

# DESIGN AND DEVELOPMENT OF AN ENHANCED MOTORIZED MAIZE THRESHER MACHINE WITH BAGGING UNIT

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## ABSTRACT

The processing of agricultural product into quality forms prolongs the useful life and also increases the net profit of these products. The development of the enhanced motorized maize thresher was done with the aim of improving the production and reduction of drudgery involved in manual packing and bagging of the threshed maize seed by the introduction of screw auger conveyor. The machine consists of the hopper with extension, threshing unit, cleaning unit, screw auger conveyor and power unit. The machine performance evaluation on three different varieties of maize (Sammaz 14 (W), TZEE-W Pop STR and ACR 97 (Y)) gives the threshing capacity of 650 kg/hr, Threshing efficiency of 70.3% at a drum speed of 860 rpm and moisture content of 12.15%. Percentages threshed, and unthreshed was 76.38% and 15.30% respectively. The comparison test with the existing thresher shows that the developed thresher threshes and bags a total of 100 kg of maize in 3 minute and 38 seconds against 6 minutes manual packing and bagging. The time difference shows 65.14% reduction in the time of threshing and bagging operation. The developed maize thresher gives improvement on the timeliness of threshing operation due to the reduction in the time of bagging. It is recommended that further work on automation of the feeding of maize cobs into the machine and stitching the bags should be carried out for the improvement of the machine productivity.

**Keywords:** Screw auger, Motorized, Development, Performance evaluation, Enhanced, Threshing

## 1 INTRODUCTION

**M**aize (*zea mays L.*) is one of most important staple cereal crops widely cultivated throughout the world from wet evergreen climate of the forest zone to the dry ecology of the Sudan Savanna [1]. Processing of agricultural product like maize into quality forms, prolong the useful shelf life of these products and ensures the availability of the product all year round. The major steps involved in the processing of maize include harvesting, drying, de-husking, threshing, storing, and milling [2]. One of the major challenges of maize production is threshing; the process involves the removal of grain from their respective cobs [1, 2]. The process is time consuming, tedious and labor-intensive especially to the larger small-scale maize farmers. Modern maize threshing machines has helped to reduce drudgery and brought about increased in productivity of maize and ensure safety and comfort of work process [3]. The existing maize threshing machines commonly available are similar in terms of the threshing, cleaning, and discharge of threshed grains beneath the machine. Other major problems associated with these threshers are the manual packing and bagging of the threshed maize which is too tedious and time consuming. Part of the solution to these problems lies in the development of a relatively low-cost labour-intensive, locally based maize motorized threshing machines that will meet the requirements of rural farmers with minimal labor, improved efficiency and promote product quality [3, 4, 5]. Various attempts have been made in Nigeria at different time to design and modify the available maize threshing machines, however, the operation is still tedious and labour intensive especially in the feeding of the machine, and the manual packing and bagging of threshed maize [4, 6]. Besides, the cost of purchasing such threshers were high for the rural farmer, hence this underscores the need for the design and development of a

specific, an efficient and affordable low-cost maize thresher machine with screw auger assembly to automatically bag the threshed maize. The developed maize thresher provides efficient and portable maize threshing with reduced labor, and improved timeliness of the threshing operations.

## 2 MATERIALS AND METHODS

### 2.1 General Design Considerations

In the design of motorized maize threshing machine, some relevant physio-mechanical properties of the varieties of maize cobs and grains commonly grown were considered. These properties include the determination of shape and size, coefficient of friction, bulk density, moisture content and, angle of repose. The procedures used were in accordance with ASAE S396 Standard [7, 8]. The motorized maize threshing machine with extended platform-hopper and screwed auger conveyor for effective bagging of threshed maize is cheap, light in weight for safe transportation, durable and high efficiency, comfort and ease of operation, low cost of maintenance, use of locally available materials. To achieve this some factors were considered among which include: the machine noise, vibration, arrangement of the component parts to be easily dis-mountable for replacement and repairs, placement of controls and the total physical efforts required to arrive at the throughput capacity.

