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DEVELOPMENT AND PERFORMANCE EVALUATION OF A MULTY-CROP (MAIZE AND SORGHUM) SHELLING MACHINE

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ABSTRACT

The processing of agricultural raw material into quality products did not only prolongs the useful life of these products but also increases the net profit farmers make from such products. The paper presents detailed comprehensive design, construction, and evaluation of a low cost multi-crop sheller that can be easily transported and electrically powered. The performance evaluation was carried out using maize and sorghum at moisture content of 12% and 13% respectively. The shaft shelling speed of the sheller was 750_rpm.Results showed that the shelling efficiency, the shelling rate, the fraction of damaged grains, fraction of unshelled grains for maize and sorghum are 93.7%, 32.53kg/hr, 10.3%,3% and 88.13% 29.30kg/hr,9.6% and 4.6% respectively. The machine effectively shelled the grains(sorghum and maize).The use of electricity, rather than fossil fuel to power the machine will ensured reduction in products contamination that may result from fuel powered sheller.

Keywords**:** Sheller, design and construction, shelling efficiency, shelling rate, grains.

INTRODUCTION

In Nigeria maize and sorghum constitute the staple food of large chunk of the populace. They are also responsible for about 60% by weight of most of livestock feed formulations (Awika, 2017). Peasant farmers are responsible for more than 70% of the maize produced annually while large scale commercial farmers constitute the remaining 30% (Adewumi, 2004). The problems of post-harvest processing and storage of agricultural produce are well documented and various approaches are being employed in tackling it (Sheahanand Barrett, 2017). For maize and sorghum, one of their post-harvest challenges is shelling. Shelling is the process of removing seed or grain from their respective cobs (Aremu et al., 2015). Shelling is the first and most important postharvest operation for grain crops. It involves, among other things, the detachment of grain kernels from the heads, cobs or pods as the case may be. The sheller consists of a cone with three to four lines of serrated ribs (Orioku et al., 2014). The dehusked cob is rotated in the cone by one hand while the sheller is held in the other hand rotating the cob against the internal rib of the sheller to detach the grain from the cob.

There are many types of maize shellers, but the motorized shellers are either imported or locally fabricated by local welders who have no knowledge of both the machine and crop parameters suitable for optimum performance of the shelling machines (Adewumi, 2004). Maize can also be dehusked and shelled but this is with a lot of kernel damage at the end of the processing operation (Adebusuyi, 1983). Other types of devices used for shelling mechanism are cross flow rasp bar, axial flow rasp bar and spike tooth cylinder (Bako and Bature, 2017). A spike tooth cylinder is more positive in feeding than rasp bar cylinders with the added advantage that, it does not plug in easily. While rasp bars are easier to adjust and monitor and are relatively simple to operate and durable (Orioku et al., 2014). The efficiency of shelling machines varies from one machine to the other as affected by some factors like the crop moisture content, feeding rate, shelling mechanism and the concave cylinder clearance (Oriaku et al., 2014).Adegbulugbe, (2000) established that shelling process is a function of moisture content. It is easier to shell maize dry than wet. Adewale et al (2002) also reported that the local techniques of shelling and winnowing of shelled maize is grossly inefficient judging by the serious bruises encountered by the crops.

Maize (Zea mays) is an important cereals crop which belongs to a grass family (Gramineae) producing small edible seeds which was said to have originated from Mexico over years (Iwena, 2002).Maize is a crop per excellence for food, feed and industrial utilization. Maize is the third most important crop in the world after wheat and rice (Falong et al., 2016). Harvesting and threshing of maize pose a major challenge in Nigeria, particularly with the increase in production of the crop.

The shelling process depends on the maize variety characteristics, the design and structure of the threshing apparatus, and its adjustment.Most low acreage farmers, who grow maize in Nigeria, encounter several processing difficulties of which shelling, as it requires a relatively high expenditure of energy, is a major concern (Adewunmi, 2004). The most important quality indices for maize ears threshing are grain loss, damage, concave separation, and the degree of the ear length reduction. The threshing process depends on the maize variety characteristics, the design and structure of the threshing apparatus, and its adjustment (Petkevichius et al., 2008).

