Development of a Sorghum Thresher

*D. Lasisi[1]
Department of Agricultural and Bio-Environmental Engineering, Oyo State College of Agriculture and Technology, Igboora, Oyo State, Nigeria.

A.R. Nasirudeen[2]
Department of Agricultural and Bio-Environmental Engineering, Oyo State College of Agriculture and Technology, Igboora, Oyo State, Nigeria.

Corresponding Author: *D. Lasisi[1]

Abstract:- Sorghum is threshed mostly using traditional method, whereby bunches of panicles are beaten against hard elements. This method is slow and energy consuming which often results in some losses due to the grain being broken or buried in the earth and low quality product. Machines have been developed to thresh the grains mechanically but these machines have complex features and are in most cases fragile, hence not easily adaptable in developing countries. Threshing of the grains require modern technology (machines) that can be easily maintained and repaired for effective utilization in underdeveloped and developing countries. Hence, this study aimed at developing a simple machine that will thresh sorghum efficiently so as to increase productivity. The designed machine consists of hopper, gasoline engine, shaft, bearing, v-belt, pulley and the threshing unit. The volume of hopper, volume of threshing drum, volume of threshing chamber, shaft diameter, speed of machine, belt length, linear velocity of belt, torque transmitted by shaft, bending moment, power required to thresh and selected power were obtained as 0.4582 m^3, 0.1648 m^3, 0.3879 m^3, 0.025 m, 708.0 rpm, 0.875 m, 7.20 ms^{-1}, 13.04 Nm, 64.98 Nm, 3.75 hp and 6.5 hp respectively. The average threshing time, threshing capacity, threshing and cleaning efficiencies were also obtained as 109.2 s, 271.64 kg/hr, 82.4 % and 93.2 % respectively. The performance indices of the machine indicated that it could be used effectively by small and medium scale processors to thresh sorghum that would meet market demands and standards.

***Keywords:-** Design; Fabrication; Testing; Sorghum; Threshing; Machine*

I. INTRODUCTION

Sorghum (sorghum bicolor), a tropical plant belonging to the family of Poaceae, is one of the most important crops in Africa, Asia, Latin America [1]. It is the world's fifth most important cereal crop after maize, rice, wheat and barley. In Africa, it is second after maize in terms of importance and its dietary staple food for more than 500 million people in more than 30 countries [2]. The world annual sorghum production is over 60 million tones, out of which Africa produced about 20 million [3]. It is grown in the Sudan, northern and southern guinea savanna zones in Nigeria [4]. Sorghum is used for food, feed and beverage production [2]. It is used to manufacture wax, starch, syrup, alcohol and edible oils [5]. The grain has high levels of iron and zinc used to reduce micronutrient malnutrition [6]. Threshing of sorghum poses a major challenge in Nigeria, particularly with the increase in production of the crop. The threshing process depends on sorghum variety characteristics, the design and structure of the threshing apparatus and its adjustment [7]. Sorghum is threshed both traditionally and mechanically. The traditional method is generally done by hand. Bunches of panicles are beaten against hard elements. In many countries in Asia and Africa, the crop is threshed by being trodden underfoot by humans or animals [8]. This method often results in some losses due to the grain being broken or buried in the earth [9]. This method is slow and energy consuming. Often, this local method of processing the crop leads to low quality product due to the presence of impurities like stones, dust and chaff. In mechanical method of threshing, machines are developed to thresh the grains mechanically but these machines have complex features and are in most cases fragile, hence not easily adaptable in developing countries. Threshing and separation of the grains from impurities require modern technology (machines) that can be easily maintained and repaired for effective utilization in underdeveloped and developing countries. Hence, this study aimed at developing a simple machine that will thresh sorghum efficiently so as to increase productivity.

