

Design, fabrication and testing of a millet thresher

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ABSTRACT

A thresher was developed for threshing, separating, and cleaning millet seeds. The major components of the machine include threshing, separation and cleaning units. The threshing operation is achieved by rotational motion of a cylinder fitted with beater pegs above a stationary grid which results in the removal of the seeds from the panicles and their separation from the bulk of the straw. After being beating out, the grains fall through a concave grid into the cleaning unit which consists of two sieves that undergo reciprocating motion. Whilst the grains are moving over these sieves, a constant blast of air is being sent through them which blow out materials that are lighter than the grain. The machine was designed to be powered by a 5 hp electric motor. It was tested to thresh, separate and clean the millet seeds. The results showed that the machine had the highest threshing and cleaning efficiencies of 63.2 and 62.7%, respectively, when pearl millet panicles were processed at 13% moisture content and at an 800 rpm threshing cylinder speed. The lowest threshing and cleaning efficiencies of 40.68 and 50%, respectively, were obtained when the pearl millet panicle was processed at 17% moisture content and a 600 rpm threshing cylinder speed, and at 17% moisture content and 700 rpm. Thus, the optimum operating parameters of the machine were 13% moisture content (wet basis) of pearl millet panicles and 800 rpm threshing drum speed. The successful development of this machine is expected to reduce drudgery associated with the traditional method of threshing millet and therefore increase productivity of farmers.

Keywords: Threshing, cleaning, separation, efficiency, cylinder, rotational, beater, pegs pearl millet and panicle.

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INTRODUCTION

Millet is one of the oldest human foods and believed to be the first domesticated cereal grain (Crawford and Lee, 2003). Ikwelle et al. (1993) ranked pearl millet as the most important cereal in the southern Sudan and northern Guinea. Millets are the principal food sources in arid and semi-arid regions of the world. It is the staple food of millions of people in drier parts of tropical Africa. It has been reported that the air-dried grain of millet contains approximately 12.4% water, 11.6% protein, 5% fat, 67.1% carbohydrate, 1.2% fibre and 2.7% ash (Onwueeme and Sinha, 1991).

Millets are good sources of minerals such as calcium, iron, zinc, copper and manganese (Hulse et al., 1980).

Products from millet vary depending on people's taste and cultural preference. One of the common traditional products made from millet in Nigeria is 'kunu', a non alcoholic beverage. It is of low viscosity and has a sweet-sour taste, milky cream appearance and is popular with people of northern Nigeria (Adeyemi and Umar, 1994). Millet has also been found to be the most preferred staple in the semi-arid tropics of the region. The most important characteristic of millet is its unique ability to tolerate and survive under adverse condition of continuous or intermittent drought as compared to most other cereals like maize and sorghum (LCRI, 1997).

At present, Nigeria is the third leading millet producing

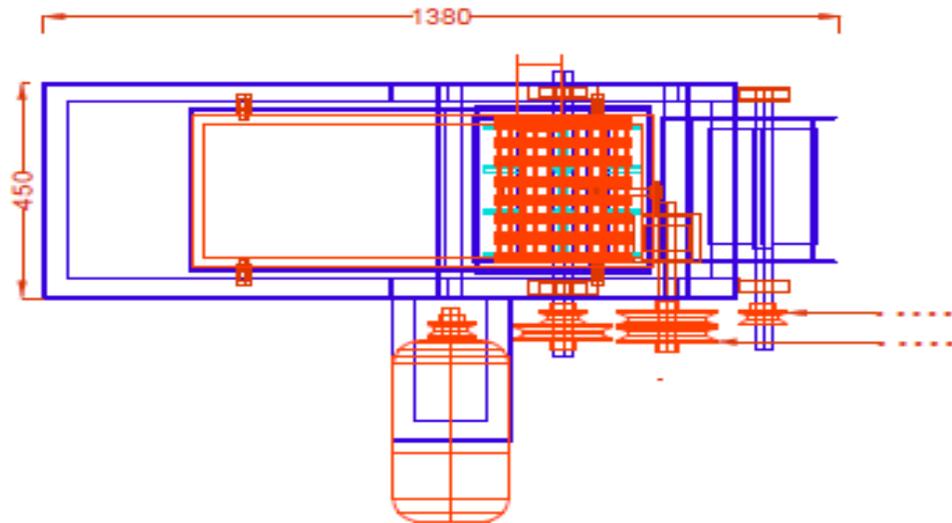


Figure 1. Plan view.

country in the world after India and China with production capacity of about 4 million tons, which is about 13.4% of total world production (FAO, 1996).

