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Development of Cowpea Thresher

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Abstract

A cowpea thresher that uses petrol engine was developed to overcome drudgery of threshing with manually operated thresher and also to replace motorized cowpea thresher that cannot be used in areas where there is no supply of electricity. The performance tests on the machine were replicated three times using 10000, 8000 and 6000 grams of kannanado cowpea pods at the threshing cylinder speed of 700, 800 and 900 rpm each and moisture contents of 11.05%, 13.65% and 14.75% respectively based on the following parameters; Threshing efficiency, throughput capacity and percentage seed damage. The findings of the tests showed that the thresher had highest threshing efficiency of 98% at moisture content of 11.05%, threshing cylinder speed of 900 rpm and feed rate of 6 kg/hr. The maximum throughput capacity was observed to be 46.18 kg/hr at the feed rate of 10 kg/hr, 11.05% grain moisture content and threshing cylinder speed of 900 rpm. A highest cleaning efficiency and grain damage of 93.06% and 4.90% respectively were observed. This revealed that as the cylinder speed increased the threshing and cleaning efficiency and the throughput capacity also increased whereas feed rate and moisture content were decreased. The test also showed that high moisture content has a tendency to reduce the mechanical seed damage for the variety (kannanado) of cowpea investigated. Therefore, cowpea moisture contents of 11.05 % and threshing cylinder speeds of 900 rpm are the crop-machine parameters combination for optimum thresher performance. The performance of the machine is satisfactory; small-scale farmers will find more comfort in using it for threshing.

Keywords: Grain damage, cowpea, moisture content, threshing, feed rate, throughput capacity, efficiency.

1.0 INTRODUCTION

Cowpea (*Vigna unguiculata*) is an annual herbaceous legume from the genus *Vigna*. It is a major staple food crop grown in the semi-arid tropics of Africa, Asia, Europe, United States, and Central and South America. Cowpea originated from Southern Africa and was later moved to Asia, East and West Africa [1].

Among many uses of cowpea, the seeds are a major source of proteins, carbohydrate and vitamins for man and animals, and also a source of cash income. All parts of cowpea are useful, the young leaves and immature pods are eaten as food and feed for human being and animal respectively [2]. Cowpea is the most commonly used crops in Nigeria in different processed form. They are boiled and eaten alone or with other cereal crops [3] or used in preference of some derbies as ‘‘akara” (fried beans paste) or ‘‘moi- moi’’ (steam beans pasta) or bean soup etc [3-6].

According to [7], Nigeria is the largest producer of cowpea, as 58% of worldwide production comes from the country. However, Nigeria is still the largest consumer of the crop. To supplement our production, substantial amounts of cowpea are imported to Nigeria from the neighboring countries like Niger Republic and Cameroon, showing that production and demand for the food crop is still inadequate [8].

In Nigeria, despite the values of cowpea, one of the major problems facing small-scale and commercial farmers in the processing of the product is threshing [9]. According to Dauda [10], threshing of the cowpea is mainly done by manual and traditional method. This is achieved by pounding in a mortar with a pestle or spreading the ripped dried crops on the floor where they are beaten with a stick. Whatever the method used cowpea seeds can be easily damaged if threshed too roughly or when too dry. Improper harvesting and threshing of cowpea usually results in losses of up to 5% of the crop [11, 12]; Cowpea should be properly threshed before storage because it increases the shelf life of the crop and reduces its venerability to weevil attack. Olaoye [13] reported that better production techniques alone are not adequate to solve the problem of postharvest losses in production of cowpea. To minimize post harvest losses, attention must also be paid to proper method of

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harvesting and threshing the crop.

Convectional mechanical threshers such as the Ben-agro paddy thresher, NIAR multi-purpose crop threshers and Alvan Blanch Midget threshers exist [14], but these machines are not suitable for threshing cowpea. The major problems of conventional mechanical threshers are that a conventional cylinder and concave thresher cannot be used to thresh cowpeas due to sensitive pericap of beans and the brittle nature [11]. Maunde [15] suggested preliminary thresher in the machine before the drum to perform the secondary threshing. Based on the work of [16] and [17], a combine shape was suggested for hopper design (upper part rectangular and lower part trapezoidal), for free flow of cowpea.

At present, various machines both of manually and mechanically operated threshers have been developed to solve the problems associated with cowpea threshing in Nigeria [13, 18-23]. However, manual operated threshers are not ergonomically fit for the operators as this operation causes fatigue, severe body pains, reduced output and great seed loses. Power supply is not also stable in Nigeria and as such farmers do not find it easily to use it when needed for threshing cowpea. Worst still, 90% of the rural areas in Nigeria where cowpea farming is carried out does not have electricity.

In a bid to overcome the identified twin problems of cowpea threshing machines and electric power supply in Nigeria, a cost effective cowpea thresher that uses petrol (I.C) engine for threshing beans becomes necessary. The general objectives of the study are to design, fabricate and test cowpea threshing machine that uses petrol engine as power source.

2.0 MATERIALS AND METHOD

2.1 Design Considerations

The selection of materials for the fabrication of the thresher was based on the design considerations.

The following design factors were taken into consideration:

The components of the machine were fabricated from mild steel materials of various sizes and shapes. The materials were selected based on the strength, suitability, cost and reliability required by each component of the machine and also on the availability of the materials in local market without compromising their quality. This is to reduce the overall cost of the machine, making it affordable. To achieve optimal threshing of the chaff from the grain, the cowpea moisture content and physical parameters of the materials to be threshed were considered.

As a matter of necessity, anthropometric data of the end users in terms of operation, height, stability and vibration were critically considered.

Since the drum shaft of the thresher will be subjected to different loads (tension, compression, twisting and bending), effort was made to calculate the forces acting on the shaft.

Petrol engine of 5.5 horsepower was used to power the thresher. The choice of petrol engine was to give room for the usage of the thresher in the villages where electric supply is not yet available and to make use of the machine in case of epileptic supply of power in places connected to national grid.

2.2 Description of Machine Parts

The developed cowpea threshing machine is shown in Figure 1 below. The machine has the following components:

Hopper: This is the feeding unit of the machine. It is made up of mild steel sheet of 2 mm thickness. It was cut and bent with cutting and bending machine to form a trapezoidal shape of the hopper and then welded at the edges. The hopper has an upper length and width of 600 mm x 350 mm and lower length and width of 536 mm x 296 mm respectively with a height of 316 mm.