II. MATERIALS AND METHODS

A. Description of the Machine

The thresher consists of hopper, threshing unit (which comprises shaft, threshing drum and beater), sieve, grain and chaff outlets, blower, v-belt, pulley, bearings, frame and the prime mover (gasoline engine with rated speed of 2,600 rpm and power rating of 6.5 hp) . The prime mover drives through a V-belt connected to the pulley attached to the shaft that drives both the threshing drum attached with set of beaters and the blower. The hopper is the component part where sorghum panicles are introduced and move into the threshing unit to remove grains from the panicles after which the separation of sorghum grains from panicles and chaffs takes place by a sieve. The cleaned sorghum grains are collected through the grain delivery chute using a collector while the chaffs are blown off with the aid of a fan made of metal blade. The overall size of the machine was 2023 mm length, 640 mm width and 1294.5 mm height.

B. Material Selection

Most of the component parts of the machine were fabricated with local materials as shown in Table 1.

Table 1 Material Selection for Fabrication of Sorghum Threshing Machine

S/N	Part	Materials used	Criterion for selection
1	Hopper	Mild steel	Strength and rigidity
2	Concave	Mild steel	Strength and rigidity
3	Transmission Shaft	Mild steel	Strength and rigidity
4	Threshing Drum	Mild steel	Strength and rigidity
5	Pulley	Mild steel	Strength and rigidity
6	Discharge chute	Mild steel	Strength and rigidity
7	V-belt	Rubber	Strength and flexibility
8	Fan	Mild steel	Strength and rigidity
9	Bearing	Cast iron	Accommodate axial Loading
10	Frame (angle iron)	Mild steel	Strength and rigidity
11	Fasteners	Cast iron	Strength and rigidity

C. Design Considerations

The following factors were considered in the development of the threshing unit of the sorghum thresher: Functionality, reliability, durability, materials and labour use, simplicity, portability and space, power supply, usability, maintenance, cost and safety.

D. Design Calculations

- *Design of Threshing Drum*

Centrifugal force (F_C) developed by the gasoline engine is given as

$$F_C = M_b \omega^2 r \quad (1)$$

Where, M_b = mass of belt used for the drive

r = radius of pulley

ω = angular velocity

But,

$$M_b = A_b \times \rho_b \times L_b \quad (2)$$

Where, A_b = cross-sectional area of belt

ρ_b ρ_b= density of belt

L_b = length of belt

And

$$A_b = ½(a+b)h \text{ (for v − belt)} \quad (3)$$

Angular velocity of rotation (ω) is given as:

$$\omega = \frac{2\pi N}{60} \quad (4)$$

Where, N = rotational speed of the gasoline engine

Since the threshing drum is cylindrical in shape, its volume (V_c) is given as:

$$V_c = \pi r^2 l \quad (5)$$

Where, r = radius of the threshing drum

l = length of drum

- *Design for Transmission Shaft*

The solid circular transmission shaft of the sorghum threshing machine is subjected to combined bending and torsional loads. The diameter (d) of the shaft is obtained from ASME code equation as:

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (6)$$

Where, at the section under consideration

S_s = Allowable combined shear stress for bending and torsion = 40 MPa for steel shaft with keyway.

K_b = Combined shock and fatigue factor applied to bending moment = 1.5 for minor shock.

K_t = Combined shock and fatigue factor applied to torsional moment = 1.0 for minor shock.

M_b = Bending moment (Nm).

M_t = Torsional moment (Nm) = 55.59 Nm.

- *Determination of Speed of Threshing Machine*

The machine's speed was determined using the equation for speed ratio as shown in equation 7:

$$D_e N_e = D_m N_m \quad (7)$$

Where,

D_e = Diameter of engine pulley (m)

N_e = Rotational speed of engine (rpm)

D_m = Diameter of machine pulley (m)

N_m = Rotational speed of machine (rpm)

