Development and Performance Evaluation of a Combined Maize Shelling and Cleaning Machine

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Abstract:- The construction, assembly and machine evaluation of the combined maize shelling was done in the department of Agricultural and Bio-Environmental Engineering Technology, Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria. The evaluation of the machine was performed using NIS standard which involve the use of three different speeds of 400rpm, 500rpm and 600rpm at moisture content of maize cobs at 11%, 12% and 13% respectively. The results showed that shelling efficiency and machine capacity in kg/hr were at highest value at 12% moisture content of maize and at 500rpm shelling speed. Thus shelling of maize at 12% moisture content dry basis using 500rpm shelling speed resulted into the highest efficiency and machine capacity when compare to other moisture content levels and machine speeds

Keywords:- *Design, Fabrication, Performance Evaluation, Maize Shelling Machine*

I. INTRODUCTION

Maize (Zeamas) is an annual legume crop. It has a distinct growth form, with the lower leaves being like broad flags, generally 50 – 100 centimeters long and 5 – 10 centimeters wide, usually the stems are upright (Joshua and Mendoza, 2007). The varieties of this crop follow same trend of growth, although specific time and interval between phases and total number of leaves produced may vary between different cross-breeds, season, time of planting and location (Ugwu and Omoruyi, 2016). Maize afford vitamins for human and animals and serving as a fundamental uncooked fabric for starch, oil, alcoholic beverages, food sweeteners and more recently fuel (Hoeft, Natziger, Johnson and Aldrich, 2000). It is an important source of carbohydrate, protein, iron, vitamin B and minerals (Amudalat, 2015). Over 30 % of the caloric consumption of human beings in sub – Saharan Africa comes from maize. All parts of the crop can be used for meal and non – meal products.

Maize accounts for 30 – 50 % of low – earnings family expenditures in Africa (IITA, 2019). Maize production in Africa became about 75 million tons in 2018, representing 7.5 % of global maize manufacturing and the largest African producer is Nigeria with over 33 million tons, followed by South Africa, Egypt and Ethiopia. In industrialized nations, maize is essentially used as farm animal feeds and as raw material for industrial products, while in low-profit nations, it is far specially used for human consumption (Ndirika, 1995). In Sub-Saharan Africa, maize is a staple meal for an envisioned 50 % of the populace (IITA, 1996). Maize is a vital supply of carbohydrate, protein, iron, vitamin B and minerals. In Africa, maize is fed on as a starchy base in huge form of porridges and pastes. Green maize (fresh on the cob) is eaten parched, baked, roasted or boiled which play an essential role in filling the massive gap after dry season (IITA, 1996). In rural communities, the dwellers use maize in manufacturing of porridge (fura) and "Tuwo" (Aremu *et al*., 2015).

In Nigeria, maize has turn out to be a staple meals crop that is recognized even to the poorest family. Many Nigerians earn direct income through production of maize but the production is incomplete without shelling and cleaning operations. It is used in numerous forms to alleviate stavation, and such forms include pap, maize flour and so forth. The most important steps involved in the processing of maize are harvesting, drying, de-husking, storing, shelling, cleaning and grinding. The processing of maize into quality forms not only extend the useful life of the crop, but also increases the net profit of the farmers (Aylor, 2002). One of the most critical processing operations done to carry out the quality of maize is shelling and cleansing. These shelling and cleansing have been and remain a serious problem to local dwellers in their communities (Wenham, 1995). For the rural farmers to maximize profit from their maize, appropriate technology that suites their needs must be used.

The conventional shelling and cleaning techniques do not assist large – scale processing of maize, in particular for industrial functions. There are unique styles of shelling machines which include the hand held sheller, small rotary hand sheller, free standing manually operated sheller and motorized sheller. The electric motor technology involves the use of mechanical assistance in shelling and cleaning of maize (Nkakini, 2007). The physical and mechanical properties of maize are extensive understanding that may be utilized in maize farming, harvesting and storage or in processing inclusive of shelling, cleaning, drying, freezing and others. This information is vital in the designing and construction of maize shelling and cleaning machines and additionally in preparation of processing chain from grain to food. Accurate design of machines and processes in the food chain from harvest to table requires an understanding of physical properties of staple materials. (Ahlgrimm, 1997).

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II. SHELLING OF MAIZE

Shelling is the act of removing seed or grain from their various cobs after dehusking for both domestic and commercial purposes. Shelling is best done when the moisture content is as little as 13% (ASHRAE, 1998). In the stone ages, primitive approach of shelling consist of beating with stick, crushing with mortar and pestle, manual shelling consequently consume much human power and time demanding (Sunghal and Thierstein, 1987).

Removal of maize from cobs if completed by hand is a great task in post harvest handling operation of maize. The prevailing maize shelling machine are sophisticated and required excessive power input to function as a result, they are low in efficiency (Wagami, 1997).

Broken seeds are liable to insect and moulds attack thereby increasing the formation of aflatoxin contamination. As a results of all these short comings, the development of a combined maize shelling and cleaning machine with higher efficiency, better product quality and powered with low powered engine became a necessity.

A. Design Considerations and Analysis

A motorized maize shelling – cum – cleaning machine was developed with local materials. The following factors were considered in the fabricating process of the machine; availability, minimum power requirement, simplicity, rigidity, stability, durability, portability, suitability and economic consideration.

