect. F_1 and F_2 are statistically significance while speed s_5 and $s_4$have similar effect. Similarly s_3 and $s_2$have similar effect the same with $s_3$and $s_{1.}$

Table 3 ANOVA showed the effect of independent variables on throughput capacity

Source	DF	Anova SS	Mean Square	F Value	Pr > F
replication	2	115070.8503	57535.4251	43.36	<.0001**
Moisture	4	83979.3157	20994.8289	15.82	<.0001**
Feed rate	1	13160.7287	13160.7287	9.92	0.0022**
Speed	4	78707.0944	19676.7736	14.83	<.0001**
Moisture*feedrate	4	35366.0582	8841.5145	6.66	<.0001**
moisture*speed	16	43407.5365	2712.9710	2.04	0.0172*
Feedrate*speed	4	22926.3732	5731.5933	4.32	0.0029**
moisture*feedrate*speed	16	58778.3952	3673.6497	2.77	0.0011**
error	98	130042.436	1326.9636		
Corrected total	149	581438.788			

3.4 Effect of independent variable on scatter losses

Table 4 presented the effect of independent variables on scatter losses. The replication, moisture content and speed are highly significance while feed rate was not significance at 0.05. Similarly the interaction between the two factors such as moisture content and feed, moisture content and speed are highly significance at 0.05 while feed rate and speed are not significance at the same probability 0.05. However, the interaction between the three factors shows highly significance at 0.05. Other Table shows Duncan range test the result shows that m_3, m_2 m_4 and m_5 no significance difference between their means while m_1 and m_3, m_2, m4, m_5 are statistically significance. $f_1$and $f_2$are not significance while s_5 and s_4, are the same likewise s_4 and $s_{3,}$ s_5, s_2 and $s_4$are not significance with $s_{1.}$

Table 4 ANOVA showed the effect of independent Variables on scatter losses

Source	DF	Anova SS	Mean Square	F Value	Pr > F
replication	2	211.1962	105.5981	19.91	<.0001**
moisture	4	389.2019	97.3004	18.34	<.0001**
Feedrate	1	8.6112	8.6112	1.62	0.2057NS
Speed	4	220.6640	55.1660	10.40	<.0001**
moisture*feedrate	4	179.2466	44.8116	8.45	<.0001**
moisture*speed	16	292.6388	18.2899	3.45	<.0001**
Feedrate*speed	4	36.6546	9.1636	1.73	0.1500NS
moisture*feedrate*speed	16	202.2409	12.6400	2.38	0.0048**
error	98	519.8988	5.3050		
Corrected total	149	2060.3533			

3.5 Effect of independent variable on mechanical grain damage

Table 5 presented the ANOVA of independent variable on mechanical grain damage. The table indicated that all the three factors (moisture content, speed and feed rate) and replication are highly significance on grain damage at 5%. The same with their interaction are also highly significance at 5%. A Duncan range test is further evaluated (Tables 6, 7 and 8) and the result showed that m_4 and m_2 are not significance with m_3 and m_5 but m_1 are statistically significance with each. s_5, s_4 and s_1 are not significance; s_4, s_1 and s_2 are also not significance while s_3 is significance with each. f_1 and f_2 are statistically significance indicating that have different effect on mechanical grain damage.

Table 5 ANOVA showed the effect of independent Variables on mechanical grain damage

Source	DF	Anova SS	Mean Square	F Value	Pr > F
replication	2	97.1892	48.5946	8.13	0.0005**
moisture content	4	262.8589	65.7147	10.99	<.0001**
feedrate	1	106.7491	106.7491	17.85	<.0001**
speed	4	157.7187	39.4296	6.59	<.0001**
moisture*feedrate	4	252.7668	63.1917	10.57	<.0001**
moisture*speed	16	643.7307	40.2331	6.73	<.0001**
Feedrate*speed	4	321.3912	80.3478	13.44	<.0001**
moisture*feedrate*speed	16	524.3384	32.7711	5.48	<.0001**
error	98	586.0045	5.9796		
Corrected total	149	2952.7478			

Table 6 Duncan multiple range test of moisture content on independent variables

Moisture content,%	11	12	13	14	15
TE	99.94[a]	98.69[b]	97.43[b]	95.96[b]	94.58[b]
CE	99.91[a]	94.19[b]	94.53[b]	87.28[b]	86.27[b]
TC	250.98[a]	192.06[b]	187.29[a]	175.54[b]	172.34[a]
SL	5.25[a]	4.01[b]	3.05[b]	2.88[b]	2.59[b]
MD	2.06[a]	2.34[b]	2.51[c]	3.29[b]	3.81[c]

Table 7 Duncan multiple range test of speed on independent variables

Speed, r/min	700	800	900	1000	1100
TE	90.39[a]	92.69[a]	96.43[a]	97.96[a]	99.96[a]
CE	91.53[a]	94.19[a]	96.05[a]	98.28[a]	99.83[a]
TC	120.43[c]	157.79[c]	164.08[b]	175.89[a]	235.57[a]
SL	2.02[c]	2.51[c]	3.55[bc]	4.01[ba]	5.28[a]
MD	2.25[a]	2.82[b]	3.22[c]	3.51[ba]	3.73[a]

Table 8 Duncan multiple range test of feed rate on independent variables

Feed rate, Kg/min	3	5
TE	99.98[a]	96.43[a]
CE	96.05[a]	91.53[a]
TC	123.86[b]	248.23[a]
SL	2.56[a]	5.38[a]
MD	2.11[b]	3.33[a]

4 Conclusion

The development of IAR sorghum thresher was conducted and the effect of independent variables (Moisture content, speed and feed rate) on the dependent variables (Threshing efficiency, cleaning efficiency, throughput capacity, grain damage and scatter losses) was evaluated. The results show that the moisture content is highly significance on the threshing and cleaning efficiency while their interaction was not significance at the same probability level (0.05). It was also observed that moisture content, feed rate and speed are highly significance on the throughput capacity, mechanical grain damage and scatter losses. Similarly all their interaction between the factor show similar effect.

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