### 2.2 Description of the Machine

The maize threshing machine is as shown in Figures 1 and 2. The thresher consists of the Hopper extension (1, 2) where the unthreshed maize cobs are placed, the threshing unit (5, 6, 8, 10), grain transporting Screw conveyor (17) that transfer threshed maize directly into stationed bags that is positioned at the grain outlet of the conveyor (25), prime mover (23), Grain discharge chute (27), the Blower/ Chaff outlet Fan housing (28). The entire machine is sitting on a frame (31) that is made up of mild steel having four legs.

### 2.3 Design of individual components

The exploded view of the designed machine is shown on Figure 1.

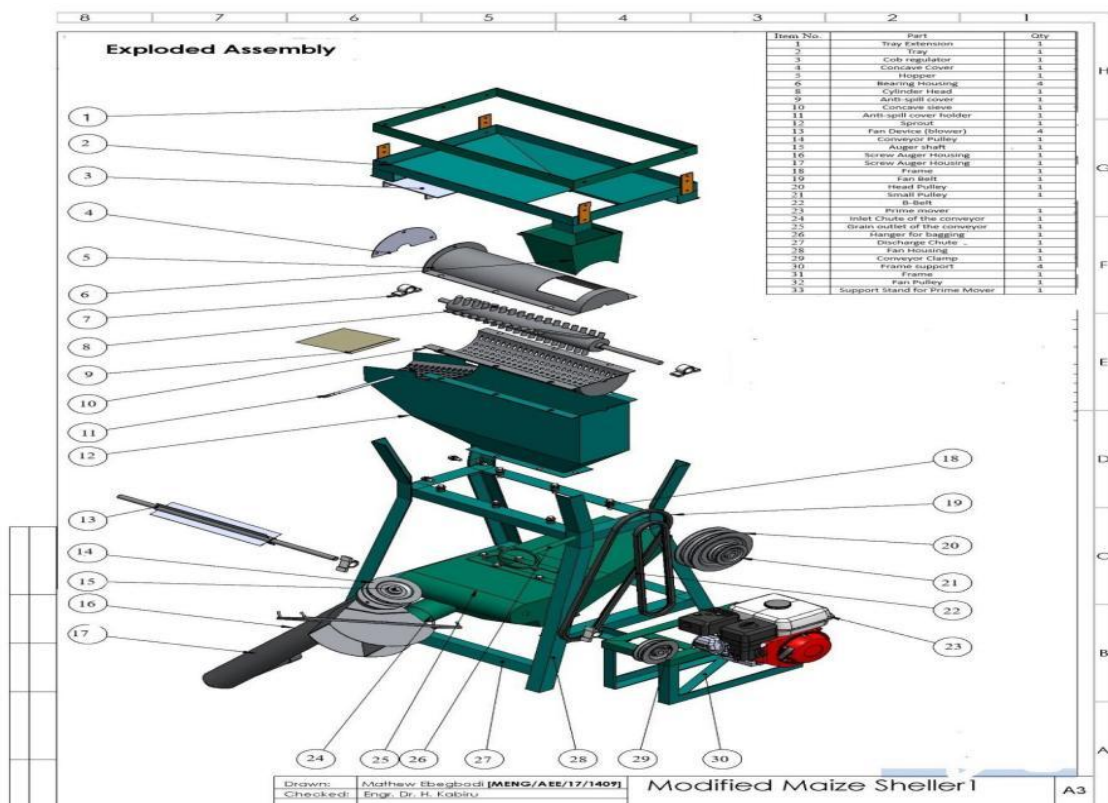


Figure 1. Exploded view of developed Thresher

## 2.4 Design analysis and Calculations

The design and calculations of various component parts of threshing unit was carried out to evaluate the necessary design parameters, strength and size of materials using the relationship reported by [4, 5, 6, 9, 10].