Sorghum (Sorghum bicolor), a tropical plant belonging to the family of Poaceae, is one of the most important crops in Africa, Asia and Latin America (Anglani,1998).). Itis the fifth most important cereal crop after wheat, rice, maize, and barley in terms of production (FAO, 2005).The acquisition of good quality grain is fundamental to produce acceptable food products from sorghum. Sorghum while playing a crucial role in food security in Africa, it is also source of income of house-hold farmers (Anglani, 1998).The main foods prepared with sorghum are: tortillas (Latino America), thin porridge, e.g. "bouillie" (Africa and Asia), stiff porridge, e.g. tô (West Africa), couscous (Africa), injera (Ethiopia), nasha and kisra (Sudan), traditional beers (dolo, tchapallo, pito, burukutu), ogi (Nigeria), baked products (USA, Japan, Africa) (Orhun, 2013) etc. More than 35% of sorghum is grown directly for human consumption. The rest is used primarily for animal feed, alcohol production and industrial products (FAO, 1995; Awika and Rooney, 2004a)

In many rural areas of developing countries, the maize kernels are removed manually.Manualshelling the annual maize harvest by hand typically takes weeks and may pull children out of school, since processing food for survival takes priority over education in subsistence farming households. The hardened, dry maize can also be difficult to shell and leads to hand injuries. In addition, manual shelling takes a lot of time. An estimated 550 million small holder farmer in the world lack access to mechanical agricultural technology(Leeand Thierfelder, 2017).Traditional shelling methods are laborious and do not support large-scale shelling of maize and sorghum, especially for commercial purposes (Enaburekan, 1994).

The increasing usage of corn and sorghum makes it imperative and significant for the designing of a multi-crops shelling machine to enable large quantity production. The available local shellers were equipped with rotating threshing drum with beaters or teeth, which cause damages to the seed, complex in design which makes it inoperable for local farmers (Adewunmi, 2004).The size and weight of the machine also posed a problem for its transportation and mobility. Besides, the cost of purchasing such shellers was high for the poor rural farmer and requires experts for maintenance.

Maize and sorghum shelling therefore is an important step towards the processing of maize and sorghum to its various finished products like flour. This necessitated the design of low cost system that will be affordable to maintain and with increased threshing efficiency but reduced damage done to the seed.The paper presentation on dual purpose shelling justify simplicity, portability, efficiency, and availability to ease transportation and affordable for subsistence farmers.

MATERIALS AND METHODS

The materials used were pulley, bearing, metal angle, mild steel plate, electrode, welding machine, shaft, cutting disc, grinding machine, bolt and nuts.

Component Design Analysis

Different design factors were taken into consideration. These are durability, strength, corrosiveness and availability.

Hopper

The material used for the construction was mild steel sheet metal, which is readily available in the market and relatively affordable. The hopper otherwise known as the feeding mechanism is the device through which maize enters into the machine. The hopper is rectangular in shape. Hopper design is based on a common criterion for it to function. The criterion is called the "Angle of repose". Angle of repose is the maximum slope at which a heap of any loose or fragmented bulk material will stand without sliding. It can also be called the angle of friction of rest (Eugene and Theodore, 1986).This type of hopper is a gravity discharge one and the recommended angle of inclination of hopper for agricultural materials is 8° or more, higher than the angle of repose (Ileleji and Zhou, 2008). The angle of repose of maize is 27° (Richey, 1982). The hopper was fabricated in trapezoidal shape, using mild steel sheet of 18-gauge thickness and had dimensions of 70 cm length, 52cm width and 58 cm height. The dimension of the unit is shown in Figure 1

The area and the volume of the hopper were calculated as follow

Area = (L X B X H; Where L is length of the hopper, B is breath of the hopper and H is the height of the hopper

Then the volume of the hopper was calculated by:
V = [(area of base) x height]/3
Where h is the overall height and x = height of the truncated top.

