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Performance Evaluation of Maize Dehusker Cum Sheller Machine for Small-Scale Maize Processing Farmers

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Abstract

To provide better on-farm maize processing operations for small and medium-scale farmers, post-harvest operations such as dehusking and shelling require mechanization and demand the use of suitable and appropriate machinery to obtain higher operational efficiencies at the optimum rate. This maize dehusking-shelling machine evaluated is easy to operate and was constructed from available local materials. The performances of the developed machine were evaluated at four (4) varying speeds to achieve different dehusking and shelling efficiencies, throughput capacity, and percentage of whole grain that passed through the designed machine sieve. It was observed that shelling process at a moisture content of 13.6% wet basis and varying machine rotating speed of 450, 400, 350, and 300 rpm for 120 seconds, the machine delivered an output of shelled grain masses of 19.72, 18.57, 17.83, and 14.46 kg respectively. The dehusking and shelling operations performance efficiency of 99.6, 92.85, 89.15, and 72.3% was recorded at 20kg undehusked and unshelled maize cob loading capacity. Maximum whole grain recovery through the sieve with minimal loss to whole grain damages was observed at 450 rpm speed. The output capacity of the machine showed that equal mass (quantity) of undehusked maize and unshelled maize cobs were dehusked and shelled 36-times faster than manual dehusking and shelling operations when compared.

Keywords: *Maize, shelling, dehusking, farmers, efficiency.*

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Introduction

In Nigeria and Africa at large, maize crop produce is next to wheat and rice consumption for every household. It is mostly consumed as staple food by the majority of its consumers who are economically disadvantaged and this among other preferences makes it a very important diet. The maize is either processed into varieties of readily consumable state such as flakes for snacks, pudding, and whole grain flour for meals or consumed when boiled or roasted.

Dehusking and shelling of maize cob is one of the operations carried out after harvesting operation either on the farm field or within the storage environment before prolonged storage in silos or grain barns. It requires outright removal of maize grains from the cob. This is done either to improve the cleanliness (quality) of grains while in storage, prolong the shelve life, or add value to the produce. The dehusking and shelling operations enhances the processing of the grains into flour product. Whole grain maize and its processed flour product are of utmost importance for both human consumption and animal feed production. According to Adewale and Babajide, (2020), maize and its processed product consumed in the form of pudding and flakes, is an undisputable readily affordable staple food for low-income earners and the economically marginalized in Nigeria and Africa at large with a large consumer-market demand. Other than its local and foreign economic income generation via trade and exports, most livestock farmers and commercial animal feed producers utilize its veracity to meet this sector consumer demands. Aremu *et al.,* (2015) investigated challenges associated with maize products large consumption demand and the available processing technology applications to meets these demands within the under-developed nations in Africa-Nigeria inclusive. The use of manual labour and crude skills portrays insufficient processed product output. The problems associated with old method of maize dehusking and shelling are little output, cumbersome, material wastage, time consuming, poor hygiene, cost and energy consuming (Ashwin, 2014).

The availability of this product in a developing nation as Nigeria to meet these increasing demands had over time been challenging owing to the crude, tiring and burdensome techniques mostly applied in it processing. Also, factors such as availability of modern processing equipment, cost of available modern equipment, and required operating technical skills, population growth and the discoveries of new purpose for it application had posed immense challenges. (Aremu *et al.,* 2015). Therefore, in order to meet this consumption demands of growing populations of human and animals, mechanized technological application becomes a necessity for large scale production of this commodity. In order to dehusk the cobs and shell the maize into grains and it subsequent milling processing into flour at large scale of production, technical application that require usage of specialized machines becomes needful. The machine must be equipped with an engine-powered technology to mechanize the production processes as a cutting edge over human manual power application.

Therefore, the purpose to develop locally a multi-functional machine that is simple to operate, perform only dehusking, shelling and cleaning (winnowing) operations as a single unit for an average Nigerian peasant farmer to afford it procurement. Significantly, it reduces the drudgery of de-husking and shelling, damage done to maize grains during these operations and overall cost of post-harvest production processes.