- *Belt Selection*

The minimum centre distance is determined by equation

$$C_d = \frac{D_e + D_m}{2} + D_e \qquad (8)$$

The pitch length of the belt is given by equation 9:

$$L = 2C_d + 1.57\frac{(D_e + D_m)}{2} + \frac{(D_m - D_e)^2}{4C_d} \qquad (9)$$

- *Angle of Contact between the Belt and the Machine Pulley*

According to [10], the angle of contact (wrap) between the belt and the machine pulley is given by

$$\propto_1 = 180 + 2\text{Sin}^{-1}\frac{R-r}{C} \qquad (10)$$

Where, r = radius of small pulley

R = radius of big pulley

C = centre distance

α_1 = angle of contact between the belt and the small pulley (rad)

α_2 = angle of contact between the belt and the big pulley

- *Angle of Contact between the Belt and the Small (Engine) Pulley* $\propto_1$

$$\propto_2 = 180 - 2\text{Sin}^{-1}\frac{R-r}{C} \qquad (11)$$

- *Determination of Linear Velocity of Belt*

Linear velocity of belt is given by

$$V = \frac{\pi dN}{60} \qquad (12)$$

Where,

V = linear velocity of belt (m/s)

ω = angular velocity of belt (rad)

r = radius of small pulley (m)

d = diameter of small pulley (m)

N = number of revolution of small pulley per minute

- *Determination of Tension in the Tight Side*

To obtain T_1 and T_2, the following equations are solved simultaneously

$(T_1 - T_2)V = P_t$ [11] (13)

and

$$\frac{T_1 - mv^2}{T_2 - mv^2} = e^{\mu\frac{\alpha}{\sin\theta/2}} \qquad (14)$$

Where,

T_1 = tension in the tight side

T_2 = tension in the slack side

$$m = bte \qquad (15)$$

Where,

b = belt width = 17 mm

t = belt thickness = 11 mm

e = belt density = 970 kg/m^3 for leather belt

θ = 40 deg. (most common angle of groove)

Force due to threshing unit (F_g) is obtained as:

$$F_g = M_g \times g \qquad (16)$$

Where, M_g = mass of threshing unit (g)

g = acceleration due to gravity

Force due to sorghum loaded (F_m)

$$F_m = M_m \times g \qquad (17)$$

Where, M_m = mass of loaded sorghum (g)

The total force (F_t) due to threshing unit and sorghum loaded into the threshing machine is obtained as:

$$F_t = F_g + F_m \qquad (18)$$

- *Power Required Threshing Sorghum*

$$P = F_t V \qquad (19)$$

Where,

P = Power required to turn the shaft

V = Speed of rotation of the shaft

But,

$$V = \frac{\pi DN}{60} \qquad (20)$$

Where,

D = Diameter of the shaft

ISSN No:-2456-2165

N = Speed in revolution per minute

Therefore,

$$P = \frac{F_t \pi D N}{60} \quad (21)$$

Consider a safety factor of 1.5 for optimum performance, reliability and durability.

➢ *Fan Design*

Fan case design: The radius of the fan case was calculated from:

$$R = \frac{1 + \theta}{360} \quad (22)$$

r = radius of fan case

R = Distance from shaft to tip of blades

θ = Angle

➢ *Fan Blade Selection:*

A 20-gauge mild steel sheet blade was used.

➢ *Determination of Air Velocity of Fan*

$$Q = A \times V \quad (23)$$

Q = Volumetric flow rate (m/s), A = Cross sectional area (m), V = Air velocity (m/s)

➢ *Determination of Fan Speed:*

$$V = \frac{\pi D N}{60} \quad (24)$$

N = Speed of fan (rpm), D = Diameter of fan (mm) and V = Velocity of fan (m/s).

E. Fabrication and Assembly of the Machine

The main components of the machine are: the hopper, threshing unit, delivery chute, the shaft, bearings, pulley, belt, frame and the power transmission unit. The conceptual views of the machine are shown in Figures 1, 2 and 3. Marking out of materials was done using rule and scriber. Cutting, drilling, welding and machining operations were also done. Table 2 showed the Bill of Engineering Measurement and Evaluation (BEME) of the machine. The various components were thereafter assembled.