## 2.5 Design of hopper

Hopper is a gravity discharge container with recommended angle ( $\alpha$ ) of inclination of the hopper for agricultural materials of  $8^\circ$  or more and the angle ( $\alpha$ ) of repose of maize is  $27^\circ$  [1, 11]. The hopper was designed to be a frustum, trapezoidal in shape. The volumetric capacity of the hopper  $V_h$  was calculated using the equation.

$$v_h = \frac{h}{3}(A_1 + A_2 + \sqrt{A_1 A_2}) \quad (1)$$

Where  $A_1$  = area of the hopper top  $m^2$ ,  $A_2$  = area of the hopper bottom  $m^2$ ,  $h$  = hopper height m. The gravimetric capacity of hopper,  $G_h$  was determined from the equation.

$$G_h = \rho V_h \quad (2)$$

Where  $\rho$  = maize density ( $415 \text{ kg/m}^3$ ),  $V_h$  = volume of hopper  $m^3$ .

## 2.6 Design of shaft

Shaft is a cylindrical solid rod for rotating machine elements such as spikes, bearings, pulleys, fans, flywheels, cranks, sprockets, gears, belts and other power transmission loaded on it. The diameter was determined using the equation [5, 7].

$$d^3 = \frac{16}{\pi \delta_{sy}} [(K_b M_b)^2 + (K_t M_t)^2]^{1/2} \quad (3)$$

Where  $d$  = diameter of shaft (mm),  $K_b$  = bending moment fatigue and shock factor (1-1.5),  $K_t$  = combined shock and fatigue factor for torsional moment (1-1.5),  $M_b$  = maximum bending moment (Nm),  $M_t$  are resultant torsional moment (Nm),  $\delta_{sy}$  = allowable bending stress ( $47 \times 10^6 \text{ N/m}$ ),  $\pi$  = constant (3.142).

## 2.7 Design of shelling cylinder

The number of spikes on the shelling cylinder is given by the equation [10, 11].

$$N_p = \frac{L_c}{S_{sr}} \times \frac{\pi d}{S_{sc}} \quad (4)$$

Where  $N_p$  = shelling cylinder spikes,  $L_c$  = length of shelling cylinder mm,  $S_{sr}$  = spike spacing on row mm,  $S_{sc}$  = spike spacing on circle mm,  $d$  = shelling cylinder diameter mm.

## 2.8 Threshing Force Required

The centripetal force ( $F$ ) required to thresh maize along the length of the threshing bar within the chamber is given by the equation given by [5, 7, 11].

$$F = m\omega^2 r \quad (5)$$

Where  $F$  = centripetal force, (N),  $m$  = mass of threshing spike, (kg),  $\omega$  = angular velocity, (rad/sec),  $r$  = radius of the arm of the threshing spike, (m). The angular velocity of the driving shaft ( $\omega$ ) is given by.

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

Where  $N$  = speed of the threshing shaft in rpm,  $\pi$  = constant.

## 2.9 Threshing Torque Requirement

The threshing torque ( $T$ ) was also determined using the equation.

$$T = F \times r \quad (7)$$

Where  $F$  = Force available along the threshing spike, (N),  $r$  = threshing radius, (m).

## 2.10 Power Requirement of motorized maize thresher

Appropriate power of motor is determined or selected when the total power requirement for shelling is determined at an appropriate shelling speed. The power delivered ( $P$ ) by shaft along the length of threshing bar is determined by [7, 10].

$$P_t = Fv = \frac{2\pi NT}{60} \quad (8)$$

Where  $P_t$  = threshing power (Nm/s),  $F$  = shelling force (N),  $v$  = velocity (m/s),  $N$  = speed of threshing (rpm);  $T$  = threshing torque =  $Fr$  (Nm). According to [10], the threshing speed that will give very low mechanical damage, but high threshing output is within the range of 300 - 650 rpm.

## 2.11 Power required to drive fan

The power required to drive the fan is given by [7, 10].

$$P_f = \frac{QP_s}{\varepsilon} \quad (9)$$

Where  $P$  = Power (hp) required,  $Q$  = Flow rate ( $1.1 \text{ m}^3/\text{s}$ ),  $P_s$  = Pressure  $\text{kg}/\text{ms}^2$  (pa),  $\varepsilon$  = Efficiency coefficient. To effectively separate maize from the chaff, outlet velocity,  $V=10\text{m/s}$  at flow rate of  $Q=1.1\text{m}^3/\text{s}$  [7, 10, 12], Power required to drive fan =  $0.57 \text{ kW}$ , =  $0.76\text{hp}$ . The recommended horsepower of machine was calculated by using the formula.

$$\text{HP} = \frac{\text{actual hp}}{\text{motor efficiency} \times \text{belt efficiency}} \quad (10)$$

The horsepower of machine was 2 HP.