Methodology

The following processing operation principles were used to design and construct the Maize Dehusker cum Sheller:

The whole maize cobs plucked from stake, will be spread under an open air and sun-dried to reduce grains moisture content to about 13 - 14% dry basis (db) and then loaded into the machine processing chamber through the open inlet unit called the hopper. The metal spikes on the embedded rotating horizontal shaft will pull the fed in maize cobs and aligns them in-between it beveled and spiral directional arrangements along the entire length of the shaft to tear off the husk. In the event of this action, impact and abrasive actions will occur between the cobs held between metal spikes and the inner lining wall with perforated hole to serve as a sieving concave drum. These actions will aids in plucking off grains from the cobs which immediately, falls by gravity through an embedded sieve holes that serves as screens into the outlet chamber for final collection. The torn husk and broken cobs will be discharged from the chamber through an open end outlet with the forceful-sweeping out effect of the rotating spikes.

Design Consideration

The following criterion were considered in the designing and construction of the machine:

1. Use of available locally sourced raw materials that were of low cost
2. Equipment overall weight for portability

3. Low operational and maintenance costs
4. Required maximum operational force and speed
5. Loading conditions and optimal output (planned to reduce wastage of maize grains).
6. Durability, strength, corrosiveness, availability and size.

Design Analysis

The designed Machine components are:

Designed Hopper

The hopper is an external component unit of the machine that serves the singular purpose of feeding the maize into the inner processing chamber of the machine.

It was shaped like a truncated pyramid at the top with a rectangular bottom to form a height of 400 mm.

Volume of hopper according to Oni *et al.,* (2018) is:

$V_h = {}^{h}/_{3}\left(A1 + A2 + \sqrt{A1 \times A2}\right)$ ………… (1)

Where; V_h = Volume of hopper, A_I = Inlet area of hopper, A_2 = Outlet area of hopper, H = Hopper vertical height

A_I = 74.2 m^2, A_2 = 33.28 m^2, H = 0.400 m (Values obtained based on maximum fed-in and discharged quantity of maize into the machine achieved)

$V_h = {}^{0.400}/_{3}\,(74.2 + 33.28 + \sqrt{74.2 \times 33.28})$

$\mathbf{V_h = 52.55\ m^3}$

Designed Dehusking and Shelling Chamber Unit

This unit comprises of a shaft carrying the shelling drum with the spikes and the beaters positioned spirally along the shelling drum length. A mild steel of 1mm gauge was shape into a concave of 150 mm diameter and 450 mm length as the chamber housing, with two closed ends flanged and attached to the frame. A mild steel sheet of 2 mm was shaped to form the Dehusking drum diameter of 160mm and 350mm in length. Dehusking and pre-winnowing operations of grains and chaffs occur inside this chamber with a concave screen which was determined by the size and diameter of dried maize. A shaft attached to the drum on both ends transmits the torque required for operation from the prime mover through the belt and pulley.

Plate 1. Dehusking and shelling chamber housing

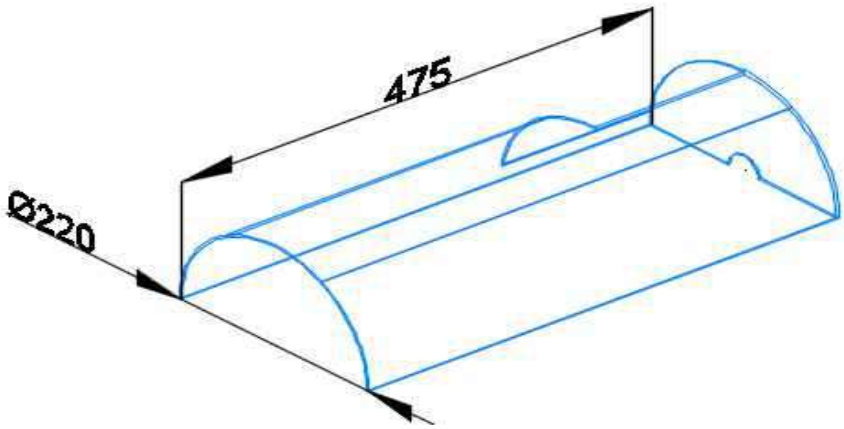

Figure 2: Concave top cover

The shelling cage diameter as suggested by Eric *et al.*, (1987):

$D_c = d + 2H_s + 2W_m + 2c$ …………………..(2)

where:

- D, shelling cage shaft diameter = 0.025m
- H_s, spike height = 0.058m
- W_m, maize cob maximum width = 0.2m and
- *C*, grain smallest diameter (with allowance) = 0.0041 m

Therefore:

*d*c = 0.025 +2(0.058) + 2(0.2) + 2(0.0041) = **0.6022m**

Spikes Design on shelling drum

Design adopted in accordance to Khurmi and Gupta, (2008):

$N_s = \frac{Lc}{SSt} \times \frac{\pi d}{SSc}$ ………………………….. (3)

Where:

- *Lc* = length of the shelling cylinder, 750mm
- *SSt* = spike spacing in the row, 50mm
- *SSc* = spike spacing on the cir
- d = diameter of the shelling cylinder. 92mm

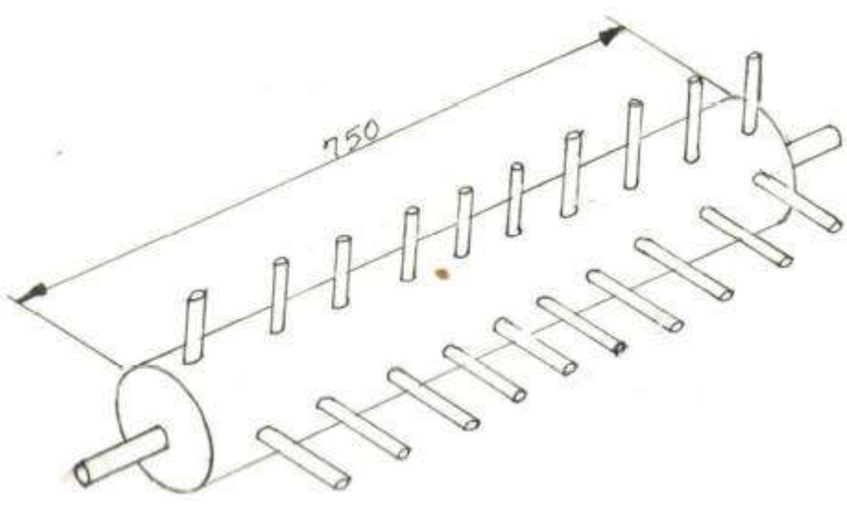

Figure 2: Spikes beaters loaded drum

$N_p = \frac{645}{50} \times \frac{3.142 \times 92}{80}$

$\mathbf{N_s = 46.6}$

Therefore, *N*s was taken as 47 for maximum numbers of spikes and beaters that will dehusk and shell the maize; evenly distributed on the shelling cage for efficiency.

Determination of Weight of Spikes (Ws)

Length of spike is chosen based on the distance between the shelling drum and the threshing chamber and the clearance. Total weight of spikes = 6.275

Determination of Weight of Beaters (Wb)

The function of the beater is to complete the shelling processes by beating the maize and removing it from the cob. Total weight of beater = 9.2416 N

Determination of Weight of Pulley on Shaft

The purpose for the design of shaft is to ensure the appropriate strength and rigidity required to transmit an applied torque is ensured.

Mass of pulley was determined using spring balance as 7.64 kg

Designed Frame

It is a rigid structural part of the machine that supports the entire members of the machine. It houses the entire shelling unit and the prime mover frame. It was made up of mild steel. The overall dimensions of frame were 80.5 cm length, 60 cm width and 136.5 cm height. The thresher-sheller unit was fixed to this framework.

Designed Screen

This component part is responsible for cleaning of shelled grains with the aid of sized-bored holes that permit passage of grains.