Shaft: It is a mild steel solid rotating shaft of dimensions 24 mm x 613 mm with beaters attached to the center of the threshing chamber. The shaft was connected to bearing on both sides and also to a pulley on one side. The shaft transmits power from the internal combustion engine to the threshing unit.

Concave section: This is a metal steel of 500 mm in dimension with thickness of 2 mm. The concave is made of mild steel sheet rolled into 180 mm diameter cylinder. The threshing cylinder was placed inside the concave. The concave has 10 mm diameter holes spaced all over its surface and at the right angle to the cylinder.

Threshing unit: The threshing units consist of a cylindrical roller with beaters iron rod steel of dimensions 10 mm x 59 mm, which was welded in a radial manner. Iron rod steel beaters were also welded in a radial manner to the housing. It is the unit where the cowpea seeds are beaten out of the pods and separated first. It is made of mild steel sheet. It consists of rotary drum (serrated type) to give room for easy flow of the cowpea.

Screen: The screen is made of mild steel sheet with thickness of 1.5 mm and drilling of 10 mm (560) bores. It is concave in shape and perforated to allow for the threshed seed and chaff to fall under gravity into the beans outlet where the threshed beans will be finally collected. The screen is located at the distance of 450 mm below the threshing cylinder.

Bearing housing: The bearing housing was made from a thick mild steel pipe, which was properly and carefully matched with the diameter of the required bearing to ensure proper fittings. The bearing housing was bolted to both ends of the frame in other to accommodate the shaft.

The chaff outlet: This outlet is situated at the right side of the machine. It has a rectangular shape and is directly below the threshing chamber for the chaff to be easily discharged.

Beans outlet: The beans outlet is situated at the left side of the machine. It was fixed at an angle of 45^0 to allow easily discharged of the shelled beans.

Machine frame: This is the rigid frame stand made from angle iron which acts as structural foundation upon which other parts are assembled or mounted on. It measures 800 mm x 740 mm with thickness of 1.5 mm. The required plates were cut according to the dimensions in the drawing and necessary holes were marked out and drilled at strategic point on the angle iron. The main frame was structured out as specified in the detailed drawing and the structure was given a temporary weld for any adjustment as the work process.

Collector: The fabrication process of the collector was similar to that of the screen; except that the collector has no perforation on it. The collector was fitted at inclined angle of 45^0 with outlet which enables the threshed beans grains to roll down at angle of 40^0 towards the collection outlet to avoid any leftover grains remaining on the surface of the collector.

Pulley: It transmits power from the petrol engine to the threshing shaft and fan shaft through the v-belt.

Blower: It is a straight blade centrifugal fan with six blades of 0.5 mm thick, 100 mm length and 60 mm breadth. The fan is stationed at the distance of 640 mm below the perforated concave screen to separate cowpea seeds from the chaff. The exit of the fan is at right angle to the direction of flow of seeds and chaff from the threshing unit.

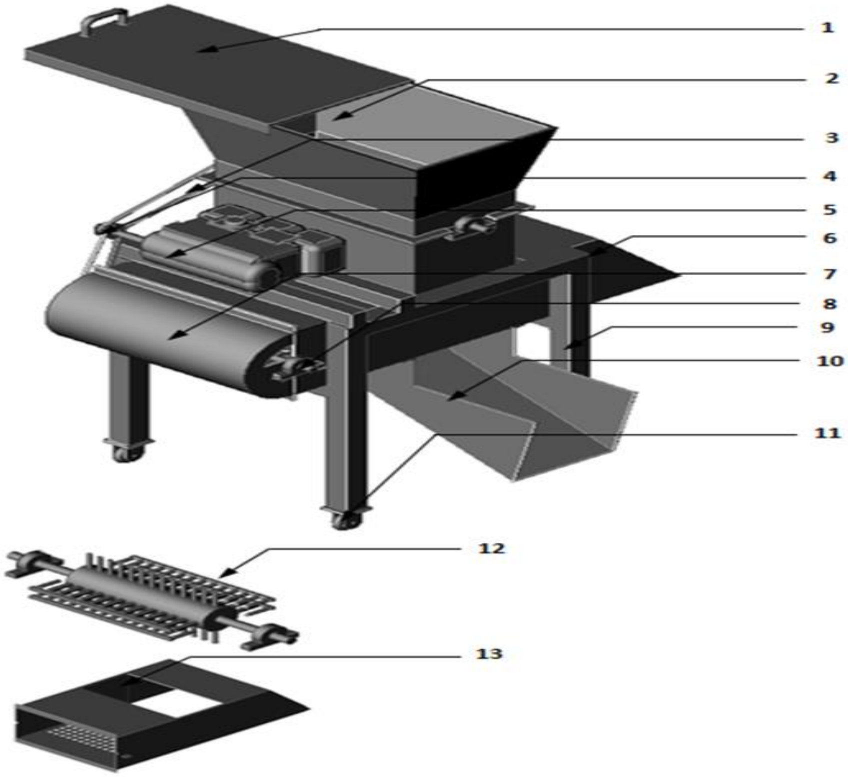
Belt: It was used for transmitting power from the prime mover to the cowpea thresher.

Figure 1: Developed Cowpea Thresher

2.3 Principle of Operation of the Machine

The unthreshed cowpea dried to a desired moisture content of a known quantity are to be fed into the threshing unit of the machine through the hopper after starting the prime mover (petrol engine) that drives the machine and the blower. The petrol engine transmits power to the shaft assembly for rotation. As the mechanism of the shaft assembly rotate, it sets up a reaction in the threshing unit, the cowpea seeds are forced out of their pods due to inner locking movement of the spikes (beaters) on the shaft assembly and the housing of the machine. This is due to the impact force that is set up between the spike (beaters) and the cowpeas that come into close contact in the threshing unit.

After this reaction in the threshing unit has taken place, the threshed beans together with the chaffs fall on the surface of the screen under before the blower incorporated in the machine blows the chaff from the beans grains. The beans then fall to seed outlet whereas chaffs fall to chaff outlet for collection. Figure 2 and 3 shows the isometric and orthographic views of the machine respectively.