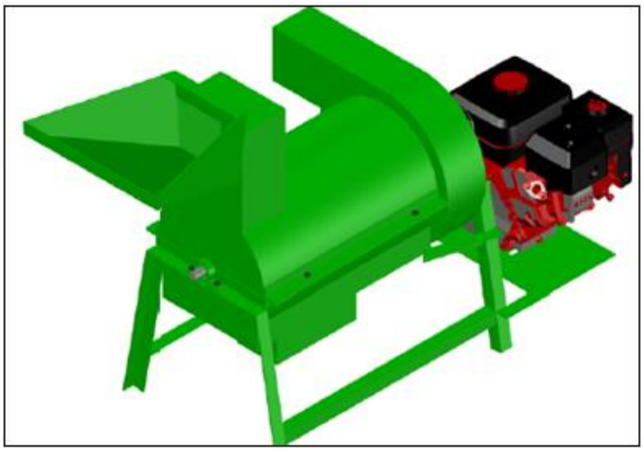

Fig 1 Isometric View of the Machine

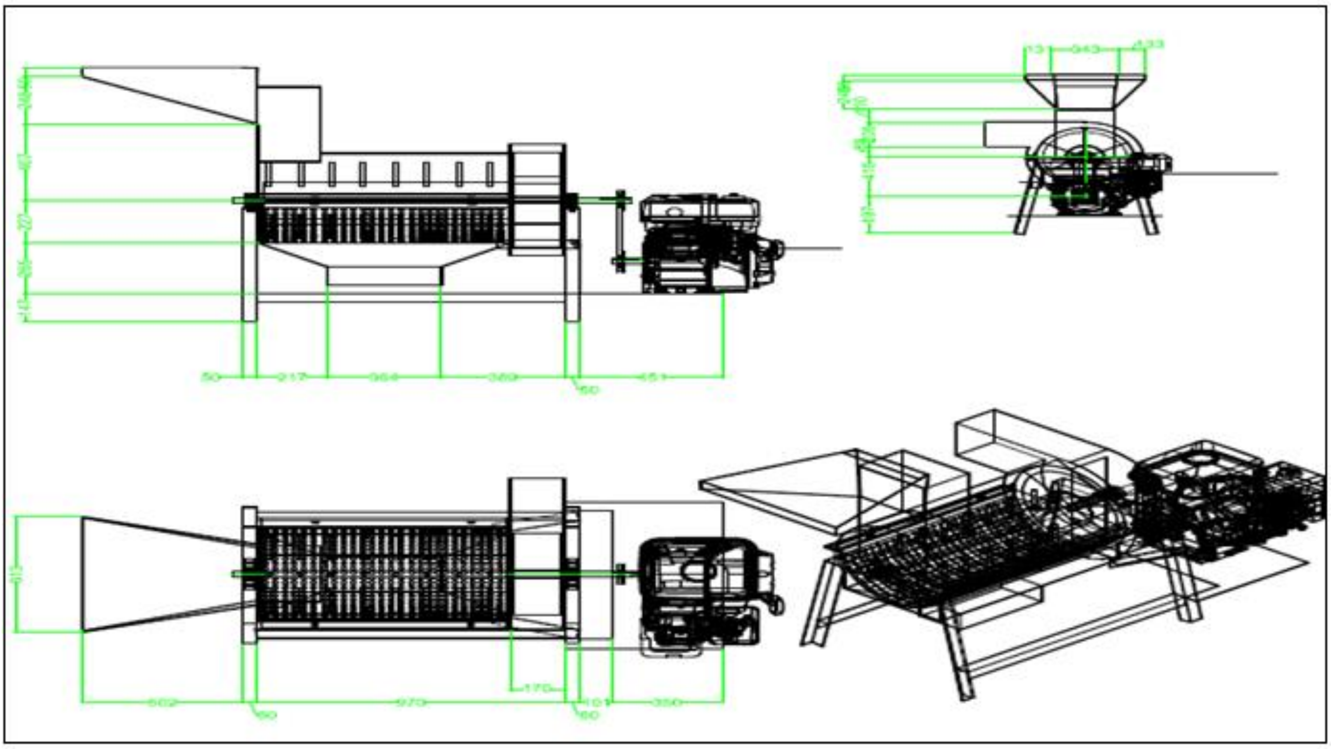

Fig 2 Orthographic View of the Machine

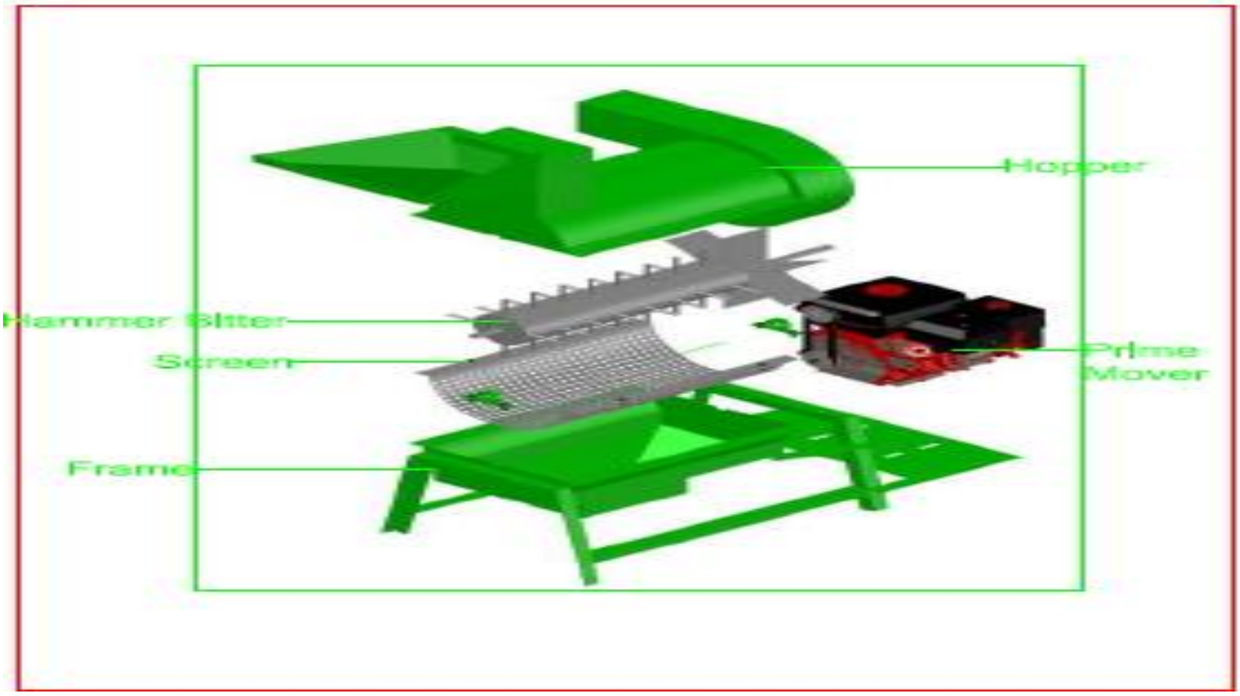

Fig 3 Exploded View of the Machine

Table 2 Bill of Engineering Measurement and Evaluation of the Machine

Material	**Specification**	**Qty**	**Unit cost (₦)**	**Total cost (₦)**
Sheet metal (mild steel)	1.5 mm	1	38,000	38,000
Angle iron (mild steel)	50 × 50 mm	2	3,800	7,600
Belt	Reinforced leather	1	2,000	2,000
Pillow Bearing	Ø25 mm	2	4,500	9,000
Pulley (cast iron)	Ø 254 mm	1	5,000	5,000
Shaft (mild steel)	Ø 25 mm	1	12,000	12,000
Iron rod	Ø 13 mm	1	6,500	6,500
Electrode	Gauge 12 (packet)	1	6,000	6,000
Hacksaw blade		2	1,000	2,000
Bolt and nut	M 17	10	150	1,500
Bolt and nut	M 19	6	200	1,200
Paint (gallon)		1	7,000	7,000
Gasoline engine	5.5 hp	1	46,000	46,000
Transportation				18,000
Machining				10,000
Total				**171,800**