## 2.12 V-belt selection

A belt provides a convenient mean of transferring power from one shaft to another.

## 2.13 Length of belt

The belt was considered as an open drive since two parallel shafts have to rotate. Belt length was obtained by using equation [7, 11].

$$L = \frac{2C + \frac{\pi}{2} \times (d_1 + d_2) + (d_1 - d_2)^2}{4C} \quad (11)$$

where  $C$  = length of central distance (cm), putting the values of  $d_1$  and  $d_2$ .

## 2.14 Design of component parts of screw conveyer

The screw conveyer comprises of a screw auger in tubular casing. The casing is made up of  $3 \text{ mm} \times 100 \text{ mm}$  internal diameter mild steel pipe and  $1100 \text{ mm}$  long. The design theories and calculations were considered as reported by [12].

### 2.14.1 Volume of Cylindrical Housing

Volume of cylindrical housing is giving by equation 12.

$$v = \pi r^2 h \quad (12)$$

Where:  $r$  = radius of the cylinder (mm);  $h$  = height of the cylinder (mm).

The orthographic view of the machine is shown in Figure 2 below.

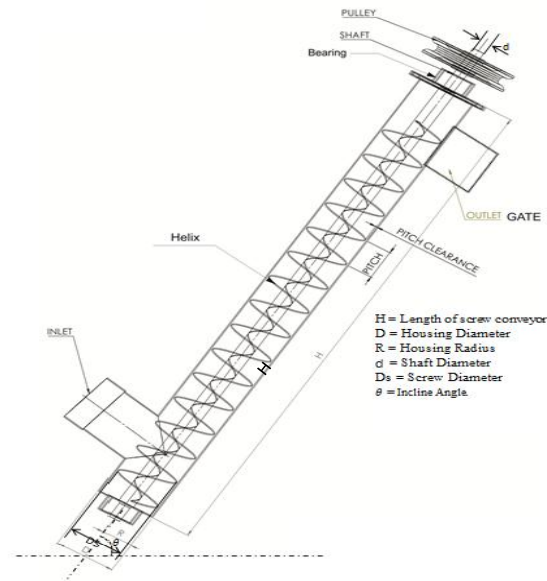


Figure 2. Screw auger in tubular casing

The angle of twist ( $\theta$ ) is calculated using the equation [12].

$$\theta = \tan^{-1} \frac{\pi D}{P} - \tan^{-1} \frac{\pi d}{p} \quad (13)$$

Where  $D$  = Outside diameter of blade,  $d$  = diameter of shaft,  $p$  = Axial pitch of the screw. Angle of twist =  $31.3^\circ$ .

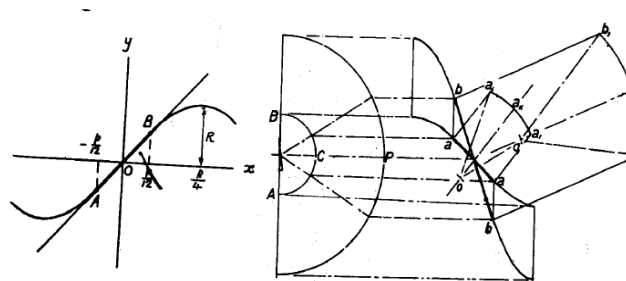


Figure 3. The transverse view of half a pitch length of a uniform spiral blade.

### 2.14.2 Driving Force of the Conveyor

For conveyor to function, the angular moment must be directly proportionally to the angular force which has to be greater than the required driving force. Actual angular force was computed using the equation [12, 13].

$$F_w = \frac{2m_w}{d_1 \tan(\alpha + \beta)} \quad (14)$$

### 2.14.3 Angular Momentum for the Shaft is calculated

$$M_w = \frac{qm}{2\pi n} (Nm) \quad (15)$$

Magnitude of the driving Force " $F_0$ " is determined using the formula.

$$F'_0 = q_m(L_v \pm H) f \cdot g (N) \quad (16)$$

The driving force  $F_0$  must be greater than the Angular force. i. e.  $F_0 > F_w$ .