S/N	DESCRIPTION	QTY	MAT	REM
1	COVER	1	M.S	FAB
2	HOPPER	1	M.S	FAB
3	BELT	2	RUB	PUR
4	PULLEY	3	M.S	FAB
5	PETROL ENGINE	1	M.S	PUR
6	CHAFF OUTLET	1	M.S	FAB
7	BLOWER	1	M.S	PUR
8	BEARING	1	M.S	PUR
9	MACHINE FRAME	1	M.S	FAB
10	BEANS OUTLET	1	M.S	FAB
11	ROLLER & TIRE	1	RUB	PUR
12	BEATERS	42	M.S	FAB
13	SCREEN CHAMBER	1	M.S	FAB
14	BOLT & NUT	20	M.S	FAB

Figure 2: Isometric view of the machine

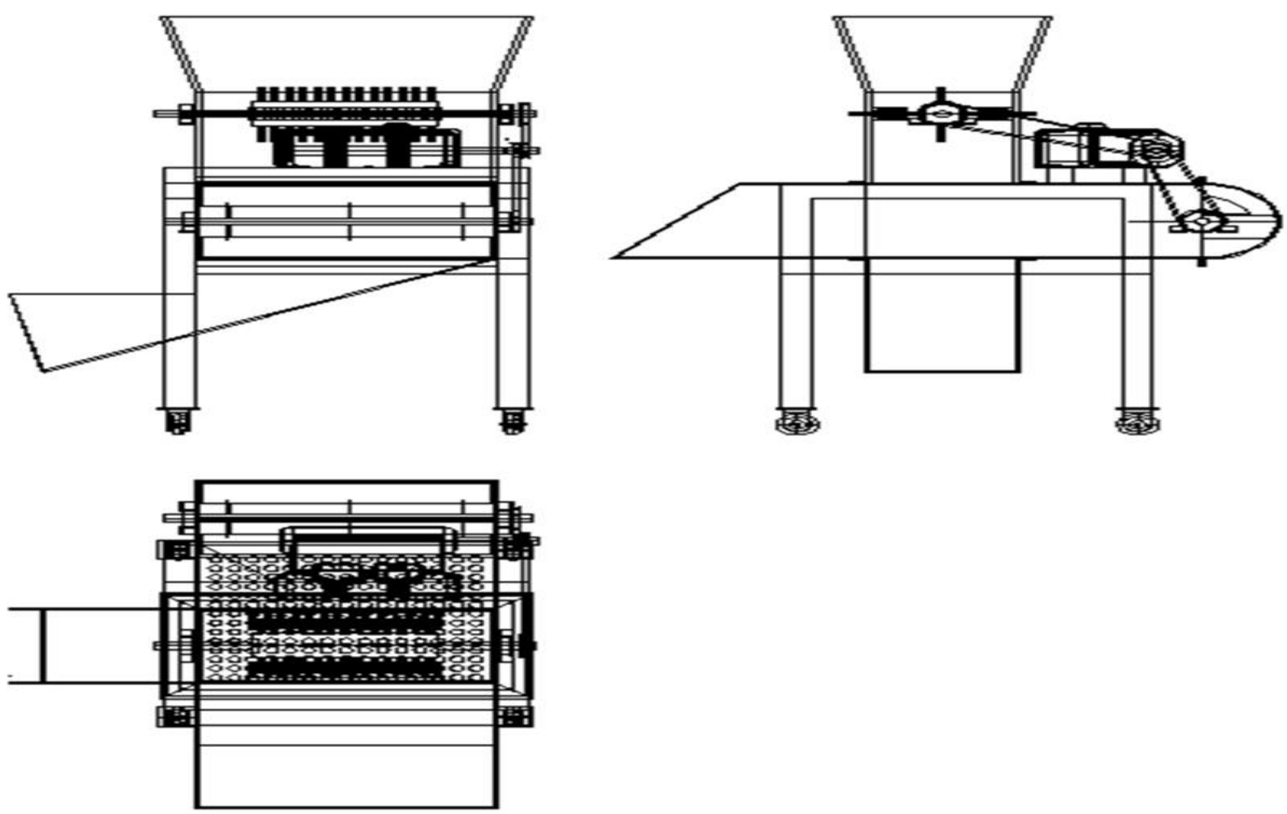


Figure 3: Orthographic View of the Machine

2.4 Design Calculations

i. Diameter of the threshing drum

The diameter of threshing cylinder was determined to know the capacity of the threshing drum. A standard formula for calculating the volume of cylinder was used and is given as follow:

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

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

Where V = volume of the drum, mm^3, d = diameter of the cylinder, mm, L = length of the cylinder, mm

ii. 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. The weight of the threshing drum is expressed as:

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

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

Where W = weight of threshing drum, N, M = mass of threshing drum, kg, g = acceleration due to gravity, m/s^2, ρ = density of the drum, kg/m^3, v = volume of the cylinder, m^3.

iii. Maximum bending moment on both vertical and horizontal loading

Maximum bending moment on both vertical and horizontal loading was obtained using the equation (5) as given by [24]:

$$M_b = \sqrt{(M_{DV})^2 + (M_{CH})^2)} \quad (5)$$

Where M_b = Maximum bending moment on both vertical and horizontal loading, Nm, M_{DV} = Bending movement on vertical loading, M_{CH} = Bending movement on horizontal loading

iv. Torque exerted on the driven pulley

The torque required to transmit the belt was determined using the equation provided by [25];

$$T = (T_1 - T_2)\ R \quad (6)$$

Where T = Torque supplied to the driven pulley, Nm, T_1 = Tension in the tight side of the pulley, N, T_2 = Tension in the slack side of the pulley, N, R = Radius of the driven pulley, mm.

v. Diameter of the shaft

The equation of a shaft having little or no axial loading was used to compute the diameter according to [24] as shown in Equation (7).

$$d = \frac{16}{\pi S_a} \sqrt{(K_b M_b)^2 + (K_t M_t)^2)}^{1/3} \quad (7)$$

Where, d = diameter of the shaft, mm, M_b = bending moment, Nm, K_b = combined shock and fatigue factor applied to bending moment, K_t = combined shock and fatigue factor applied to torsional moment, S_a = allowable stress, N/m^2. For rotating shaft where load is suddenly applied (minor shock), [24] stated that K_b and K_t range between 1.5 to 2.0 and 1.0 to 1.5 respectively.

