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Design, Construction and Performance Evaluation of Low Cost Maize Dehusker-Sheller in Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Authors BAO and MAA read and approved the final manuscript.

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ABSTRACT

An easy-to-operate maize dehusker-sheller machine was constructed from locally available materials with relatively low cost at the premises of DAF Technical Services, Ilorin, Nigeria, between June, 2017 and February, 2018. The construction of the machine was carried out by sizing and marking out of the plate using scriber and cutter. The shaft was smoothened with sand paper and various components were welded; assembling of parts was done by fastener (bolts & nuts). The machine consisted of four units (feeding unit, dehusking – shelling unit, cleaning unit and outlets). Results obtained indicated a mean de - husking efficiency of 58.67%, 57.00%, 54.16 at speed 469 rpm, 309 rpm and 298 rpm respectively. The mean shelling efficiencies were 73.36%, 71.53%, 65 55% at 469 rpm to 298 rpm. And mean through put capacity of 55.90 kg/hr, 41.10 kg/hr and 36.00 kg/hr at speed stated above. Also the mean cleaning efficiencies were 79.97%, 79.77%, 82.23% at speed 469 rpm, 309 rpm and 298 rpm respectively. The mean grain losses were 20.37%, 21.20% and 17.16% using the three speeds stated above. In conclusion, the mean dehusking efficiency, shelling and mean through put capacity performed best at 469 rpm while mean cleaning efficiency and mean grain loss was best at speed 298 rpm.

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Keywords: Design; fabrication; dehusking; shelling unit; cleaning unit; performance evaluation.

1. INTRODUCTION

Maize (*Zea mays.*) is one of the most important cereal crops in the world agricultural economy. It is one of the most important crops in Nigeria. The crop is produced two times in a year in southern Nigeria by rain- fed farming and throughout the year by irrigation. It is highly productive, cheap, and less rigorous to produce and adapts to wide range of agro-ecological zones [1].

Maize ranks first in the world cereal production; it accounts for 38% of the total grain production with 868 million tonnes from 168 million hectare whereas 30% of wheat (691 million tonnes) and rice is 20% (461 million tonnes) [2]. (Anon., 2011). United States has the lion's share of 43% of the total world production followed by China (19%), EU- (6%) and Brazil (7%), sum of which equals to 75% of the total global production. India stands sixth in terms of production with 2.4% to the total world maize production from 8.5 million hectare with 5% share in world harvested area [3] (Anon.,2013a). Nigeria produce 10.4 million tonnes as at 2016 [4].

Production of maize in Nigeria generates income for the government through exportation. It also serves as source of raw materials for the industry such as production of animal feeds, infant or baby foods and alcoholic beverages, for baking and snacks foods, canner/packers and fuel alcohol [5].

Maize satisfies all the qualities of a good diet; it is a rich source of complex carbohydrates, fibres, protein, fats and also a good source of vitamin B and vitamin E. Eating cooked fresh corn and drinking a glass of the water (in which corn is cooked) with a spoon of pure honey, increase flow of urine, detoxifying the kidney and preventing stone along urinary tract. Taking a glass cup of infusion (tea) from fresh corn seeds with pure honey can prevent vomiting, bed wetting in children [6]. It is also used as raw materials for generating biogas, and in making silage for animals.

Nutritional value of the crop cannot be over-emphasized. The starch, oil and some other fatty acids are extracted mainly from wheat and corn. These play a major role in keeping the persons healthy. Obtaining the corn seeds for extracting fatty products is difficult due to frequent power cuts in rural areas and because of the traditional processes that are followed. Traditionally most of the shelling works are done by hand. There were hand operated maize shellers which were cumbersome to use. Large scale shelling for commercial purposes was not possible due to fatigue. There are, of course, machines which can shell maize, but these are usually unaffordable for rural farmers [7].