#### 2.14.4 Screw Conveyor Driving power (P)

Driving power of the screw conveyor was computed using the equation.

$$P_c = Qg(L_v k_i \pm H)kw \quad (17)$$

Where  $L_v$  = Length of the conveyor (1.1m),  $H$  = Perpendicular height (0.9m),  $g$  = Acceleration due to gravity = 9.81 (m/s<sup>2</sup>).

#### 2.14.5 Total Power of the maize thresher

The power required to drive the Maize shelling machine ( $P_{min}$ ) [11].

$$P_{min} = \left[ \frac{2\pi NT}{60} + \frac{QP_s}{\varepsilon} + Qg(L_v k_i \pm H) \right] kw \quad (18)$$

Where  $P_{min}$  = Power required to thresh + fan power + Driving power of screw conveyor .

### 2.15 Material Selection for Construction

Table 1: Material for Construction

sn	Description	Specifications
1	Frame	45×45×5mm angle iron full length
2	Threshing concave/Inlet Hoppers	A 16-gauge sheet metal, ½ sheet size
3	Threshing Drum	A 62×5mm steel pipe
4	Threshing spikes and frame extension.	12mm steel rod
5	frame for hopper extension	A 45×5mm flat bar
6	Spout/Blower chamber	An 18-gauge sheet metal
7	Shafts	A 25×85cm, 20×85cm, 20×120cm
8	Fan blades	A gauge 18 sheet metal
9	Screw conveyor	A gauge 16 sheet metal
10	Conveyor housing	A gauge 18 sheet metal 110cm long
11	Cob Outlet	An 18-gauge sheet metal
12	Bearings	-A 20mm internal diameter radial bearing (6303) -A 25mm internal diameter (6305)

### 2.16 Machine Assembly and Working Principle

Plate I shows the full assembly of the developed motorized maize thresher. The machine is powered by a prime mover (Diesel Engine) 7.3hp capacity. The incoming maize cob fed through the hopper is threshed by the rotating cylinder head in stationary concave threshing Chamber, while the threshed grains falling by gravity through the concave screen are winnowed as they fall across blast of air generated by the rotating fans in the blower chamber.



Plate I. Full assembly of the developed motorized maize thresher

The discharged clean grains are conveyed directly into bags by the operating screw conveyor attached to the discharge chute.

### 2.17 Performance Evaluation of the maize thresher

The developed maize thresher was subjected to test using three different maize seed varieties (Sammaz 14 (W), (TZEE-W Pop STR) and ACR 97 (Y)). 50kg each of unthreshed maize cobs of the three varieties of maize seed was threshed at various speeds at an average moisture content of 12%. The following expression was used to determine the following parameters [4].

$$\text{Throughput Capacity: } T_p = \frac{A}{T_t} \text{ (kg/hr)} \quad (19)$$

$$\text{The Percentage Threshed (\%): } (S) = \frac{M_T - M_{un}}{M_T} \times 100 \quad (20)$$

$$\text{Percentage Unthreshed (\%): } S_{un} = \frac{M_{un}}{M_T} \times 100 \quad (21)$$

$$\text{Threshing efficiency (\%): } \eta = \frac{W_a}{W_t} \cdot 100 \quad (22)$$

Where, A =total weight of material handled (which includes threshed and un-threshed); T<sub>t</sub> = the total time taken in handling the materials; S = Percentage Threshed (%); S<sub>un</sub> = Percentage Unthreshed (%); M<sub>un</sub>= mass of unthreshed grains, (kg); M<sub>T</sub> = mass of total grains in the sample, (kg).; W<sub>a</sub> = total weight of threshed grains (output) in (kg); W<sub>t</sub> = total weight of grains (input) in (kg).