vi. Second polar moment of the area of the shaft

The second polar movement of the area of the shaft was calculated using the expression according to [25]

$$J = \frac{\pi d_S^4}{32} \quad (8)$$

J = second polar movement of the area of the shaft, mm^4, Ds = diameter of the shaft, mm

vii. Torsional shear stress on shaft

Torsional shear stress on shaft is given by [26]

$$\tau = \frac{Tr}{J} \quad (9)$$

Where τ = Torsional shear stress, N/m^2, J = second polar movement of the area of the shaft, mm^4, ds = Diameter of the driven shaft, mm.

viii. Torsional rigidity

The amount of twist permissible is given by [25]

$$\theta = \frac{TL}{CJ} \quad (10)$$

Where, L = Length of shaft, mm, θ = Angle of twist in radians, T = Torque or twisting moment on shaft, N/m, C = Modulus of rigidity, N/mm^2, J = Second moment of area of the section about its polar axis or polar moment of inertia.

ix. Strain energy in the shaft

The strain in the shaft due to torsion as shown in the equation (11) is given by [27]:

$E_s = ½ T\theta$ (11)

Where E_s = Strain energy in joules, T = Torsion on the shaft, Nm, θ = Radian deformation (angle of twist)

x. Belt and pulley drive mechanism

The thresher requires two pulleys for operation: one pulley will be attached to the petrol engine (driver) and the second pulley will be attached to the shaft (driven) carrying the cowpea threshing compartment and beaters. The intended ratio of the speed driven pulley to that of the driver is 2:3. The relationship shown in equation (12) below was used to determine the transmitted speed as provided by [25]:

$$N_1D_1 = N_2D_2 \quad (12)$$

Where N_1=rpm of the petrol engine, D_1=Diameter of petrol engine (driver) pulley, mm, N_2=rpm of the driven pulley, D_2=Diameter of driven pulley, mm.

xi. Angular speed of the driven shaft

The angular speed of the driven shaft was calculated using the following equation as provided by [25]:

$$W_2 = \frac{2\pi N_2}{60} \quad (13)$$

Where W_2 = Angular speed of the driven shaft, rad/s, N_2 = rpm of the driven pulley

xii. Velocity of the belt

The velocity of the belt was calculated using the expression according to [25] as:

$$V = \frac{\pi D_1 N_1}{60} \quad (14)$$

Where V = Velocity of the belt, m/s, D_1 = Diameter of the driver pulley, mm, N_1= Speed of the motor, rpm.

xiii. Power requirement to drive the machine

The maximum power transmitted by the belt is given by [24]:

$$P = (T_1 – T_2) V \quad (15)$$

Where: P = Power transmitted by belt to drive the machine, kw, T_1 = Tension in the tight side of the belt, N, T_2 = Tension in the slack side of the belt, N, V = Velocity of the belt in m/s.

xiv. Pulley Centre Distance

The centre distance was determined using the expression established by [24] as:

$$C = \frac{D_2 + D_1}{2} + D_1 \quad (16)$$

Where: C = Centre distance between the threshing drum shaft pulley and the motor pulley, mm. D_1 = Diameter of the petrol engine pulley in mm, D_2 = Diameter of the driven pulley in mm.

xv. Length of belt required for power transmission.

According to Sarkar [26];

$$l_b = \frac{\pi}{2}(D_1 + D_2) + \frac{(D_2 - D_1)^2}{4C} + 2c \quad (17)$$

Where: L_b = Length of the belt in mm, D_1 = Diameter of the petrol engine pulley in mm, D_2 = Diameter of the driven pulley in mm, C = Centre distance between the threshing drum shaft pulley and the motor pulley, mm.

xvi. Angle of contact between pulleys and the belt.

The contact angle α_1 and α_2 for small and large pulley respectively may be calculated as given by [28]:

For the driver,

$$a_1 = 180 + 2\alpha \quad (18)$$

$$where, \alpha = sin^{-1}\left(\frac{D_2 - D_1}{2C}\right) = 180 + 2\left(sin^{-1}\left(\frac{D_2 + D_1}{2C}\right)\right)$$

For the driven

$$a_2 = 180 – 2\alpha \quad (19)$$

xvii. Size of belt required for power transmission

According to British Standard (B.S. 1440:1979) the V-belts are made in seven types i.e. A, B, C,D,E,Y and Z. Selection A, B, C, D, and E are designed for heavier industrial requirements whereas the Y and Z sections are for single belt drives on domestic and lightly loaded equipment. Hence, standard V-belt with the following nominal cross-section in accordance with B.S. 1440:1979 will be adequate. Cross-section Area, Y, Nominal top width = 6.5mm Nominal height, T = 4mm

xviii. Centrifugal tension in the belt

The tension on both sides of the belt could be obtained from the following expressions given by [27]:

$$\frac{T_1 - T_C}{T_2 - T_C} = e^{\mu\theta} \quad (20)$$

Where: T_c = Centrifugal tension which tends to cause the belt to leave the pulley and reduces the power that may be transmitted.

Belt tension

The tension on the belt was determined using the following relation [25]:

$$2.3\log\frac{T_1}{T_2} = \mu\theta \quad (21)$$

Where T= Tension on the belt, T_1 = Tension on the tight sight, N, T_2 = Tension on the slack side, N, θ = Angle of wrap.

2.5 Testing Of the Machine with Cowpea Pods

The performance test of the cowpea threshing machine was carried out using kannanado variety harvested from Auchi polytechnic, Auchi demonstration farm, Edo state, Nigeria. Dry cowpea pods of 10000 grams were fed into the hopper which was held from leaving the chamber by the help of protective cover and control slot. The machine prime mover was started and stop watch switched on for the threshing operation to take place. After the threshing operation was completed, the entire output were collected and weighed, using weighing balance. Then time used for the threshing operation was recorded. Also weighed were damaged seeds, mass of threshed pods, mass of pods of removed, mass of unthreshed pods and mass of clean seeds. The test was repeated three more times with 8000 grams and 6000 grams of cowpea pods using the same procedure under three different moisture contents of 11.05%, 13.65% and 14.75% respectively. The threshing cylinder speed was varied at 700, 800 and 900 rpm at different moisture contents during the test operations. The machine performance was evaluated on the basis of threshing efficiency, throughput capacity, percentage damage and percent material loss parameters and were calculated using the relations below as suggested by [21, 23, 29]:

$$Cleaning\ \text{efficiency}, \eta\ (\%) = \frac{W_S - W_C}{W_S} \times 100 \quad (23)$$

$$\text{Percentage Damage}\ (\%) = \frac{Q_d}{Q_d + Q_U} \times 100 \quad (24)$$

$$\text{Throughput Capacity}\left(\frac{kg}{hr}\right) = \frac{W_s}{T_m} \quad (25)$$

$$\text{Threshing efficiency}(\%) = \frac{W_s}{W_s + W_u} \times 100 \quad (26)$$