The operation of a maize dehusker-sheller is similar to a threshing machine, but with some differences to deal with larger grain size and other differences of corn compared to wheat and other crops. Corn Sheller can be powered by a hand crank, a tractor, a stationary engine, or by an electric motor. Whole corn cobs are fed in. They are pulled between the spikes some are bevel to tear the maize chaff usually made of metal. Each spike are arrange in a spiral direction. The teeth pull the kernels off the cob until there are no kernels left. The kernels fall out through a screen into a container (such as a bucket) placed underneath the machine. The cob is then ejected out, since it cannot pass through the screen. Some models have a "walker", similar to a threshing machine or combine, to take the cobs out [8].

Maize shelling is the most important aspect of post-harvest operations of maize. Shelling is one of the most important crop processing operations to separate the grains from ear heads or the plants and prepare it for market. Traditionally, dehusking and shelling of maize are carried out manually which involves a lot of drudgery. The grains were detached from dried cobs by manual or mechanical device, which is known as shelling. This operation is however highly labour-intensive and more drudgery in addition to losses of grains in terms of quantity and quality. With an increase in the shelling drum speed, the shelling efficiency increases and vice-versa. The increase in the shelling efficiency is not only due to the increase in the speed, but to an increase in the feed rate and applied force [9].

Singh et al. [10] reported that even though hand operated maize dehusker - sheller is suitable for farm women, it is difficult for women to operate and yields very low level of efficiency and dehusking as a separate activity precedes shelling that brings additional burden on women. The available equipment are suitable for certain group of farmers (medium and large farmers); about 80.3% of farmers of marginal and small groups operate 36% of the area. The prevalent shelling and dehusking methods such as rubbing the maize cobs on one another, rubbing on bricks, stone and wire mesh by using iron cylinder are tedious and time consuming, involves drudgery, and exposes the crop over time to natural hazards like rain, fire, animals, birds and insects which leads to losses in quantity and quality of grains [11]. Moreover, dehusking as a separate activity precedes shelling that brings additional burden on farmers. They may employ labourers or use machines. But in villages, there is a shortage of labour and their equivalent wages are very expensive. The farmers or field owners also find it difficult to afford the machines even when those machines are available.

Starch, oil and some other fatty acids are extracted mainly from wheat and corn. These play a major role in keeping the persons healthy. Obtaining the corn seeds for extraction of fatty products is difficult due to frequent power cuts in rural areas and because of the traditional processes that are followed. Traditionally most of the shelling works are done by hand. There were hand operated maize shellers which were cumbersome to use. Large scale shelling for commercial purposes was not possible due to fatigue. There are of course, machines which can shell maize, but these are usually unaffordable for rural farmers [7]. Besides, where they are available, the output is full of contaminants such as broken cobs, chaffs and other impurities. There is therefore a need for a cost effective and eco-friendly solution for shelling maize. Hence, the need for the design, fabrication and performance evaluation of an affordable (low cost) maize dehusking and shelling machine (Table 1) (which can be powered electrically or with internal combustion engine), using locally available materials.

2. MATERIALS AND METHODS

2.1 Material Selection

Materials used for the fabrication of the maize dehusker-sheller were obtained locally from Surulere Market, Ilorin, Nigeria and selected based on strength, availability, durability and affordability. The materials used for construction of the maize dehusker-sheller included metal plate, angle iron, hollow pipe, and iron.

2.2 Design Considerations

In designing the dehusker-sheller, the following factors were taken into consideration: Loading conditions of a maize dehusker-sheller, optimal layout (planned to reduce waste of maize grains), restrain size number of weld, fitness of the end product, and cost of design.

2.3 Machine Description

Maize dehusker-sheller is made-up of the following components:

2.3.1 Hopper

The hopper is the component part that serves as a feeding unit for the harvested crop (maize) to the threshing chamber of the machine. Available information on the cob length, width, thickness and angle of repose was used in designing this component. Maize cobs were poured into hopper. It is shaped as a frustum and has a height of 200 mm.