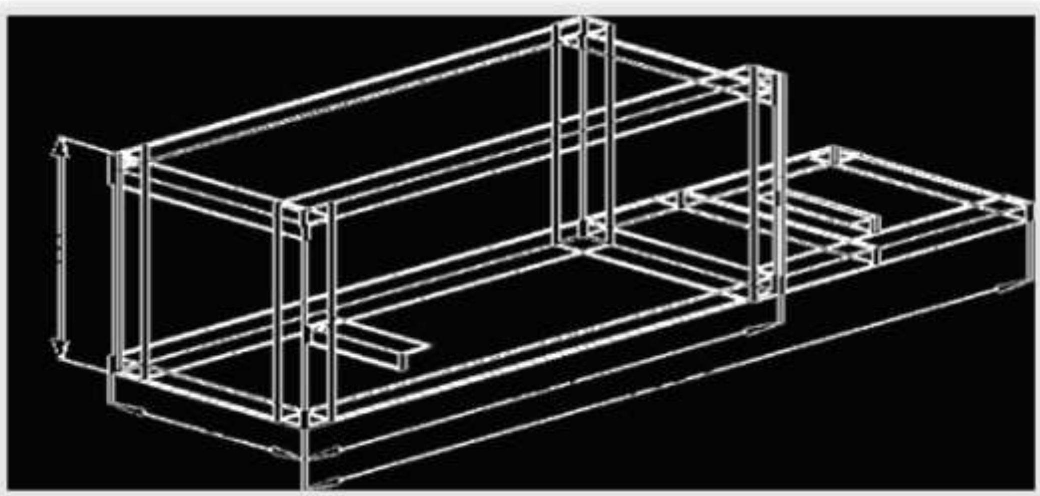

Figure 3: Structural Frame with prime mover seat

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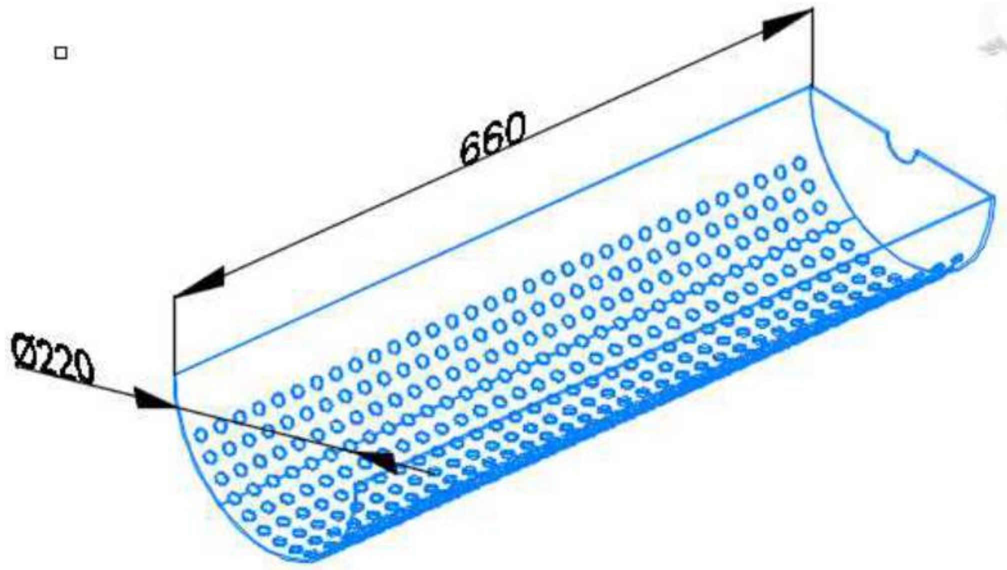

Figure 4: Bottom Concave Sieve

Designed Outlet

The outlets were designed for ejection of chaff/cob and collection of grains. A 1 mm mild steel metal was used to for these outlets with open ends for recovery of dehusked and shelled cobs and grains. Grains outlet was fabricated with a 1 mm mild steel metal sheet attached to the machine under the dehusking unit. Chaff outlet formed an extension of the grain collection chamber. It was made with 1 mm mild steel metal sheet and tapered outward. It extended out by 160 mm and the width, 380 mm.

Power Requirement

Determination of power required to drive the pulley and shaft was calculated as:

Weight of pulley = 74.85 N, Radius of pulley, r = 0.15 m, Speed of Prime mover in minutes = 1440 rev/min

Speed of prime mover in Seconds, n = 1440/60 = 24 rev/sec

Angular velocity (ω) = 2 π n (5) ……………… (4)
= 150.816 rad/sec

Power required = weight $\times$ linear velocity = 1.69 kW

Total power required = 1.7 kW

1.7 kW = 5.15 hp

A mechanical Prime mover of 6.5 hp was selected to accommodate miscellaneous power that may be required during operation.