Shelling unit

In this model, shelling was done by the impact of a cylindrical drum equipped with a number of spikes mounted on its periphery. The crop was brushed into fine straw, which resulted in good feed. The spike size was reduced to increase the shelling clearance, because the existing aperture shells cobs with maize. Plate1 showed the concave configuration of the dual crop sheller.

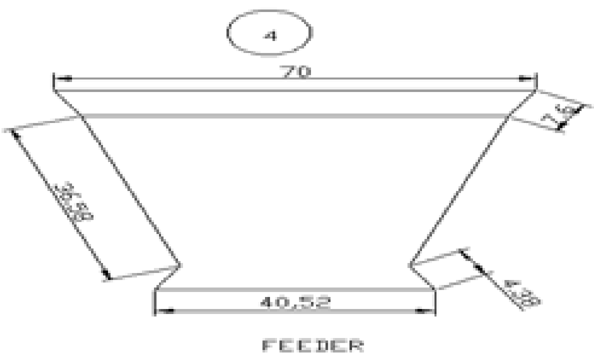

Figure.1: Schematic diagram of the hopper

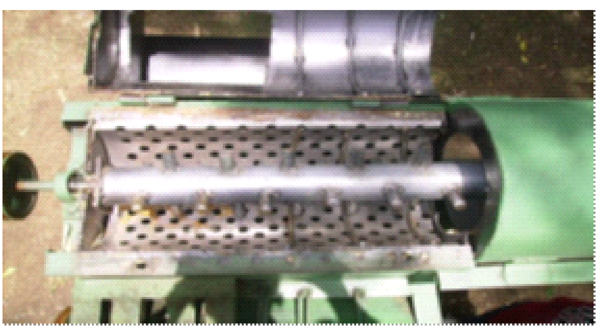

Plate 1: Cylinder concave configuration of the dual-crop sheller

Shelling Cylinder

The cylinder was made up of steel of 6.5cm diameter. The cylinder length was 15 cm, having beaters which rotated along the cylinder and separated grains from the cobs.

Separating unit

While being shelled, the material undergoes a spiral motion in a closed cylindrical casing. Meanwhile, the grain with the fine straw is dropped to the sieve while cobs were delivered to the outlet through which it was discharged. The spiral motion is done by the special arrangement of curves on the inner side of the cover (Spikes). The sieve aperture was made between 12mm to 13mm, in order to make the shell grains to pass through it easily

Fly wheel

The fly wheel was provided to transfer the power coming from belt pulley to the cylinder sprocket. This wheel was fitted to the horizontal steel rod which is connected to the pillow bearings and at the top chain sprocket attached to shelling cylinder.

Perforated concave

The concave was fabricated using 6 mm diameter mild steelrods. The length of concave was 25 cm with slotted opening size of 7.7cm ×1cm. It was designed by considering average dimensions of maize cobs and kernels. It was designed in such way that kernels should not fall through the slots. It was fabricated using two half round rings, on which 6 mm mild steel rods were welded at a spacing of 1 cm as showed in Figure 2. The clearance between concave and cylinder was maintained at 2.1 cm. Figure 3 shows the removable perforated concave.

Outer cover

It was made up of 18-gauge mild steel sheet and was bentto semicircular shape of diameter 18 cm and rigidly fixed to give protection to the cylinder and avoid grains spilling out. It had the provision for attachment to a hopper. A flange was attached to it along the length to facilitate cleaning of inner cylinder.

Rotor shaft

It is one of the key components of the machine. Other parts of cylinders and bearings were mounted on the shaft. The standard size and length of the shaft were selected based on the shaft design. The pulley was attached to give drive to shaft from motor.