Where Q_t = Total weight of threshed and unthreshed pods (kg)
T_m =Ttime taken for threshing operation (hr)
W_S = Weight of total mixture of grain and chaff received at the grain outlet (kg).
W_C = Weight of chaff at the main outlet of the thresher (kg).
Q_u = Weight of undamaged seeds (kg).
Q_d = Weighof damaged seeds (kg).
Wu = Weight of unthreshed cowpeas (kg).
Note that:

$Q_s = W_s + W_u$
$Q_t = W_s + W_u + W_h$
$W_s = Q_u + Q_d$

3.0 RESULTS AND DISCUSSION

3.1 Effects of varying pulley size of petrol engine on free run test of the cowpea thresher without load.

The effect of varying pulley size of petrol engine on free run test of the cowpea thresher without load is shown in Table 1. With the same pulley size of 150 mm diameter on both petrol engine and rotor pulley ends, it was observed that the machine vibrated excessively with noise. As the pulley diameter size on the petrol engine was reduced from 150 mm to 100 mm, the rotor speed reduced from 1425 to 967 rpm and there was still vibration of machine parts but not excessive.

Table 1: Effect of Varying Speed on the Machine

Diameter of pulley on electric motor, d(mm)	Diameter of pulley on rotor chaff, d(mm)	Electric motor speed, N rpm	Rotor speed, N rpm
150	150	1425	1425
100	150	1425	976
90	150	1425	870
80	150	1425	773
65	150	1425	628

As the diameter of pulley on petrol engine was reduced further to an interval of 100 mm and keeping the diameter of pulley on the rotor constant, there was corresponding reduction in the rotor speed. Consequently as the diameter of pulley on the petrol engine was gradually reduced up to point of 80mm which has a corresponding rotor speed of 773 rpm, the machine ran smoothly without vibration and material damage was reduced to a minimal. Further reduction of the petrol engine pulley diameter to 65 mm showed drastic poor performance of the machine and excessive low output was observed. Therefore, the efficient running speed of the machine is 773 rpm with petrol engine pulley diameter of 80 mm.

The results of the performance tests on the developed machine with cowpea pods are presented in Figure 4, 5, 6 and 7.

3.2 Effects of threshing cylinder speed on threshing efficiency at various feed rates and moisture contents

Figure 4 shows the effects of cylinder speed on threshing efficiency of the cowpea thresher at different feed rate and moisture contents. The highest threshing efficiency of 98% was obtained at the highest speed of 900 rpm, lowest moisture content and feed rate of 11.05% and 6 kg/hr respectively. This result is a bit higher than that obtained by Oforka [30] and Fawohunre and Olajide [22] which were 96%.and 91.2% respectively. This could be attributed to lower moisture content of the cowpea pods and high speed of the beaters on the threshing drum which resulted to more impact on the cowpea pods to dislodge the grains. Threshing efficiency decreased to 96.50% as the feed rate was increased to 10 kg/hr at higher moisture content of 13.65% and cylinder speed of 800 rpm. This result shows that moisture content has great effects on threshing efficiency of cowpea. This might also be attributed to the fact that at higher feed rate, more grains clustered within the threshing drum which reduces the chances of individual grains getting into contact with the surface area available for frictional impact and this cushioning effect reduces efficiency.

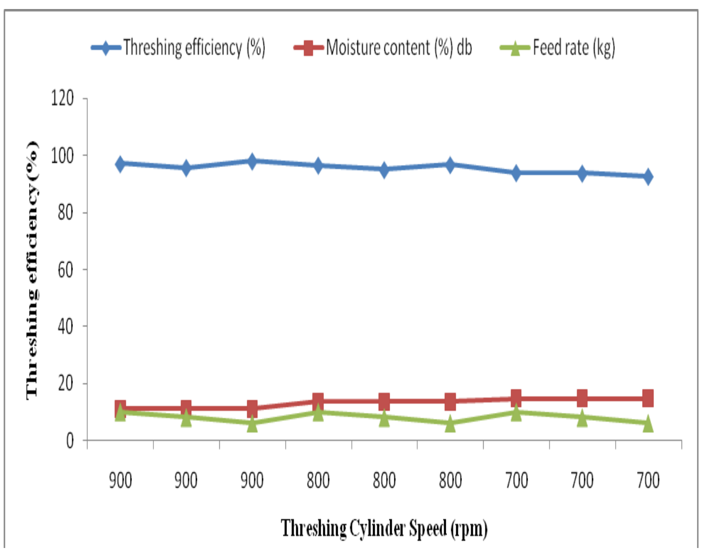


Figure 4: Effects of Threshing Cylinder on Threshing Efficiency at various Feed Rates and Moisture Contents

This result is in close range to that obtained by [31] which was 98.28% at drum speed of 1200 rpm. The lowest threshing efficiency of 92.50% occurred at the lowest speed of 700 rpm, feed rate of 10 kg/hr and highest moisture content of 14.75%. Irtwange [21] and Mohammed et al; [31] obtained threshing efficiency of 96.29% and 98.28% at moisture content of 11.06% to 12.02% and 9.01% with speed of 1400 rpm and 1200 rpm respectively for cowpea. Dauda [10] also reported a threshing efficiency in the range of 84.1% - 85.9% for a manually operated cowpea thresher whereas [32] obtained a threshing efficiency in the range of 67.5% - 97.7% for a motorized medium scale thresher-cleaner. This indicates that threshing efficiency increases with increase in cylinder speed and decrease in moisture content and feed rate.