Calculating threshing speed

$N_t d_t = N_m d_m$ ….(ii)

N_t = Thresher speed

d= diameter of pulley or thresher

N_m = Prime mover speed

D_m = diameter of pulley

Speed using 178 mm pulley

Nt dt = Nmdm

Nt x 178 = 1440 x 58

Nt = 469.21rpm

By tacometer reading = ***472 rpm***

Operational Principle of the Machine

The machine constructed is made up of the Dehusking cum Shelling (DS) unit, the blowing unit and the collecting unit. The DS unit consists of the hopper with cover and the sieve. The DS unit is supported with the aid of a frame.

The machine designed works on the principles of shearing and impact forces. Motion from the prime mover through the driving pulley provides an angular velocity that is translated to the driven pulley that is fixed on the primary shaft which is supported by the bearings on both ends. The generated power on the driven pulley provides rotary motion on the beater and the spikes mounted on the cylinder, which force out the grains from the maize cobs by friction and shearing actions against the confining walls holding them. The clean maize leaves the machine at the output section of the machine (the lover discharge chute). The husk and cob are forced out of the machine via the upper discharge chute with the aid of paddle plates.

Results and Discussion

Results

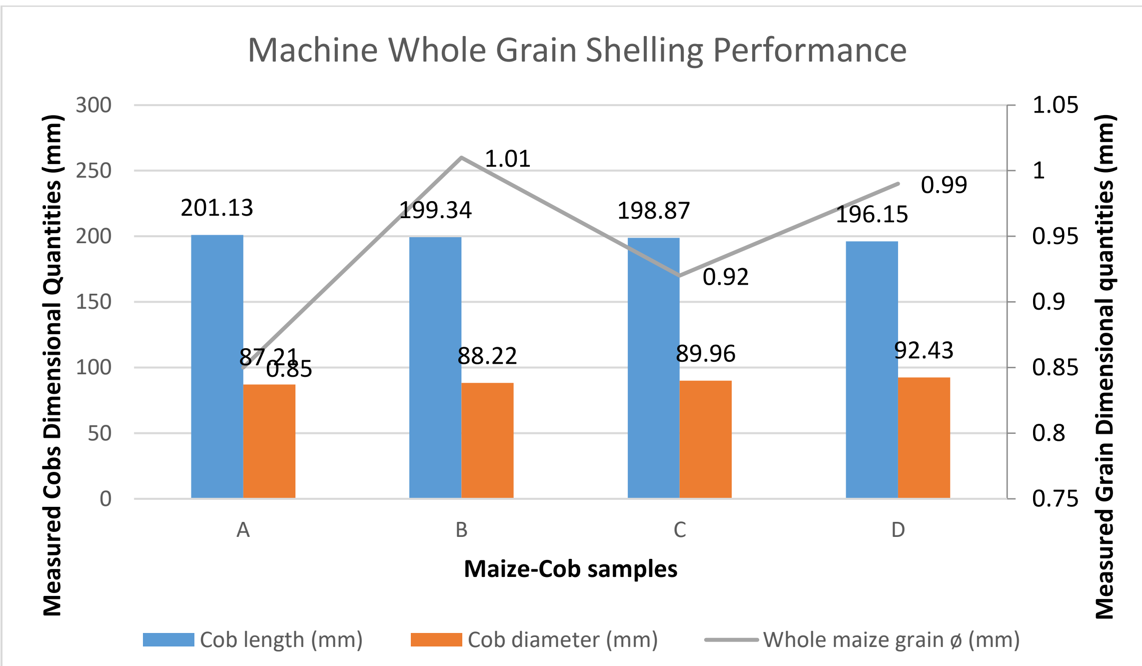

Figure 5. Shelling Parameters Trials Compared

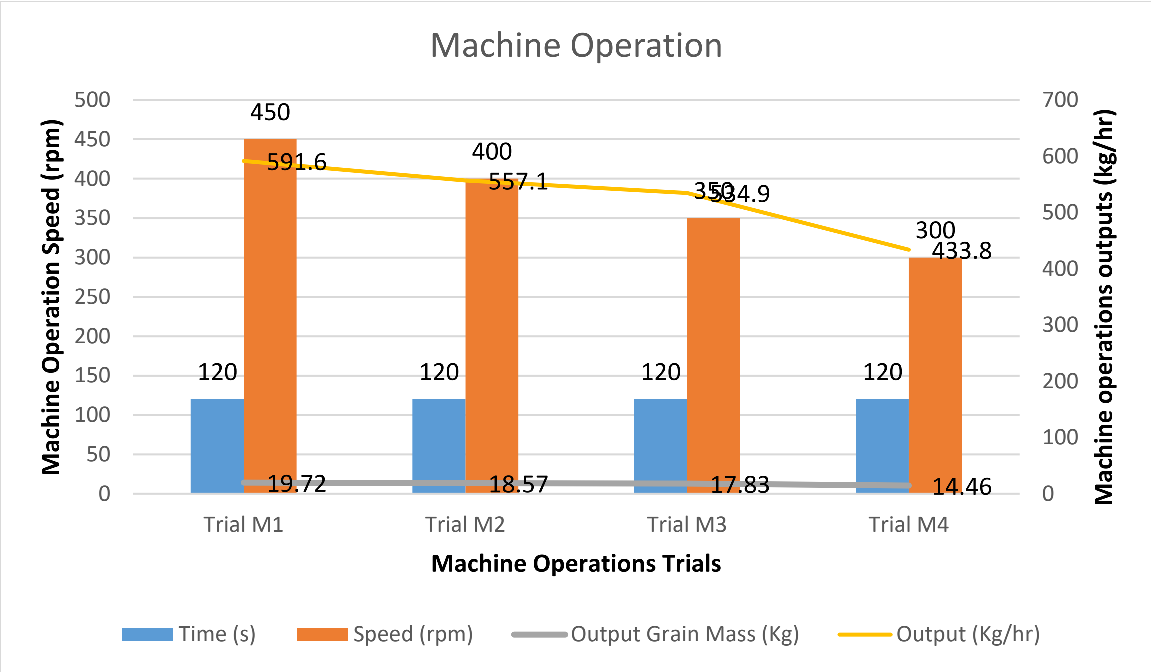