Outlet

The outlet for separated grains was made at the bottom of the shelling cylinder. It was made up of metal sheet to collect grains without shattering outside. The diagrammatic representation is shown in Figure 3

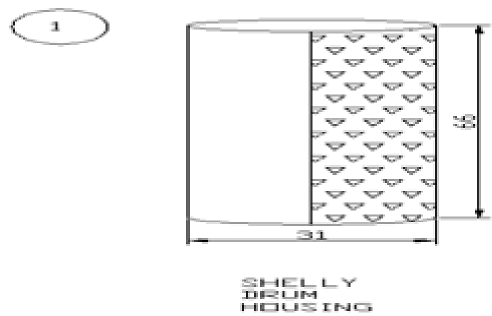

Figure 2: Removable perforated concave

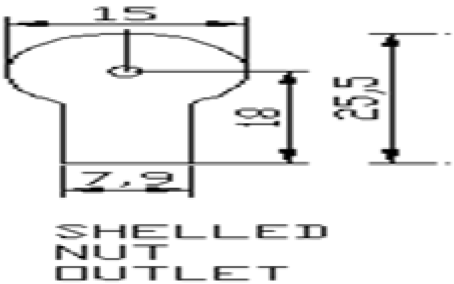

Figure 3: **The grain outlet**

Power transmission unit

An electric motor of 3 horse power was used to evaluate the performance of the machine with the use of different pulleys at different speed; it supplied the rotary power needed for driving the rotary components of the machine.

The main frame

The main frame supports the entire weight of the machine. The total weights carried by the main frame are:Weight of the hopper and housing; weight of the threshing chamber; the collector and pot and the bearings and pulleys.

Shaft design

The shaft of this machine has a threshing tool attached to it (by welding) at two opposing sides and a pulley mounted on it. It was supported on bearings. Shaft design consists primarily of the determination of the correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading conditions.

Machine Design and Development

A motorized multi- crop (maize and sorghum) sheller of about 58kg/hr capacity was designed and constructed. The height of the machine was 500mm, the breadth of the machine is 225mm and the weight of the machine is 73.9kg. The machine consists of the loading unit, the shelling units, the separating unit (sieve), and the power transmission unit. The hopper 700 x 485 x 468mm is rectangular in shape and made of mild steel to withstand vibration. The cob falls into the shelling unit through the action of gravity. The shelling unit consists of a spike welded to the cylinder and concave. The spikes are made of ½ inch iron rods, the maize cobs as well as the sorghum are being shelled by the action of the spikes on the maize and the sorghum against the concave. The length of the cylinder shaft is 475mm with 36 spikes attached at 50mm apart and the length of the concave is 540mm. The standing was measured at 410mm. the wheel attached to the standing is 300mm. The cob outlet was measured at 255mm. Power transmitted through pulley, belt and the prime mover (3horse power electric motor).

The machine was developed in such a way that the motor was attached with the pulley where the motion from the motor was transmitted with the help of a belt to the main shaft and as a result the shaft rotation. The modification on the previously design machine was based on the shaft, whereby the shaft of the already existing machine was removed and replaced with a removable shaft designed for maize and sorghum respectively. Maize or sorghum was fed manually through the main head and as a result the maize or sorghum were separated from the cobs and chaff respectively. The two elevations (right and rear) are shown in Figure 4 and the fabricated sheller is shown in plate 2