3.3 Effects of threshing cylinder speed on percentage mechanical seed damage at various feed rates and moisture contents

The mean values of the mechanical grain damage at different moisture content, threshing cylinder speed and feed rate are shown in Figure 5. The mechanical seed damage ranged from 0.50 to 4.90% with increasing moisture content. The least grain damage of 0.50% was observed at the threshing cylinder speed of 700 rpm and lowest feed rate of 6 kg/hr whereas the highest grain damage of 4.90% was obtained at the highest cylinder speed, feed rate of 900 rpm and 10 kg/hr.

However, it was observed that grain damage decreased slightly to 3.40% with an increase in feed rate which occurred at 8kg/hr and 11.06% of moisture content. This could be compared to that of [31] where they obtained a grain damage of 1.56% at moisture content of 9.01% and cylinder speed of 1200 rpm. Dauda [10] reported grain damage of 1.8 - 2.3% for a manually operated cowpea thresher while [33], [21] and [21] reported grain damage of 4.17%, 3.55% and 5.1% for cowpea respectively. The 11.05 and 13.65% moisture content proved to be better options for the effective thresher performance. However, the values of seed damage percent obtained from the 11.05 and 13.65% moisture content at different cylinder speed are higher than the accepted level of 1.1 % [34]. This may be due to the high threshing cylinder speed of 900 rpm used [35] which seems to have higher influence on seed damage. Therefore, it is expected that lower speeds could bring the damage to the acceptable level.

The quantities of grains that were broken during threshing increased with a decrease in moisture content and increase in feed rate with slight increase in threshing cylinder speed. The highest mechanical grain damage of 4.90% compares favourably with the presumption by [11] that depending on the amount of cowpea threshed, the amount of broken cowpea should not exceed 15% of the total weight of threshed cowpea.

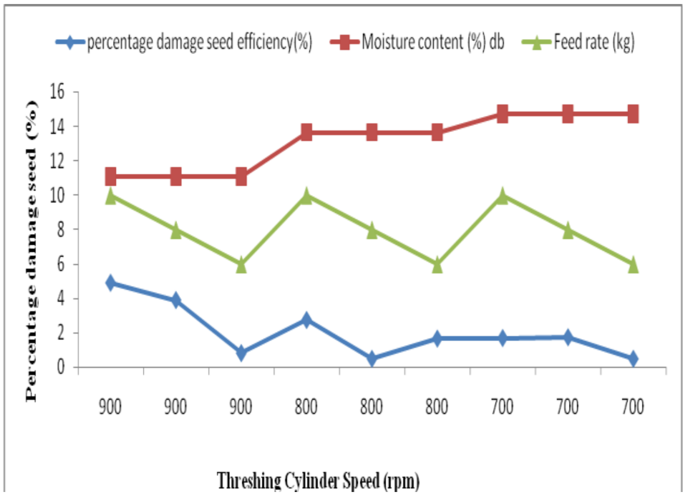


Figure 5: Effects of Threshing Cylinder on Percentage damage seed at various Feed Rates and Moisture Contents

Nevertheless, moisture content condition and force on the cowpea pods during threshing are overriding factors in determining crop mechanical damage [10, 11]. From the Figure 5 presented above, it shows that an increase in speed gives a linear increase in grain damage at all the stages of feed rate.

3.4 Effects of threshing cylinder speed on cleaning efficiency at various feed rates and moisture contents

A cleaning efficiency of 93.06% was observed at the lowest moisture content of 11.05% and feed rate of 8 kg/hr as presented in Figure 6. The highest cleaning efficiency of 94.89% was obtained at the highest speed of 900 rpm and lowest feed rate of 6 kg/hr. The lowest cleaning efficiency of 92.35% was obtained at lowest speed of 700 rpm and highest feed rate of 10 kg/hr.

Irtwange [21] reported a cleaning efficiency of 95.60% at 11.06% moisture content and feed rate of 120.72 gm. As the feed rate was increased from 6 to 10 kg/hr at 13.65% moisture content, there was a corresponding reduction in the cleaning efficiency at different moisture level. This shows that the drier the material to be threshed, the higher the cleaning efficiency. Mohammed et al; [31] obtained the highest average cleaning efficiency of 97.72% at the moisture content of 9.01% and threshing cylinder speed of 1200 rpm whereas Muhammed-Bashir et al; [19] reported cleaning efficiency of 88.90% at the feed rate of 1 kg/hr and threshing cylinder speed of 472 rpm.

3.5 Effects of threshing cylinder speed on grain throughput capacity at various feed rates and moisture contents

The results of throughput capacity of the machine are presented in Figure 7. The performance test resulted in the lowest throughput capacity of 26.67 kg/h for the 13.65% grain moisture content. The maximum throughput capacity of 46.18 kg/hr was obtained at the highest feed rate of 10 kg/hr, 11.05% grain moisture content and highest threshing cylinder speed of 900 rpm.

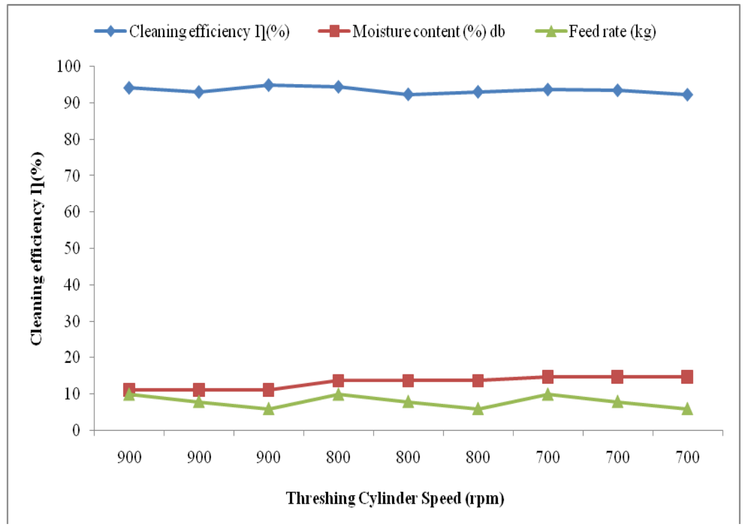


Figure 6: Effects of Threshing Cylinder Speed on Cleaning Efficiency at various Feed Rates and Moisture Contents

Irtwange [21] and Mohammed et al; [31] reported throughput capacity of 74.33 to 110.6 kg/hr and 107.7 kg/hr for cowpea respectively. Dauda [10] obtained a throughput capacity of 92.8 kg/h for a manually operated cowpea thresher whereas Oforka [30] got a throughput capacity of 33 kg/hr at moisture content of 10%. From the Figure, it could be seen that throughput capacity tends to increase with increase in cylinder speed and at all level of feed rate as moisture content was decreased.