Figure 6. Machine Maize Shelling Operation Performances

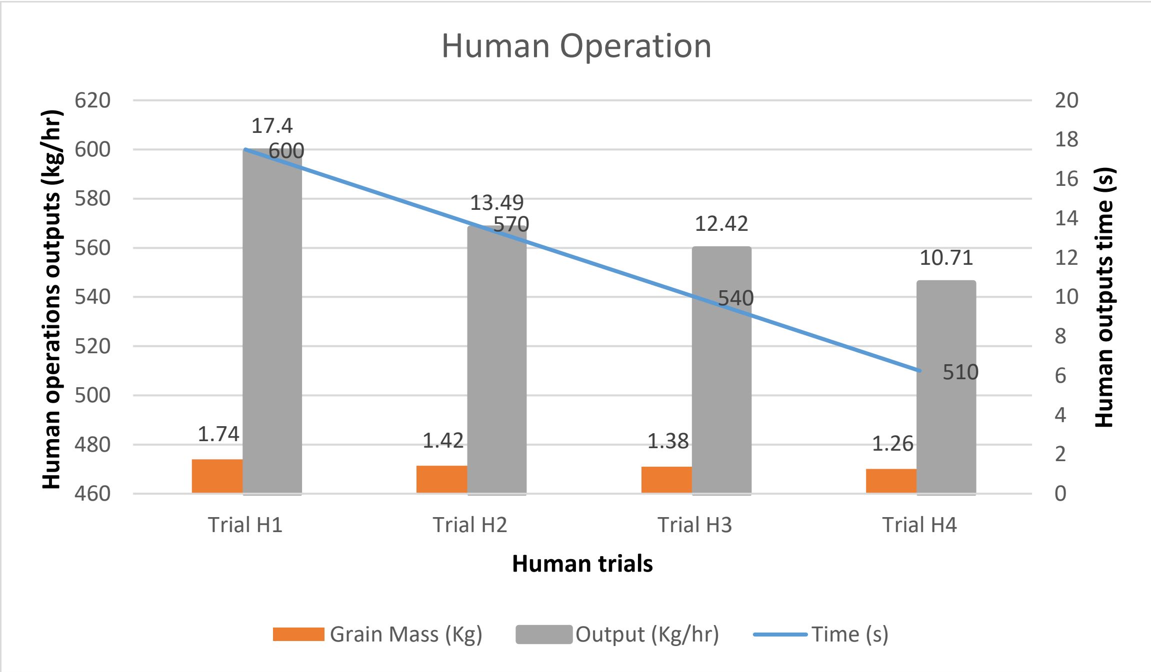

Figure 7. Human Maize Shelling Operation Performances

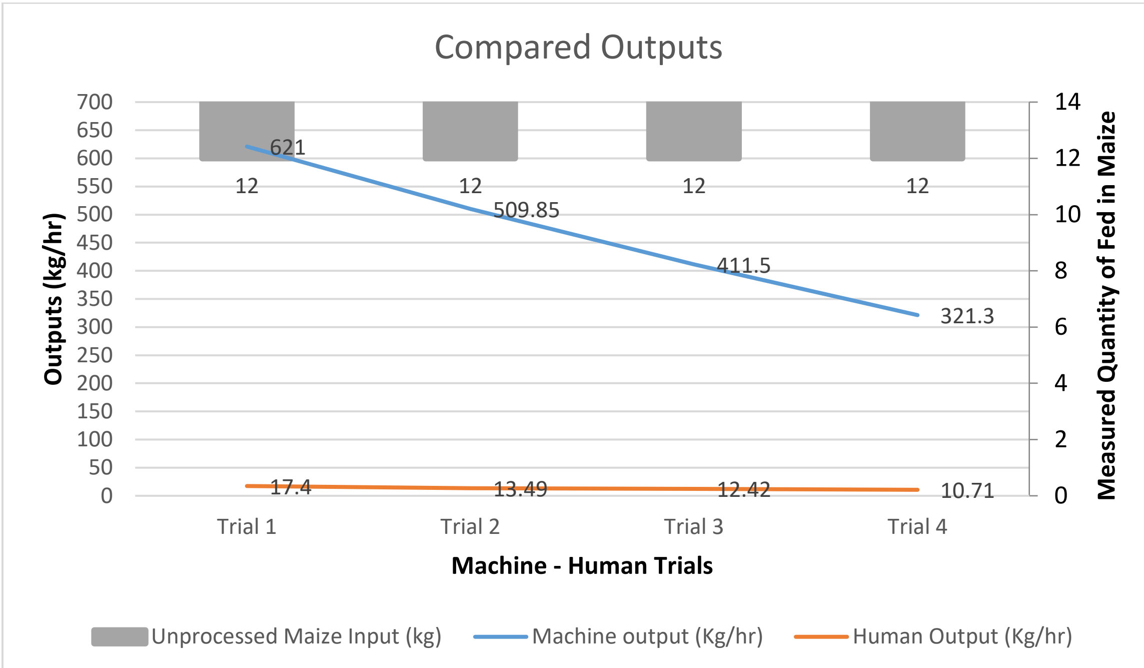

Figure 8. Operational Outputs Performances Compared

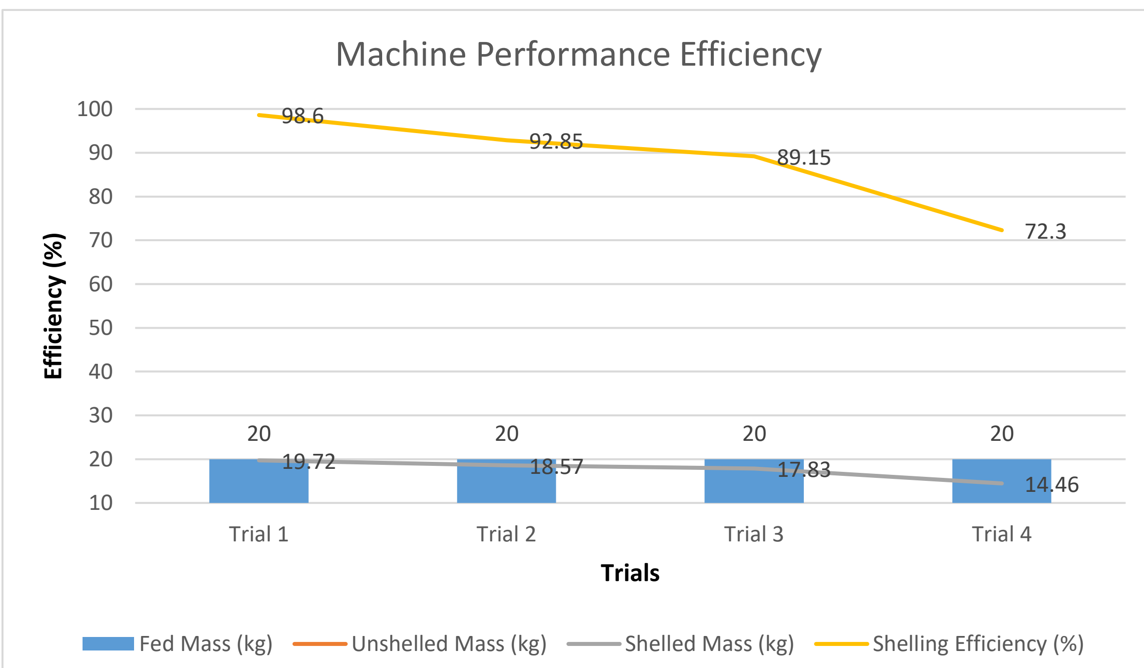

Figure 9. Machine Shelling Operation Efficiency Analyzed

Plate 2. Fabricated maize dehusking-shelling machine

Discussions

The average initial moisture content of maize (with husk) using grain moisture tester was found to be 33.1% wet basis (w.b) and 13.6% dry basus (d.b) when dried in the open air for 10days. This value agreed well with the reports from the literature about thermo-physical properties of maize as investigated by Adelaja *et al*., (2020). According to figure 5, average maize cobs with measured similar physical parameters such as diameter and length were selected into four (4) trial batches of A, B, C and D respectively for the purpose of evaluating the whole grain shelling performance. The measurement of these physical parameters were done with the aid of a vernier caliper.

Average grain sizes ranging from trials A, B, C and D respectively after dehusking and shelling operations were measured to be 0.85, 1.01, 0.92 and 0.99 cm respectively. These values represented the sizes of maize grains the machine would shell out when whole grain cobs are fed into the machine for dehusking and shelling processing operations. From figure 6, in order to ascertain the