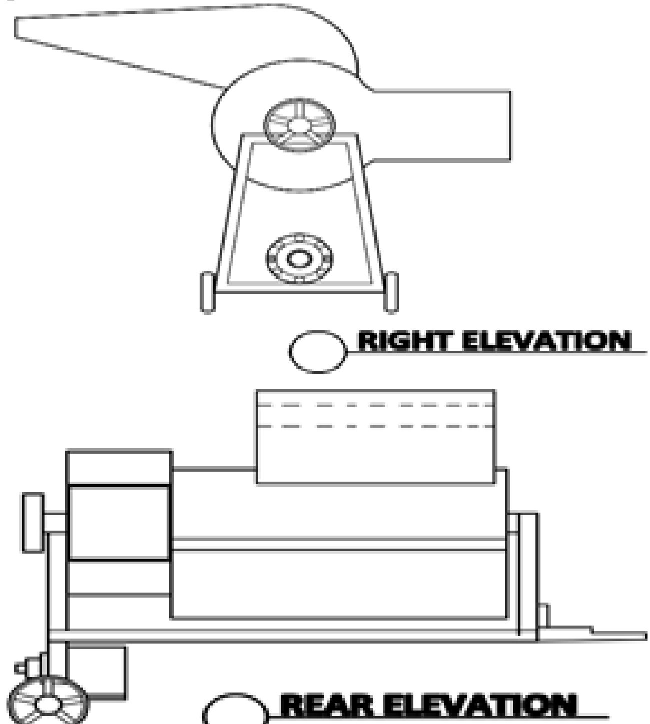

Fig. 4: Schematic representation of the right and rear elevation of the dual-crop sheller

Plate 2: The fabricated dual-crop sheller

Working Principle of The Machine

The electric motor provides the primary motion required to power the machine. The motion and torque were transmitted via pulleys, v-belt and bearings to the shaft carrying the spikes and blower shaft connected to the impeller. Both the spikes and blower containing the fan rotate in a clockwise direction. The whole maize (together with the cobs) was introduced into the machine through the inlet (hopper). They reach the rotating spikes inside the concave by gravity. The spikes gave continuous impact force on the whole maize, thereby removing the grains and chaff. Because the spikes were arranged in a spiral form, the whole maize moves along the length of the concave in the forward direction until they reach the cob outlet. Before the whole maize reached this point, almost all the grains (seeds) are removed thereby letting the cob go out of the machine clean. Due to the impact of the spikes some of the cobs may be broken, though both broken and whole exit through the cob outlet. The maize or sorghum then runs out through the maize grains outlet into the receiver where they are collected.

Performance Evaluation

The following parameters were measured; shelling time, weight of shelled grain, shelling speed, moisture content, weight of corn, weight of shelled grain, weight of unshelled grains, weight of cobs, weight of chaff, weight of clean grain and weight of grain that mix with cobs.

Test procedure

Maize and sorghum were bought from Igbo-ora market in Igbo-ora, Oyo state, Nigeria.

Moisture content: Moisture content (M_c) of the grain and cobs of each sample were first determined using oven drying method described by Willits, 1951and calculated using the equation below;

$$\frac{W_{bd} - W_{ad}}{W_{bd}} \times 100 \qquad (1)$$

Where Mc = moisture content of the grain, Wbd = weight before drying, Wad = weight after drying.

Shelling efficiency: The shelling efficiency of the machine was evaluated for each sample by the method described by (Abdulkadir *et al*., 2009). The quantity of unshelled grains on the cob, after the unshelled grains were removed from the cobs manually (with the hand) and weighed. The shelling efficiencies were then determined by using the equation below;

$$Efficiency = \frac{W_1 - W_2}{W_1} \times 100 \qquad (2)$$

Where W_1 = weight of un-threshed cobs; W_2 = weight of cobs not well threshed. The shelling efficiency was evaluated by the amount of corn left unshelled on the cob (called cylinder loss) and damage on the kernels. Shelling effectiveness is related to the peripheral speed of the cylinder, the cylinder-concave clearance, the number of times the material passes the concave (e g., axial-flow cylinder), the number of rows of concave teeth used with a spike-tooth cylinder, the condition of the crop in terms of moisture content, maturity, etc., and the rate at which material is fed into the machine.

Shelling rate: The shelling rate of the multi crop sheller was evaluated by the method described by Fernando *et al*., 2004 using the equation below;

$$\text{Shelling rate} = \frac{W_s}{t} \times 100, W_s = W_w - W_b \qquad (3)$$

Where W_s s weight of shelled (detached) maize kernels, gm, W_w is Weight of whole kernels detached from the cobs, gm, W_b is the Weight of broken kernels detached from the cobs, gm, t is time, Sec.