F. Testing of the Machine

The fabricated machine was tested for functionality under no load and load conditions. The machine was run empty under no load testing in order to establish that there were no functional defects. Sorghum panicles were obtained at the Teaching and Research Farm of Oyo State College of Agriculture and Technology, Igboora. Under load testing, when the prime mover (gasoline engine) was started, it propelled the shaft by transferring power via the belt-pulley transmission system to the machine. Moisture content of the grains was determined using moisture metre.

- *Threshing Efficiency*

The quantity of unthreshed grains after they were removed from the panicles manually (with the hand) was weighed. The threshing efficiency (E_T) was then determined by using the equation below;

$$E_T = \frac{W_T - W_U}{W_T} \times 100 \quad (25)$$

Where W_T is the total mass of sorghum fed into the machine; W_U is the mass of the unthreshed sorghum

- *Cleaning Efficiency*

The mass of cleaned grains was measured and cleaning efficiency calculated using the equation below:

$$E_C = \frac{W_C}{W_T} \quad (26)$$

Where W_C is the mass of cleaned maize delivered by the mahine.

ISSN No:-2456-2165

➢ *Threshing Capacity (C_T)*

This is the quantity of sorghum grains the machine was able to thresh in one hour and was calculate using the equation below:

$$C_T = \frac{W_T}{T} \qquad (27)$$

III. RESULTS AND DISCUSSION

The results obtained from design calculations of the sorghum threshing machine is shown in Table 3. The machine was fabricated using locally available materials. The pictorial view of the fabricated machine is shown in plate 1. From the performance test, the values of threshing capacity from five replicates were obtained as 270.8, 274.91, 270.86, 270 and 271.64 kg/hr while the average threshing capacity was obtained as 271.64 kg/hr as shown in Table 4. In the same vein, the threshing efficiency values were obtained as 85.0, 84.0, 79.0, 81.0 and 83.0 % with an average value of 82.4 %. These high efficiencies could be as a result of more dryness of the sorghum panicle which allowed easy dislodging of the grains from the panicle and high speed of rotation of the threshing drum that resulted in more

Table 3 Results of Design Calculations

S/N	Parameter	Unit	Value
1	Volume of hopper	m^3	0.4582
2	Volume of threshing drum	m^3	0.1648
3	Volume of threshing chamber	m^3	0.3879
4	Calculated shaft diameter	M	0.021
5	Selected shaft diameter	M	0.025
6	Speed of machine	Rpm	681.0
7	Length of belt	M	0.875
8	Linear velocity of belt	ms^{-1}	7.20
9	Torque transmitted by shaft	Nm	13.04
11	Power required to thresh sorghum panicles	Hp	3.75
12	Selected power requirement	Hp	6.5
13	Bending moment	Nm	64.98
14	Moisture content of grain	% w.b.	13.0

Plate 1 Pictorial View of the Fabricated Machine

Table 4 Performance Indices of Sorghum Threshing Machine

Total wt of grain (kg)	Wt of threshed grain (kg)	Wt. of clean grain (kg)	Threshing time (s)	Threshing capacity (kg/hr)	Threshing efficiency (%)	Cleaning efficiency (%)
10.0	8.50	7.90	113.0	270.80	85.0	92.9
10.0	8.40	7.60	110.0	274.91	84.0	90.5
10.0	7.90	7.20	105.0	270.86	79.0	91.1
10.0	8.10	7.70	108.0	270.00	81.0	95.1
10.0	8.30	8.00	110.0	271.64	83.0	96.4
Mean	8.24	7.68	109.2	271.64	82.4	93.2
S.D.	0.215	0.279	2.638	1.714	2.154	2.26