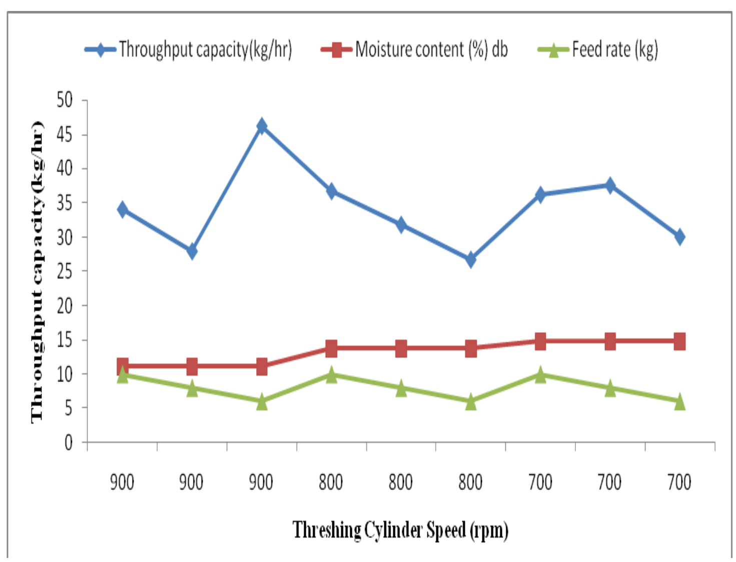


Figure 7: Effect of Threshing Cylinder Speed on Throughput Capacity at various Feed Rate and Moisture Contents

4.0 CONCLUSIONS

Based on the design, fabrication and testing of this machine, the following conclusions are drawn. The Maximum threshing efficiency of the machine is 98%. It was obtained at grain moisture content of 11.05%, cylinder speed of 900 rpm and feed rate of 6 kg/hr This threshing efficiency was found to be appropriate threshing performance for the cowpea.

The highest cleaning efficiency of 94.89% was obtained at the highest speed of 900 rpm and feed rate of 6 kg/hr. The cleaning efficiency for the threshing machine increases as the cylinder speed increases and as the feed rate and moisture content decreased. Thus, threshing at the lowest cowpea moisture content of 11.05 % on the thresher would give the best cleaning efficiency.

The performance test resulted in the lowest throughput capacity of 26.67 kg/h for the 13.65% grain moisture content and the highest throughput capacity of 46.18 kg/h for 11.05% grain moisture content. The thresher maximum throughput capacity of 46.18 kg/hr was also obtained at the highest feed rate and threshing cylinder speed of 10 kg/hr and 900 rpm respectively. This shows that the throughput capacity tends to increase with increase in cylinder speed at all level of feed rate as moisture content was decreased.

The mechanical seed damage ranged from 0.50 to 4.90% with increasing moisture content. The 11.05 and 13.65% moisture content proved to be better options for effective thresher performance. However, the values of seed damage percent obtained from the 11.05 and 13.65% moisture content at different cylinder speed are higher than the accepted level of 1.1 % recommended by [34]. This may be due to the high rotor speed of 900 rpm used [35] which seems to have higher influence on seed damage. Therefore, it is expected that lower speeds could bring the damage to the acceptable level. The 11.05% has proven to be the most reliable for optimum thresher performance.

High moisture content has a tendency to reduce the mechanical damage for the variety (kannanado) of cowpea investigated.

The machine is suitable for small-scale farmers due to the fact that it is affordable, easy to couple and dismantle. It can also be operated by an average farmer without complications.

The machine is limited to availability of petrol.

REFERENCES

[1] Ngalamu, T., Odra, J. and Tongun, N. Cowpea Production Handbook, College of Natural Resources andEnvironmental Studies University, Juba, 2014. pp. 33-35.

[2] IITA. Cowpea.http://www.iita.org/cowpea;jsessionid=77F383.FF296B6B1B70E258F7BF5033F, pp. 1-10, Accessed June, 2019.

[3] Onuorah, V.L, Uwaegbute, A. C., and Enwere, N.J. “Cowpea Utilization and Nutrition (practical)”. *In Food Crops Production Utilization and Nutrition (M.B.Mbah and D.O.Nnanyelugo, eds.),* 1989, pp. 121-126.

[4] IFT, ‘‘Legumes: Production, Food Value and Health Benefits. Food Technology’’, 45, 1991, pp. 96-130

[5] Okechukwu, P. E; Rao, M.A; Ngoddy, P.O and Macatters, K.H. ‘‘Firmness of Cowpea Gel as a Function of Moisture and Oil Content, and Storage’’, *Journal of Food Science,* 57(1), 1992.

[6] Lawrence, K. Essentials of Crop Farming, Spectrum Books Limited, 2006, pp107-119.

[7] Abubakar, M.I. and Olukosi, J.O. ‘‘Analysis of Cowpea Production under the National Programme on Food Security in Argungu Local Government Area of Kebbi State, Nigeria’’, *Nigerian Journal of Basic and Applied Sciences*, 16(2), 2008, pp.243–247.

[8] Abugu, M. N. ‘‘Repositioning Cowpea as the Food Security Crop for Nigeria’’, 2016, pp.1-2. https://allianceforscience.cornell.edu/blog/2016/12/repositioning-cowpea-as-the-food-security-crop-for-nigeria/#:~:text=Currently%2C%20Nigeria%20consumes%20cowpea%20imported,Cameroon%2C%20Niger%20and%20Benin%20Republic. Accessed on September 12 , 2020.

[9] Maunde, F. A., Yalama, S. M. and Richard.,T. E. ‘‘Design of a Manual Cowpea Thresher” *African Journal of Agricultural Research,* 5(12), 2010, pp.1419-1423. http://www.academicjournals.org/AJAR, Accessed on January 25, 2020.

[10] Dauda, A. ‘‘Design, Construction and Performance Evaluation of a Manually Operated Cowpea Thresher for small scale farmers in Northern Nigeria’’, *Agricultural Mechanization in Asia, Africa and Latin America*, 32(4), 2001, pp.47-49.