### 3 RESULTS AND DISCUSSION

Table 2 shows the result of Physico-mechanical properties of maize Seed determined for the design and construction of maize thresher. The results of dimensions is in agreement with that reported by [4, 14, 15].

Table 2. Physico-mechanical properties of maize Seed

Properties	Moisture content (%)	Seed length (mm)	Seed width (mm)	Seed thickness (mm)	Diameter (mm)	Surface area(mm <sup>2</sup> )	Seed mass (g)	Bulk density (g/cm <sup>3</sup> )	Angle of repose(°)	Frictional angle (α°)	
										Maize Seed	Maize Cob
ACR97(Y)STR	11.74	14.98	10.95	6.88	9.40	109.64	110.10	69.12	30.62	27.12	46.74
Standard diviation	0.00	0.21	0.21	0.16	0.11	0.00	0.00	0.01	0.21	0.02	0.02
Sammaz 14	11.74	15.39	11.57	8.18	94.46	130.03	125.14	70.30	28.82	27.00	41.64
Standard diviation	0.00	0.11	0.16	0.08	0.04	0.00	0.00	0.00	0.21	0.00	0.01
TZEE(W) STR	12.60	8.69	6.01	3.01	5.88	44.52	53.11	111.41	26.00	26.20	36.12
Standard diviation	0.00	0.15	0.30	0.23	0.12	0.00	0.00	0.00	0.00	0.02	0.01

Table 3 shows the design results of the principal parameters of the maize thresher

Table 3. Design Results of the thresher

Parameters	Specifications
Overall machine dimension (LxWxH)	1284x1026x1250mm
Hopper extension (LxWxH); Angle of inclination	720x440x220 mm; 22°
Hopper opening dimension (LxWxH)	220x200x150 mm
Inclination angle of inlet hopper	55°
Length of threshing drum	520mm
Length of concave	560mm
Grain Conveyor length	1100mm
Diameter of the threshing cylinder Head	110mm
Diameter of cylinder threshing concave/cylinder clearance	180mm; 35mm
Threshing drum speed	860rpm
Grain Conveyor length	1100mm
Screw Pitch; Screw Diameter	80mm; 100mm
Diameter of tubular Casing; Pitch/Tube clearance	110mm; 5mm
Diameter of tubular Casing; Pitch/Tube clearance	110mm; 5mm
Inclination angle of screw conveyor	65°
Diameter of screw shaft	25mm
Power required to drive fan	0.57kW
Power required to drive screw conveyor	0.76kW
Powered required for threshing	4.1kW
Power required to drive thresher	5.43kW (7.5hp)

The designed results were in agreement with analysis reported by [6, 9, 12]. Table 4 below shows the Mean Values of maize thresher performance results at different drum speed and moisture content. The threshing capacity of 650kg/hr, Threshing efficiency of 70.3% was achieved at a drum speed of 860rpm and moisture content of 12.15%. The results agree with [1, 4, 10].

Table 4. Mean Values of maize thresher performance results

Sn	Drum speed rpm	Thoroughput capacity (kg/hr)	Threshing Efficiency (%)	Percentage threshed (%)	Percentage unthreshed (%)	Moisture content (%)
1	540	396	51.3	66.21	21.6	12.15
2	750	500	61.7	66.21	19.3	12.15
3	860	650	70.3	76.38	15.3	12.15
4	900	648	67.0	71.24	16.6	12.15

Comparison of the developed maize thresher and the commonly existing maize thresher in terms of performance the developed thresher threshes and bags a total of 100 kg quantity of threshed maize in 3 minute and 38 seconds against 6 minutes manual packing and bagging.

#### 4 CONCLUSIONS

The machine performance results gives the threshing capacity of 650kg/hr, threshing efficiency of 70.3% was achieved at a drum speed of 860rpm and moisture content of 12.15%. Percentage threshed, and unthreshed was 76.38% and 15.30% respectively. The comparison test with the existing thresher shows that the developed thresher threshes and bags a total of 100 kg quantity of maize in 3 minute and 38 seconds against 6 minutes manual packing and bagging. The developed maize thresher gives improvement on the timeliness of threshing operation due to the reduction in the time of bagging.

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