According to Ogunlowo and Adesuyi (1999), in order to increase millet production, it is necessary to modernize the production techniques and optimize the processing conditions with a view to realizing some basic quality requirements such as improved flavor and increased shelf life. Millet is threshed both mechanically and traditionally. In mechanized threshing, two main types of stationary threshing machines have been developed. The machine of Western design is known as “through-flow” thresher, because stalks and ears pass through the machine. It consists of a threshing device with pegs, teeth or loops, and (in more complex models) a cleaning winnowing mechanism based upon shakers, sieves and centrifugal fan. In the 70s, an axial flow thresher was developed which has been widely manufactured at local level (Sexena et al., 1971). More recently, a small mobile mechanism provided with either one or two threshers was also developed. This machine has been widely adopted in many millet growing areas (Policarpio and Mannamy, 1978). The simple design and work rates of these machines seem to meet the requirements of rural communities (FAO, 1995). However, the main disadvantages of these machines are that they have complex features and are in most cases fragile, hence not easily adoptable in developing countries.

The traditional method is generally done by hand. Bunches of panicles are beaten against hard elements (e.g. a wooden bar log, bamboo table or stone). In many countries in Asia and Africa, the crop is threshed by being trodden underfoot by humans or animals. This method often results in some losses due to the grain being broken or buried in the earth (FAO, 1995). This process 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. Threshing and separation of the grain from these impurities requires modern technology that can be easily maintained and repaired for effectively utilization in underdeveloped and developing countries. Therefore, the development this thresher is aimed at threshing millet efficiently so as to increase productivity.

MATERIALS AND METHODS

Machine description

The millet threshing machine was designed to be made up of the following major parts as shown in Figures 1 to 6.

- i) Hopper: It is the part where the millet panicles are being fed into the threshing drum. It is made of galvanized material and has a height of 0.3 m.
- ii) Threshing chamber: It is the part where the millet grains are beaten out of the panicles and separated from the bulk of the straw. It is made of mild steel material, has length of 0.352 m and diameter of 0.302 m. It consists of a rotary drum with beater pegs and a stationary concave grid.
- iii) Separating chamber: It is the part where the separation of grain from trash, sand and broken grains take place. It is made of mild steel, with length of 0.80 m and diameter of 0.337 m.
- iv) Cleaning chamber: It is the part is made up of two sieves that undergo to and fro motion and centrifugal fan which blows air into the sieves. Whilst the grain is moving over these sieves the air which is being blown through them disallows settling of trash on the sieve and anything lighter in weight than the grains.
- v) Blower housing: It is made of mild steel. It accommodates the blower blade and the shaft. It has a length of 0.30 m and diameter of 0.244 m.
- vi) Threshing drum: It is the part is made of galvanized material and it is housed inside the threshing chamber. It accommodates the shaft on the concave with a clearance of 6 mm.
- vii) Screen: It is the part is made of mild steel material. It is concave in shape and perforated, with 0.30 m length and 0.232 m diameter.