2.3.2 Threshing chamber housing

Threshing chamber housing was fabricated with 1mm mild steel metal which was bent to form a concave of diameter 190 mm and 500mm in length, sealed at the two ends. Both sides were flanged to form an attachment to the frame. Threshing and pre –cleaning of the crop (grain and chaff separation) take place in the threshing chamber. The unit consists of threshing drum, the lower concave screens and the side plate cover. Threshing drum was made from 2 mm mild steel sheet rolled into a perfect cylinder of 200 mm diameter and 380 mm length. The spikes were welded in a spirally arranged form along the length of the drum. The drum was welded on the main shaft which supported, carried and transmitted torque to it.

2.3.3 Frame

The frame is a rigid part of the machine that gives the entire machine member support. It houses the entire shelling unit and the motor frame.

2.3.4 Blower

The blower functions by blowing cobs and other foreign materials. It improves the sieving operation of the screen by introducing a heavy stream of air across.

2.3.5 Screen

This is one of the important components responsible for cleaning grains as a result of size of the bored holes which allowed the passage of grains.

2.3.6 Outlet

These are channels for ejection of the straw/cob and collection of grains and chaff. Each outlet was made with 1 mm mild steel metal with open end so that escaped threshed grains dropping at seed outlet was recovered. Seed outlet was fabricated by 1 mm mild steel metal sheet. It was attached to the machine under the threshing unit. Chaff outlet forms an extension of the seed collection chamber. It was made with 1 mm mild steel metal sheet and tapered outward. It extended out by 180 mm and the width, 400 mm.

Plate 1. Pictorial view of maize dehusker – sheller

2.4 Design Calculation of the Machine

The assumption made for the work
Factor of safety = 1.5
Electric motor power rating = 3.67 kW
To use standard type of belt and corresponding sizes
Width, (b) = 17 mm
Thickness, (t) = 11 mm
Groove angle of the pulley 40^{0s}

Speed of motor require for the design, Nm =1440 rpm

Diameter of pulley on motor, = 58 mm

2.4.1 To calculate the torque (T) of Motor

$$T = (Mp \times 60/2\pi) \times Nm \quad \text{... (i)}$$

Where Mp is the motor power

$$= (3.75 \times 10^3 \times 60)/(2 \times 3.142 \times 1440) \quad [8]$$
$$= 24.86 \text{ Nm}$$

2.4.2 To calculate the speed of threshing

$$N_t d_t = N_m d_m \quad \text{....(ii)}$$

N_t = Thresher speed
d= diameter of pulley or thresher
N_m = motor speed
d_m = diameter of pulley

1st speed using 178 mm pulley

$N_t\, d_t = N_m d_m$ [7]
N_t x 178 = 1440 x 58
$N_t = \frac{1440 \, x \, 58}{178} =$
N_t = 469.21rpm
By tacometer = 472 rpm

2nd pulley

$N_{t2} d_{t2} = Nm_2 dm_2$
N_{t2} x 270 = $\frac{1440 \, x \, 58}{270}$
= 309.33rpm
By tacometer 338.5 rpm

3rd speed

$N_{t3} d_{t3} = N_{m3}\, d_{m3}$
N_{t3} x 300 = $\frac{1440 \, x \, 58}{300}$ = 278.4 rpm
By tacometer = 283.12 rpm

2.5 Performance Evaluation

The other materials used for performance evaluation were digital tachometer, weighing balance, stop watch, transparent polythene bag to collect the samples and 13.5 kg whole (undehusked) maize cobs. Pulleys with diameters 178, 270 and 300 mm were employed in the machine at 469.00, 309.33 and 278.00 rpm respectively to determine the speed at which the machine will operate optimally. The machine was test-run with 3 kg of undehusked maize to ascertain the machine's condition. One, 1.50 and 2.00 kg undehusked maize samples were thereafter loaded into the machine at each of the three pulley diameter/speed instances. The various speeds were determined/measured using digital tachometer, while the time taken at each instance was recorded with the aid of a stop watch. Each maize sample was fed into the machine one after the other and the time taken to dehusk, shell and clean the grains were recorded.