ISSN No:-2456-2165

Impact of beaters on the millet stalks. These values were similar to the values obtained by [12], where decrease in moisture content of unthreshed grains resulted to an increase in threshing efficiency. Cleaning efficiency values were also obtained as 92.9, 90.5, 91.1, 95.1 and 96.4 % with an average value of 93.2 %. These results were higher than the values obtained by [13] that got 62.7 % cleaning efficiency.

IV. CONCLUSION

A sorghum threshing machine was designed, fabricated and tested and found to have an average threshing capacity of 271.64 kg/hr, sifting efficiency of 82.4 % and cleaning efficiency of 93.2. The design analysis revealed that the machine was successfully designed and could be fabricated for commercialization. The results obtained from the performance test carried out on the grating machine showed that it could be used efficiently and effectively by small and medium scale processors to thresh sorghum that would meet market demands and standards.

REFERENCES

[1]. C. Anglani. Sorghum for human food: a review. *Plant Foods Human. Nutrition*. 52: 85- 89. 1998.

[2]. C.W. Muui, R.M. Muasya, and D.T. Kirubi. Baseline Survey on Factors Affecting Sorghum Production and Use in Eastern Kenya. *Ajfand*. 13(1): 7340 – 7342, 2013.

[3]. N.A. Sale. Development of an Improved IAR Sorghum Thresher. MSc. Thesis: Ahmadu Bello University, Zaria, Nigeria, 2015.

[4]. L.W. Rooney. Overview of sorghum and millet research failures and successes. Faculty of food science, cereal quality laboratory, soil and crop science department, Taxas A&M University USA.http://www.afripo.org.uk/ paper.rooney.pdf.15/10/03 Rural sector enhancement programme (RUSEP), 2001. Need assessment study for market-driven agricultural technology transfer and commercialization in Katsina State. USAID/IITA, pp. 51, 2003.

[5]. H.A. Agrama, and M.R. Tuinstra. Phylogenetic Diversity and Relationships among Sorghum Accessions Using Ssrs and Rapds. *Afric. J. Biotech.* 2(10): 334 – 340, 2003.

[6]. M.B. Gerda, and D.V. Christopher. Can GM Sorghum Impact Africa? *Trends In Biotechnology*; 26(2):64 – 69, 2007.

[7]. S. Petkevichius, L. Shpokas, and H. D. Kutzbach. Investigation of the Maize Ear Threshing Process. *Biosystems Engineering* 99: 532 – 539, 2008.

[8]. G. Agidi, M.G. Ibrahim and S.A. Matthew. Design, fabrication and testing of a millet thresher. Net J. Agric. Sci. Vol. 1(4), pp. 100-106, 2013.

[9]. FAO (Food and Agriculture Organization). Sorghum and millets in human nutrition. (Food and Nutrition Series, No. 27) *ISBN 92-5-103381-1*, 1995.

[10]. A.S. Hall, A.R. Holowenko, and A.G. Lauglin. Theory and Problems of Machine Design., Schaum's Outline Series. McGraw Hill Book Co., New York, 1983.

[11]. R.S. Khurmi, and J.K. Gupta. Shaft, V-belt and Rope Drives: A Textbook of Machine Design. 13thEdn., S. Chand and Company Ltd., New Delhi, pp:456-498, 657-659, 2004.

[12]. B.K. Adeoye, and A.I. Alao. Development and performance evaluation of a multy-crop (maize and sorghum) shelling machine. *Applied Tropical Agriculture, Volume 24, No 1, 56-63,* 2019.

[13]. A. Gbabo , Mohammed, I. G., and Amoto, M. S. Design, Fabrication and Testing of a Millet Thresher. *Net Journal of Agricultural Science* 1(4):100 – 106, 2013.