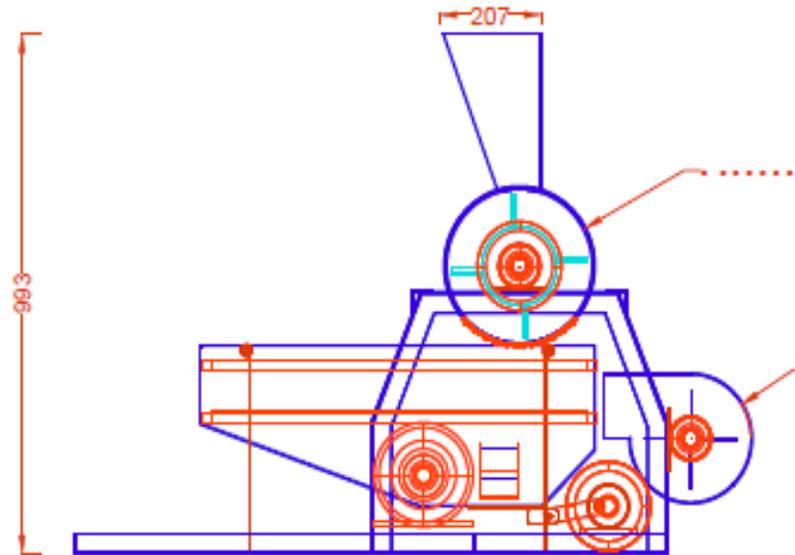


Figure 2. Side view.

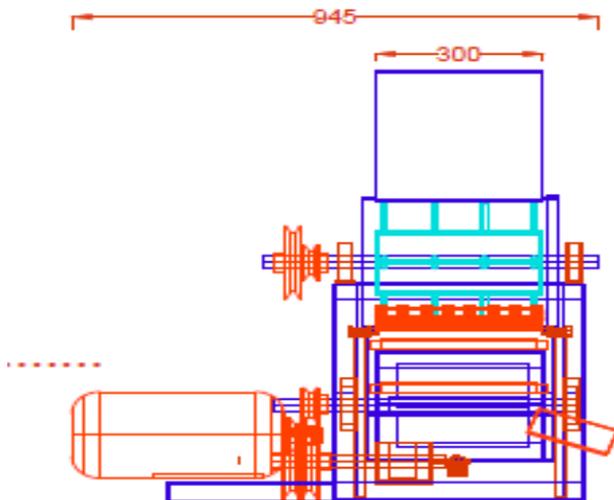


Figure 3. Front view.

viii) Drive and driven assembly: This assembly consists of an electric motor of 5 hp with a shaft and pulley unit which is connected by a v-belt.

Working mode of the machine

A 5 hp electric motor provides power to the threshing drum shaft. The threshing drum shaft which rotates with the help of bearings provides drive to the shaft of the cleaning chamber through belts and pulleys. As the millet panicles are being fed into the threshing drum through the hopper, the grains are beaten out of the panicle and separated from the bulk of the straw. This is done by a cylinder fitted with beater pegs that rotates above a stationary grid known as a concave. The concave is also fitted with bars throughout its width and it is between these bars and pegs of the cylinder that the grains are beaten out. The bulk of the grain falls through the concave grid

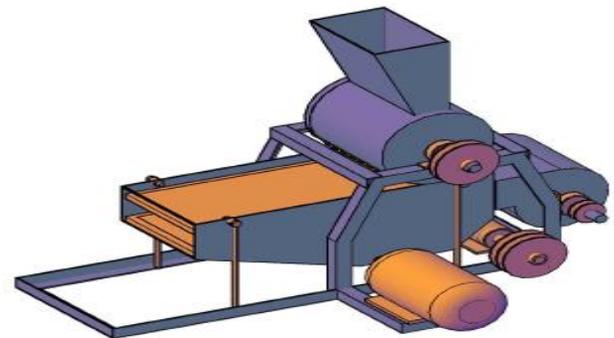


Figure 4. The millet thresher.

into the cleaning unit which consists of two sieves that undergoes to and fro shaking motion and centrifugal fan which blows air into the sieves. The top sieve helps to retain the chaff and allows the passage of the grains into the bottom sieve, called the grain sieve which has holes that are of the grain size diameter. The purpose of the grain sieve is to carry out further separation of grain from trash, sand and broken grains. Whilst the grain is moving over these sieves the air which is blown through them from the blower disallows settling of trash and materials lighter in weight than the grains on the sieve. The grain pans beneath the grain sieve conveys the grain (which are quite free from impurities) to the clean grain outlet for collection while the other pan transfers the broken grains and other materials that are smaller than the grain to the other outlet.

Design analysis

The design analysis was carried out with a view to evaluate the necessary design parameters, strength and size of materials for consideration in the selection of the various machine parts in order to avoid failure by excessive yielding and fatigue during the required working life of the machine.