3. RESULTS AND DISCUSSION

Table 2 depicts the physical properties of maize grains used that guided in designing the minimum and maximum holes that was used in drill holes on the separating drum and to determine the spike length and some other parameters. Table 3 shows the result of test carried out on the maize dehusker-sheller. The Table shows that as the speed was lowered from 469 to 309 to 278 rpm, threshing time increased from 123.60 to 127.20 to 138.60s respectively.

Tables 4, 5 and 6 show how rates of loading affect shelling and cleaning efficiencies using three different speeds. The results on Table 4 indicate that as sample weight increased from 1.0 to 2.0 kg, the dehusking, shelling and cleaning efficiencies decreased from 67.00 to 53.00%, 78.00 to 69.50% and 85.00 to 76.90% respectively at a constant speed of 469 rpm. The dehusking, shelling and cleaning efficiencies at reduced speeds of 309 and 278 rpm also followed similar trend (Tables 5 and 6).

Fig. 1 shows that at a speed of 469 rpm, the highest average shelling and dehusking efficiencies of 73.36 and 58.67% respectively, and a through put capacity of 55.90% were obtained. The highest cleaning efficiency (82.23%) and least grains loss (17.16%) were however achieved at a lower speed of 278 rpm.

Table 1. The costs of engineering measurement and evaluation of materials for the maize dehusker - sheller machine

S/N	Description	Quantity	Unit Cost (₦)	Amount(₦)
1.	1mm thick mild steel sheet	$1^1/_2$	10,000	15,000
2.	Shaft	3	2,000	6,000
3.	Bearing	4	250	1,000
4.	Threshing	1	1,000	1,000
5.	40 mm x 40 mm x 2 mm angle iron	5	5,000	25,000
6.	Painting		4,000	4,000
7.	Bolt, nut and washer (17 & 13)	$1^1/_2$ dozens	83.3	1,500
8.	Pulleys (178 & 67 mm)	2	1,250	2,500
9.	Thresher and fan belt	1 each	800 & 200	1,000
10.	Transportation			6,000
11.	Miscellaneous			8,000
12.	Workmanship			20,000
Total				₦91,000 (USD249.32)

Table 2. Physical parameters of maize

S/N	Parameter	Mean value	Standard deviation
1.	Length	9.991- 10.793	1.165 – 1.553
2.	Breadth	8.511 – 8.791	0.939 – 1.125
3.	Thickness	4.099 – 5.127	0.735 – 1.147
4.	Equivalent Diameter	7,584 – 8.092	0.587 – 0.731
5.	Sphericity	0.699 – 0.762	0.066 – 0.093

Table 3. Mean result collected from maize dehusker-sheller machine

S/N	Speed (rpm)	Sample weight (kg)	Time taken(min)	Weight of grain from (kg)	Weight of chaff (kg)	Weight of cob (kg)	Weight of husk (kg)
1	469	1.5	2:06	0.85	0.041	0.30	0.22
2	309	1.5	2:12	0.84	0.036	0.39	0.23
3	278	1.5	2:31	0.8	0.037	0.42	0.24

Table 4. Effect of loading rate on dehusking, shelling and cleaning efficiencies (eff)

S / N	Speed (rpm)	Sample weight (kg)	Time taken (min)	Shelling eff (%)	Dehusking eff (%)	Cleaning eff (%)
1	469	1.0	1:50	78	67	85
2	469	1.5	2:05	72	56	78
3	469	2.0	2:23	69.5	53	76

Table 5. Effect of loading rate on dehusking, shelling and cleaning efficiencies (eff)

S / N	Speed (rpm)	Sample weight (kg)	Time taken (min)	Shelling eff (%)	Dehusking eff (%)	Cleaning eff (%)
1	309	1.0	1:55	75	65	86
2	309	1.5	2:!5	69.3	54	78.8
3	309	2.0	2:25	68.2	52	74.5

Table 6. Effect of loading rate on dehusking, shelling, and cleaning efficiencies (eff)

S / N	Speed (rpm)	Sample weight (kg)	Time taken (min)	Shelling eff (%)	Dehusking eff (%)	Cleaning eff (%)
1	278	1.0	2:02	69	86.7	60
2	278	1.5	2:35	64.7	81.0	52
3	278	2.0	2:56	63.0	79.0	50.5

The interaction of selected performance parameters with speed is as shown in Table 7. There was a positive correlation between the various speeds employed in this study and the mean shelling efficiency, dehusking efficiency and the through put capacity. This was however contrary to what was observed between the speed and the mean cleaning efficiency (Table 7).