Grain loss evaluation: Grain loss was evaluated in term of fraction of damaged grains (%) and fraction of unthreshed head (%).

$$Fraction\ of\ damaged\ grains\ F_{dg} = \frac{Q_b}{QT} \times 100 \qquad (4)$$

$$Fraction\ of\ unthreshed\ head\ F_{ug} = \frac{UT}{QT} \times 100 \qquad (5)$$

Where F_{dg} is fraction of damaged grain; F_{ug} is fraction of un-threshea grain; Q_b is quantity of broken grain in sample; QT is total grains in the sample; UT is total un-threshed heads in sample

RESULTS AND DISCUSSION

Effect of Feed Weight on the Shelling of Maize

The results of the shelling of maize were presented in Table 1. At 12% moisture content, 15kg of maize was fed into the hopper, 12.3kg of maize was shelled, 0.6kg of maize was unshelled, 1.8kg of maize was damaged and the shelling time was 12 min. 10kg of maize was fed into the hopper, 8.6kg of maize was shelled, 0.1kg of maize was unshelled, 1.1kg of maize was damaged and the shelling time was 7 min. 5kg of maize was fed into the hopper, 4.0kg of maize was shelled, 0.2kg of maize was unshelled, 0.8kg of maize was damaged and the shelling time was 3 min. The weight of the unshelled maize and damaged maize in the various weight categories was minimal, this can be attributed to the low moisture content of the maize and was also reported by (Nwakairea *et al*., 2011; Adegbulugbe, 2000) they both established that shelling process is a function of moisture content. It is easier to shell maize dry than wet. The higher the weight of crop fed into the hopper, the higher the shelling time, this might be due to the fact that at higher weight of the crop fed into the hopper there is an increase gap which may not only allow the escape of the crop from the beat of the peg but also reduce the resistance between the crop and the shelling drum. This agrees with FAO (1995), the higher the feed rate, the higher the shelling time.

Effect of Feed Weight on the Shelling of Sorghum

The result of shelling of the sorghum is presented in Table 2. At 13% moisture content, 6kg of Sorghum was fed into the hopper, 5.1kg of sorghum was shelled, 0.4kg of sorghum was unshelled, 0.5kg of sorghum was damaged and the shelling time was 10 min. 4kg of sorghum was fed into the hopper, 3.0kg of sorghum was shelled, 1.2kg of sorghum was unshelled, 0.9kg of sorghum was damaged and the shelling time was 6 minutes. 2kg of sorghum was fed into the hopper, 1.1kg of maize was shelled, 0.8kg of sorghum was unshelled, 0.3kg of sorghum was damaged and the shelling time was 2 min.

The higher the weight of crop fed into the hopper, the higher the threshing time and this may be due to the fact that that at higher weight of the crop fed into the hopper, there is an increase gap which may not only allow the escape of the crop from the beat of the peg but also reduce the resistance between the crop and the shelling drum. This agrees with FAO (1994), the higher the feed rate, the higher the shelling time. Wacker (1987) also stated that grain damage from an axial shelling machine is less than that of a tangential machine.

Performance Evaluation of Grain Shelling

The result of performance evaluation of grain using the designed machine is presented in Table 3. 12% of the 15kg maize with 12% moisture content was damaged, 4% of the maize was unshelled and 92.0% of shelling efficiency was obtained at shelling rate of 32.6kg/hr. 10kg maize produce

Table 1: Weight of shelled and unshelled maize at 12% moisture content

Maize	Weight(kg)	Weight of shelled grains(kg)	Weight of unshelled grains(kg)	Weight of damaged grains(kg)	Shelling time(min)
	15	12.3	0.6	1.8	12
	10	8.6	0.1	1.1	7
	5	4.0	0.2	0.8	3