Figure 5. Completed millet thresher and cleaner.

Determination of the threshing drum diameter

The threshing drum diameter is needed in order to determine the capacity of the threshing drum. Therefore, the diameter of the threshing drum was determined using the standard formula for calculating the volume of a cylinder and is given as follows:

$$V = \frac{\pi d^2}{4} \times L \quad (1)$$

$$d = \sqrt{\frac{4 \times V}{\pi L}} \quad (2)$$

Where V = the volume of the drum (m³)

d = the diameter of the cylinder (m)

L = the length of the cylinder (m)

Evaluation of weight of threshing drum

The weight of the threshing drum was determined in order to know the amount of load being exerted on the shaft by the threshing drum. Therefore the weight of the threshing drum is expressed as:

$$W = Mg \quad (3)$$

$$M = \rho V \quad (4)$$

Where W = the weight of threshing drum (N)

M = mass of threshing drum (kg)

g = acceleration due to gravity (m/s²)

ρ = the density of the drum (kg/m³)

V = the volume of the cylinder (m³)

Power required to thresh grain from the panicle

The power required to thresh grains from the millet panicles is expressed as:



Figure 6. Threshing in progress.

$$P = T\omega \quad (5)$$

$$\omega = \frac{2\pi N}{60} \quad (6)$$

$$T = Fr \quad (7)$$

Where P is the power required (watts)

T = torque of the drum (Nm)

ω = angular velocity (rad/s)

N = speed of the threshing drum in rpm/min

F = the impact force required to thresh millet

r_i = the distance of point of force application from axis of rotation (m)

(Ndirika, 1997; Abu, 2006)

The torque resulting from individual force is given by

$$T = F_i \times r_i \quad (8)$$

Where F_i and r_i are force and radius respectively

Total torque (T) on the drum is calculated as follows:

$$T = T_R \times K_B \quad (9)$$

Where, K_b is the number of beaters on the drum

Design of the pulley and belt

The nominal pitch length of the motor to threshing drum belt was determined in order to know the actual belt size that is needed to transfer power from the electric motor to the threshing drum. Therefore, according to Gupta and Khurmi (2005), the nominal pitch length (L) is given as follows:

$$L = 2C + \frac{\pi}{2} (D_1 + D_2) + \left[\frac{(D_2 - D_1)^2}{4C} \right] \quad (10)$$

Where; D₁ = diameter of the motor pulley (m)

D₂ = diameter of the threshing drum pulley (m)

C = the center distance between the motor pulley and the threshing drum shaft pulley, which is expressed as:

$$C = \left(\frac{D_2 + D_1}{2}\right) + D_1 \quad (11)$$

Determination of angle of contact of the belt between the shaker pulley and the fan pulley

The angle of contact of belt between the shaker pulley and the fan pulley was determined in order to know the tensions which exist between the belt and the pulleys. Therefore, the angle of lap of the belt between the two pulleys was calculated from the expression below:

$$\theta = (180 - 2\alpha) \times \frac{\pi}{180} \text{ rad} \quad (12)$$

$$\text{Such that, } \alpha = \sin^{-1} \left(\frac{r_4 - r_3}{C}\right)$$

Where,

θ - Angle of contact of belt between the pulleys
 r_4 - radius of the fan pulley (mm)

Evaluation of the tension in shaker-belt

The tension of the belt is determined so as to ascertain the power transmitted by the shaker to fan belt, therefore the tension on the two sides of the open belt was calculated as shown below:

$$\frac{T_1}{T_2} = e^{k\theta} \quad (\text{Gupta and Khurmi, 2005}) \quad (13)$$

Where, T_1 = the tension of the belt on the tight side.

T_2 = the tension of the belt on the slack side.

K = the coefficient of friction between the belt and the pulley.