Table 7. Relationship between speed, through-put capacity, grain loss and shelling, cleaning and dehusking efficiencies

	Speed	Shelling efficiency	Cleaning efficiency	Dehusking efficiency	Through-put capacity	Grain loss
Speed	1.0000					
Shelling efficiency	0.9909	1.0000				
Cleaning efficiency	-0.5664	-0.4573	1.0000			
Dehusking efficiency	0.8676	0.7975	-0.9002	1.0000		
Through-put capacity	0.8567	0.7844	-0.9104	0.998	1.0000	
Grain loss	0.4624	0.3458	-0.9925	0.8415	0.8530	1.0000

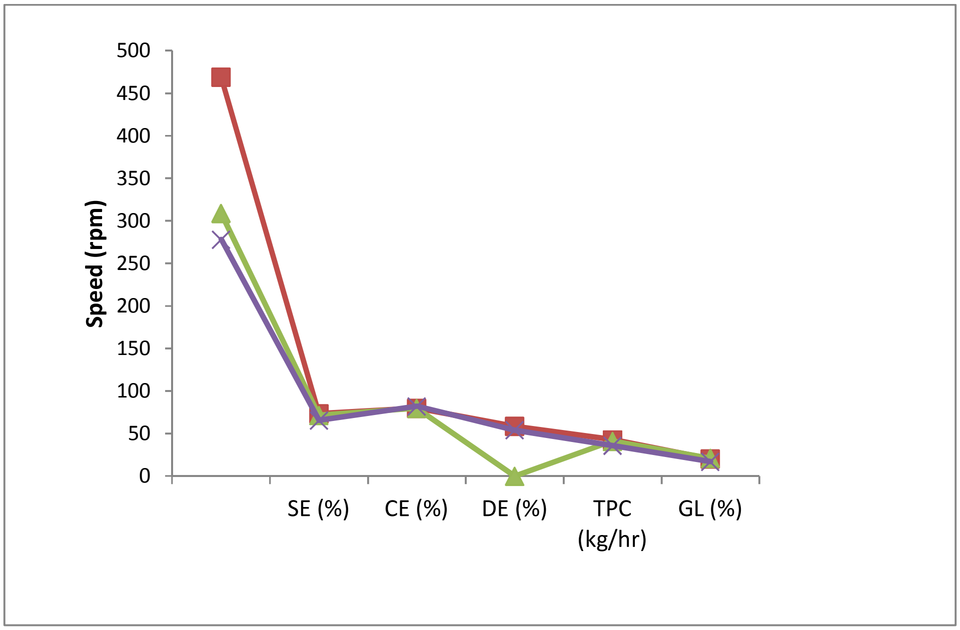

Fig. 1. Interaction of selected performance parameters with speed

Note: SE: Shelling efficiency; CE: Cleaning efficiency; DE: Dehusking efficiency; TPC: Through-put capacity; GL: Grain loss

4. CONCLUSION AND RECOMMENDATIONS

The designed and fabricated low-cost whole maize dehusker-sheller had good mean husking and shelling efficiencies, which decreased with reduced speed of operation. The machine's cleaning efficiency also increased with reduced speed. The throughput capacity was however low. Materials used in the design and fabrication of the machine were locally available and affordable. The machine is therefore suitable for small/medium scale maize production in Nigeria. Further improvements however need to be made on its through-put capacity for more effective dehusking/shelling operations. The hopper can also be widened for a better performance.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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