Table 2: Weight of shelled and unshelled sorghum at 13% moisture content

Sorghum	Weight of grain (kg)	Weight of shelled grain(kg)	Weight of unshelled grain(kg)	Weight of damaged grain (kg)	Shelling time(mins)
	6	5.1	0.4	0.5	10
	4	3.0	1.2	0.9	6
	2	1.1	0.8	0.3	2

93.1% shelling efficiency at shelling rate of 32.3kg/hr. The fractions of damaged and unshelled grain were 11% and 1% respectively. 96% shelling efficiency at 26.7kg/hr was obtained for 5kg of maize. The fractions of damaged grain and unshelled grain were 8% and 4% respectively.

The shelling efficiencies of 85.3%, 86.7%, and 92.4% were obtained at shelling rate of 29.3kg/hr, 23.0kg/hr and 21.6kg/hr of sorghum respectively. The fractions of damaged sorghum were 8.3%, 12.5%, and 7.9% respectively. The fractions of unshelled sorghum were 6.7%, 3.0% and 4.0% respectively. The higher the weight of the feed, the decrease the shelling efficiency. The decrease in shelling as a result of increase feed rate may be attributed to the fact that at higher feed rate, there would be crop steam material build up. This trend applies to both maize and sorghum. This agrees with Enaburekhan (1994): the higher the feed rate, the decrease the shelling efficiency. According to (Nalado, 2015) at higher moisture, the higher the grain adhesion to the cob, thus, decreases in the shelling rate. At lower moisture, less impact force is required to detach the grain from the cob, hence higher shelling. With less moisture, the crop stream build up tend to be less, separation could thus be enhanced and therefore an increased output. Grain damage is high at lower moisture content. This agrees with Oluwale *et al.*, (2007). A possible explanation is that at higher moisture, the grain tends to be more elastic and hence less brittle. At lower moisture, it becomes more brittle and therefore yields easier to beater impacts.

Parameters of the Multi-crop Sheller

The representation in Table 4 revealed that the multi crop sheller designed has a shelling speed, angular velocity of shaft, torsional moment of shaft and volume of hopper to be 750rpm,92.79rad/sec,29.2Nm and $0.7753m^3$ respectively.

Table 3: Performance evaluation of grain shelling

Moisture content	Shelling efficiency	Fraction of damaged grain (%)	Fraction of unshelled (%)	Shelling rate(kg/hr)	grain	Weight of grain(kg)
12%	94.0	12.0	4.0	32.6	Maize	15.0
12%	93.1	11.0	1.0	32.3	Maize	10.0
12%	96.0	8.0	4.0	32.7	Maize	5.0
13%	93.3	8.3	6.7	29.3	Sorghum	6.0
13%	86.7	12.5	3.0	29.0	Sorghum	4.0
13%	92.4	7.9	4.0	29.6	Sorghum	2.0

Table 4: Parameters of the multi-crop sheller

Parameters	Maize	Sorghum
Shelling efficiency	94.4%	90.8%
Shelling rate	30.5kg/hr	24.6kg/hr
Fraction of damaged grain	10.3%	9.6%
Fraction of unshelled grain	3%	4.6%
Moisture content	12%	13%
Shelling speed	750rpm	750rpm
Angular velocity of shaft	92.79rad/sec	92.79rad/sec
Torsional moment of shaft	29.2Nm	29.2Nm
Volume of hopper	$0.7753m^3$	$0.7753m^3$

CONCLUSION

The designed machine capable of efficiently separating maize from its cob and sorghum from its chaff was satisfactorily developed. The modified machine was able to reduce the shelling time per kg of both the sorghum and the maize. The shelling of the maize and sorghum was done efficiently using the modified sheller when compared to existing ones in literature. This machine was constructed with the aim of shelling maize and sorghum efficiently alone; hence, more research should be done on subsequent shellers on the inclusion of blower in order to increase the cleaning efficiency.

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