θ = the angle of contact or lap of belt between the two pulleys = 3.10 rad

The power transmitted by an open belt is given by

$$P = (T_1 - T_2)V \quad (14)$$

Where, V = the velocity of the belt (m/s)

P = the power transmitted by belt (watts)

Shaft design

Determination of threshing drum shaft diameter: This was determined to know the shaft diameter that can withstand the applied loads. For a solid shaft with little or no axial load, the diameter of the shaft was determined using:

$$d^3 = \frac{16}{\pi S_s} \times \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (15)$$

Where d is the diameter of the shaft

S_s = the allowable stress = $40 \times 10^6 \text{ Nm}^{-2}$

K_b = the combine shock and fatigue factor applied to bending moment

M_b = the bending moment (Nm)

K_t = the combine shock and fatigue factor applied to torsional moment

M_t = the torsional moment (Nm)

(Hall et al., 1980)

Determination of angle of twist

The angle of twist helps to know whether the diameter of the shaft is safe to carry the applied load. According to Hall et al. (1980), the amount of twist permissible depends on the type of load application and varies about 0.3 degree per meter for a machine tool shaft and about 3 degrees per meter for line shafting.

Therefore, angle of twist (θ); for solid shaft is given as follow:

$$\theta = \frac{584 M_t L}{G d^4} \quad (16)$$

Where,

L = the length of shaft (m)

M_t = the torsional moment (Nm)

G = the torsional modulus (Nm²)

d = the diameter of the shaft (m)

Testing of machine

135 kg of pearl millet panicle were obtained from a farmers' field in Dabarako village, Bida Local Government Area, Niger state. The pearl millet panicle was divided into three samples, 45 kg each which was then subjected to oven drying in order to obtain three different moisture contents (13, 15 and 17% wet basis). An instant moisture meter was used to determine their moisture contents.

As shown in Figures 5 and 6, the machine was first run under no load condition using an electric motor of 5.0 kW with speed rating of 1500 rpm whereas the threshing drum was running at a speed of 800 rpm under no load condition. This was done in order to ascertain the smoothness of operation for the machines rotating parts. The testing of the machine was targeted to evaluate its threshing efficiency, cleaning efficiency and the percentage losses based on the moisture content of the seeds and the speed of rotation of the threshing drum. The overall effects of these parameters on the threshing and cleaning efficiencies were investigated. For running the test, 135 kg of millet panicle were used in the whole testing. The 135 kg sample of millet panicle was divided into of 45 kg samples each of 13, 15 and 17% moisture content. The performance test was conducted using 45 kg of millet panicles of each of the moisture content at 800, 700 and 600 rpm threshing cylinder speeds each. Each of the experiment was replicated three times.

Computation of the performance parameters

The formulae used in computing the threshing efficiency, cleaning efficiency and the percentage loss are stated as follows:

Threshing efficiency (TE): It is the ratio of the mass of threshed millet to the total mass of the millet panicle expressed in percentage and is given as:

$$TE = \frac{M_T}{M_A} \times 100 \quad (17)$$

Table 1. Machine Performance parameters at different crop moisture content and cylinder speeds.

Threshin speed	M.C	Mass of grains panicle [M _A (g)]	Avg. mass of threshed grains [M _T (g)]	Avg. mass of unthreshed grain [M _{UT} (g)]	Avg. mass separated impurities [M _{SI} (g)]	Avg. mass of unseparated impurities [M _{UI} (g)]	Avg. qty of recovered grains [M _{RG} (g)]	Qty of loss grains [M _{LG} (g)]	Threshing efficiency (TE%)	Cleaning efficiency (CE%)	Percentage loss (%)
800	13	5000	3160	1840	190	110	3160	1840	63.2	62.7	36.8
	15	5000	3075	1925	182.5	117.5	3075	1925	61.5	60.2	38.5
	17	5000	2910	2090	180	120	2910	2090	58.2	59.4	41.8
700	13	5000	2850	2150	175.05	124.95	2870	2130	57.4	57.8	42.6
	15	5000	2685	2315	165	135	2685	2315	53.7	54.5	46.3
	17	5000	2526	2474	154.85	145.15	2526	2474	50.52	51.1	49.48
600	13	5000	2620	129.52	170.48	129.52	2380	2620	48.19	56.3	47.6
	15	5000	2526	142.4	157.6	142.4	2474	2526	43.04	52	49.48
	17	5000	2416	148.3	151.7	148.3	2584	48.32	40.68	50	51.68

Where, TE = the threshing efficiency (%)