outputs of grains to be delivered at each varying machine operational revolution per minutes (rpm) of 450, 400, 350 and 300 rpm respectively for each trials, a constant machine dehusking and shelling operations time of 120 seconds and 20kg mass of fed-in undehusked and unshelled maize cobs were utilized for all four (4) trials. The machine delivered an outputs of shelled grain masses of 19.72, 18.57, 17.83 and 14.46 kg respectively. Results obtained from the machine operations revealed that, the quantity of shelled grains outputs were directly proportional to the machine revolution per minutes (rpm) utilized for each dehusking and shelling operations. Similar trend with higher shelling efficiency was observed by Naveenkumar, (2021), Adewole et al., (2015) and Patil et al., (2016). The whole grains recovery was significantly affected by different machine speeds. The higher the machine speed, the higher the percentage recovery of shelled grains via the lower discharge chute. This similar trend was observed by

Vyavahare and Kallurkar, (2015) and Olaoye, (2002).

An increased in machine speed increased maize cobs-grains shelling efficiency from 72.3, 89.15, 92.85 and 98.6 % respectively, and this increased the rate of grains discharged via the sieve. These values recorded represented the percentage of the useful fed-in maize cobs delivered as outputs. The result and trends obtained agreed well with the observations of Kumar *et al*., (2020) and Olaoye (2012).

While the human operations outputs recorded as shown in figure 7 indicated that, production outputs were directly proportional to time spent given the same measure of 20kg mass of undehusked and unshelled maize cobs. Time was a determinant factor for mass of cobs-grain to be dehusked and shelled for each of the trials. The adequately calculated and designed shelled grain sieving mesh diameter precision resulted in the increased output efficiency of the machine.

Conclusion

By considering the performance of the machine from each trials, the total duration of operations, labour and energy requirement, it was observed that at feed rate of 20 kg and machine speed of 450 rpm, the machine gave the best performance efficiency of 98.6 % when dehusking and shelling operations were carried out.

Recommendations

Construction materials used for this machine were considerately affordable because they were locally sourced owing to their availability. This post-harvest operation machine is suitable for on-farm and off-farm post-harvest production of maize by the small and medium scale farmers in Nigeria owing to it ease of mobility and moderate size as designed. It is however recommended that, improved technological design features should be applied on the machine to enhance better output capacity through efficient dehusking and shelling operations as may be required by individual farmers.

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