[11] Allen, C. A. W, and Watts, K. C. ‘‘Design of a Belt Thresher for Cowpea Beans’’, *Agricultural Mechanization in Asia, Africa and Latin America*, 29(3), 1998, pp.42-46.

[12] Bruce, D. M, Hobson, R. N, Morgan, C. L. and Child, R. D. ‘‘Threshability of Shatter-resistant Seed Pods in Oilseed rape’’, *Journal of Agricultural Engineering Research*, 80(4), 2001, pp.343 – 350.

[13] Olaoye, J. O. ‘‘Development of a Treadle Operated Abrasive-Cylinder for Threshing Cowpea’’,

International Journal of Engineering Science and Technology, 3(12), pp. 8548- 8557.

[14] Arnon, I. "Modernization of Agriculture in Developing Countries: Resources", Potentials and Problems. 2nd edition, John Wiley and Sons, Chichester, 1987, pp. 38-45.

[15] Maunde, F. A. ''Study of Cowpea Threshing with Alvan Blanch Aspra'', Master, part of Visiting Ph.D Research Report for Six Months submitted to the department of Agricultural Engineering, Cranfield University at Silsoe (unpublished), 2008.

[16] Maunde, F.A, Ali, M.A.; El-Okene, A and Riji, B.B. ''Physiomechanical Properties of Some Cowpea Varieties for the Mechanization of Threshing Operation'', *International Conference of Engineering Research and Development Impact on Industry*'', University of Benin, Nigeria September 5-7, 2006, pp. 382-386.

[17] Maunde, F. A, Ali, M. A.; El-Okene, A. and Riji, B. B. ''Determination of Physicomechanical Properties of Cowpe to Aid Thresher Designs'', *Advanced Material Research, Transaction Technology Publication Switzerland*. 18(19), 2007, pp159-64. http://technology.materialsscience.net/0-87849-450-2/159/, Accessed on March 18, 2020.

[18] Omale, J.O, Onum, E, Odeh, S.A. ''Design of African Yam Bean Thresher''. *International Journal of Current Research in Life Science*, 4(11), 2014, pp. 446-448.

[19] Muhammed-Bashir, O. W. Oriola, K. O. Ogundeji B. A. and M. A. Adesokan ''Fabrication and Performance Evaluation of Cowpea Thresher for Small Scale Cowpea Farm Holders in Nigeria'', *Current Journal of Applied Science and Technology*, 31(6), 2018, pp. 1-11.

[20] Adekanye, A.T, Olaoye, J.O. ''Performance evaluation of motirized and treadle Cowpea threshers'', *Agricultural Engineering International: CIGR Journal*, Vol.15. Number 4, 2013, pp. 300 - 306.

[21] Irtwange, S. V. ''Design, Fabrication and Performance of A Motorized Cowpea Thresher for Nigerian Small Scale Farmers'', *African Journal of Agricultural Research*, 4(12), 2009, pp. 1383-1391. http://www.academicjournals.org/AJAR, Accessed on May 25, 2020.

[22] Fawohunre, A. J. and Olajide, O. G. ''Development and Performance of a Motorized Cowpea Threshing Machine for Small Scale Farmers in Nigeria'', *Global Journal of Engineering and Technology Advances*, Vol.5, Number 1, 2020, pp 1–7.

[23] Eric, A. A, Wilson K K, John B, Randy, A. ''Performance Evaluation of a Cowpea Thresher at Various Moisture Contents'' *International Journal of Technology and Management Research*, Vol. 2, No. 2, 2017, pp 32-37

[24] Khurmi, R.S. and Gupta, J.K. ''Machine Design'', Revised Edition, Eurasia Publishing House Ltd, New Delhi, 2007, pp. 597.

[25] Khurmi, R. S. and Gupta, J. K. A. ''A Textbook of Machine Design'', Eurasia Publishing House Ltd, 7361. Ram Nagar, New Delhi-10055, 2006, pp. 697-711.

[26] Sarka, B.K. ''Theory of Machines'', Tata McGraw-Hill Publishing Company Ltd, New Delhi, 2002, pp. 44–65.

[27] Budynas, R. G and Nisbett, J. K. ''Shigley's Mechanical Engineering Design'' McGraw-Hill Companies, Inc., 1221 Avenue of the Americas, New York, NY 10020, .9th Edition, 2011, pp. 75-79, 162.

[28] Hannah, J and Stephen, R. ''Advanced Theory and Examples in Mechanics of Machines'', Edward Arnold Ltd. New Delhi, India. 1st Edition. 2014; 677- 819.

[29] Simonyan, K.J and Yiljep, Y. D. ''Investigating grain separation and clean efficiency distribution of a conventional stationary rasp-bar sorghum thresher'' *Agricultural Engineering International: the CIGR Ejournal Manuscript* PM 07 028, X, August, 2008.

[30] Oforka, O.M. ''Improvement of IAR Soybean Thresher'' Unpublished B. Engr. Thesis of Agric Engineering Department, A.B.U. Zaria, 2004, pp 24-36.

[31] Mohammed, B.I, Fulani, A.U and Kuje, J.Y. ''Effect of Moisture Content on Performance of a Locally Fabricated Cowpea Thresher'', *Journal of Engineering and Applied Sciences*, 5(2), 2013, pp 1–15.

[32] Adewumi, B.A, Ademosun, O.C and Ogunlowo, A.S. ''Design, Fabrication and Preliminary Testing of a Thresher-Cleaner for Grain Legume'', *Journal of Food Sciences Technology*, 44(3), 2007a, pp 276-280.

[33] Ahaneku, I. E, Kamal, A. R and Ogunjirin, O. A. ''Design, Construction and Performance Evaluation of a Multipurpose Crop Thresher'', *Journal of Agricultural Engineering and Technology*, Vol.11, 2003, pp17-23.

[34] Ukatu, A. C. ''A Modified Threshing Unit for Soya Beans", *Biosystems Engineering*, 95(3), 2006, pp 371–377.

[35] Herbek, J. H. and Bitzer, M. J. ''Soybean Production in Kentucky: part V-Harvesting, Drying, Storage, and Marketing. Lexington", Ky.: Cooperative Extension Service Bulletin AGR 132. 2004, pp. 1-12.