M_T = mass of threshed millet (g)

M_A = mass of the total mass of millet panicle (g)

Cleaning efficiency (CE): It is the ratio of mass of separated impurities to the total mass of impurities in the millet expressed in percentage and is given as:

$$CE = \frac{M_{SI}}{M_{UI}} \times 100 \quad (18)$$

Where, CE = the cleaning efficiency (%)

M_{SI} = mass of separated impurities (g)

M_{UI} = mass of un-separated impurities (g)

Percentage loss (PL): It is the ratio of quantity of millet loss to the total quantity of the millet panicle expressed as a percentage and is given as:

$$PL = \frac{M_{RG}}{M_{RG} + M_{LG}} \times 100 \quad (19)$$

Where, PL= the percentage loss (%)

M_{RG} = the mass of recovered millet seed (g)

M_{LG} = mass of millet seed losses (unthreshed loss + separation loss + scattering Loss + blower loss) (g)

RESULTS AND DISCUSSION

Threshing efficiency

The results of threshing efficiency of the machine are presented in Table 1. Threshing millet at 13% moisture content with a speed of 800 rpm produced the highest efficiency of 63.20% and threshing millet with 17% with the speed of 600 rpm produced the lowest threshing efficiency of 40.68%. This could be as a result of more dryness of the millet stalk which allowed easy dislodging of the grains from the stalk and high speed of rotation of the threshing drum that resulted in more impact of beaters on the millet stalks. This agreed with the result of an earlier study by

Simonyan and Oni (2001), where decrease in moisture content of unthreshed grains resulted to an increase in threshing efficiency and extractor efficiency. It was also reported by Helmy et al. (2000), that threshing effectiveness was also found to be affected by the cylinder speed, the concave clearance, feed rate of crops, the number of rows of concave teeth used with spike tooth cylinder, and the type of crop.

Cleaning efficiency

The results of cleaning efficiency of the machine are presented in Table 1. From the results, the highest values of cleaning efficiency range from 56.3 to 62.7% when the millet was processed with 13% moisture content. The lowest values of cleaning efficiency range from 50 to 59.4% when processed at 17% moisture content. A speed of 800 rpm produced the highest cleaning efficiency of 62.7% and lowest efficiency of 56.3% at a drum

speed of 600 rpm. This is in lined with the result of an earlier study by Afify et al. (2007) where cleaning efficiencies was found to be increased by increased of drum speed and decreased by increasing both the feed rate and seed moisture content. The increase in the percentage of threshing and cleaning efficiencies by increasing drum speed was attributed to the high stripping and impacting forces applied to the black seed materials, which tend to improve the threshing operation and increase threshing and cleaning efficiencies.

Percentage loss

The results of percentage losses of the machine are presented in Table 1. Threshing millet at 17% moisture content and speed of 600 rpm produced the highest value of percentage loss of 51.68%. This could be as a result of high moisture content of the seed that produced resistance to dislodging as such more of the seed were lost with the stalk. It was also observed that the percentage loss decreased with decrease in moisture content of the seed and increased with increase in seed moisture content.

Conclusions

1. The highest threshing efficiency of the machine was 63.20% when millet was threshed at 13% moisture content with a drum speed of 800 rpm while the lowest threshing efficiency of 40.68% was recorded when threshed at 17% moisture content with drum speed of 600 rpm.
2. The highest machine cleaning efficiency of 62.7% was achieved when the millet was threshed at 13% moisture content at a drum speed of 800 rpm and the lowest cleaning efficiency of 50% was obtained at 17% moisture content with drum speed of 600 rpm.
3. The highest percentage loss of 51.68% was obtained when the millet was threshed at 17% moisture content with drum speed of 600 rpm and the lowest percentage loss of 36.8% was realized when millet was processed at 13% moisture content with drum speed of 800 rpm.
4. Generally, the millet thresher works more efficiently as the moisture content decreased and the threshing drum speed increases. Since the average threshing and cleaning efficiencies were about 63.0 and 62.7% respectively, the optimum operating parameters of the thresher are demonstrated at 13% moisture content (wet basis) and 800 rpm threshing drum speed.

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