B. Design Analysis

➢ *Power Requirement for the Machine.*

The power required to turn the shafts of the machine on the maximum applicable load and speed for effective shelling and cleaning is given by Hall, Holowenko and Laughlen (1982) as:

$$P = \omega^2 \text{ x r} \qquad \text{(i)}$$

$$\omega = \frac{2\pi N}{60} \qquad (ii)$$

Where:

ω = speed in radian
r = radius of shelling spike
P = power required
N = maximum rpm

➢ *Determination of Hopper Capacity*

The angle that was used for Hopper Inclination (H_i) in the design is $\alpha = \tan^{-1} \mu$ as given by Bucklin, Thomson, Ross and Biggs (2003) as:

$$H_i(\alpha) = \tan^{-1} \mu \qquad \text{(iii)}$$

Where:

α = Angle of inclination.
μ = Coefficient of friction (0.3-0.7)

➢ *Belt Design.*

The determination of type of belt was based on the amount of power to be transmitted, this is based on the Indian standard (I S Code No. 2494- 1974) for belt (Sadhu, 2004).

The following equations were used for belt design

- Equation (iv) was suggested by Khumi and Gupta (2006) for calculating the length of belt as:

$$L = 2C + \frac{\pi}{2}(D + d) + \frac{(D - d)^2}{4C} \qquad (iv)$$

Where:

L is length of belt in millimeter (mm).
d is diameter of driver (smaller pulley) in mm
D is diameter of driven (bigger pulley) in mm
C is distance between center of the two pulley in mm

$$\pi = \frac{22}{7} = 3.124$$

- Determination of the belt tension was suggested by Khumi and Gupta (2006) as:

$$\frac{T_1 - W}{T_2 - W} = e^{\mu a/(Sin\ 1/2\theta)} \qquad \text{(v)}$$

$$T_1 = S \text{ x } A \qquad \text{(vi)}$$

$$V = \frac{\pi D_1 N_1}{60} \qquad \text{(vii)}$$

$$M = A \text{ x } E \text{ x } L \qquad \text{(viii)}$$

$$W = MV^2 \qquad \text{(ix)}$$

$$A = {}^{1}/_{2}\,(W_1 + W_2)\ T \qquad \text{(x)}$$

Where:

T_1 is the Tension in the Tight Side of the Belt, N.
T_2 is the Tension in the Slack Side of the Belt, N.
S is the Maximum per Permissible Belt Stress, MNm^{-2}
M is mass per unit Length of Belt, Kg
V is linear Velocity of Belt, ms^{-1}
A is area of Belt, m^2.
θ is groove Angle of V-belt, 40^0

➢ *Shaft Design*

The following equations were also used for the shaft design:

- *Shaft Diameter*

The mathematical expression for calculating shaft diameter was suggested by Khumi and Gupta (2006) as:

$$d^3 = \frac{16n}{\pi Ss}\sqrt{(Kb \; x \; CBM)^2 + (Kt \; x \; CTM)^2} \qquad \text{(xi)}$$

Where,

d is diameter of shaft (mm),
π *is constant* (3.142)
CBM is combine Bending Moment
CTM is combine Torsional Moment
Ss is 8000psi for Shaft without Keyway
n is factor of Safety
Kb is combine Shock and fatigue factor applied to Bending Moment for Rotating Shaft with sudden applied load
Kt is combine Shock and Fatigue factor applied to Torsional Moment for Rotating Shaft with sudden applied load

- *Speed of Shaft.*

To determine the shaft speed, the rotors pulley diameter was selected using the equation for speed rotation, according to Matthew, Hoseney and Faubion (1999)

$$\frac{D_1}{D_2} = \frac{N_2}{N_1} \qquad \text{(xii)}$$

Where:

N_1 is revolution of smaller pulley, rpm
N_2 is revolution of larger pulley, rpm
D_2 is diameter of bigger pulley, mm
D_2 is diameter of smaller pulley, mm

III. SELECTION OF BEARING

The selection was based on the types of load the bearing will support when at rest and during operation and also based on the diameter of shaft.

A. Machine Description and Component Parts

The combined maize shelling and cleaning machine consist of these components; the supporting frame, the feed hopper, the shelling chamber, the chaff removing chamber, cob outlet, clean grain outlet and the power source unit. The frame act as the support for the entire machine. It was produced from a 50 mm by 50 mm angle iron. The feed hopper is produced from a galvanize metal sheet with a cuboid shape to enhance easy handling of maize during shelling. The shelling unit consists of the upper trough, lower trough, arrangement of beaters and screen. The shelling of the maize takes place in this unit of the machine. Immediately after the screen of the shelling unit is the cleaning unit which separates the shelled maize into cleaned maize and chaff by a pneumatic mechanism which consists of a blower through which the blast of air removes chaff and other light unwanted materials from shelled maize as it falls from the shelling unit to the outlet. The cleaned maize outlet is located below the cleaning chamber and cleaned shelled maize is collected at this unit. The cob outlet is located at one side of the lower trough just after the hopper and the cob are received through it after shelling. The power source of the machine consists of a 3-horse power motor, 3-pullies and 2-belts.

B. Machine Operation

The combined maize shelling and cleaning machine is operated through the cranking of the prime mover which operate the shelling unit and drive the fan. An amount of maize cobs are fed into the machine through the hopper and a feed gate in the hopper regulates the flow of the maize into the machine (Feed Rate). As the maize get to the shelling chamber where beaters rotate, the maize cobs are shelled with the action of the beaters that beat the maize cob repeatedly. The shelled maize pass through the screen of the shelling unit and falls across an air stream of the cleaning unit and cleaned maize seeds are collected at the cleaned maize outlet. The chaffs and other foreign materials that are lighter than the grains are blown out of the machine through chaff outlet. The exploded view and picture of the machine are shown in **figures 1 and 2**.

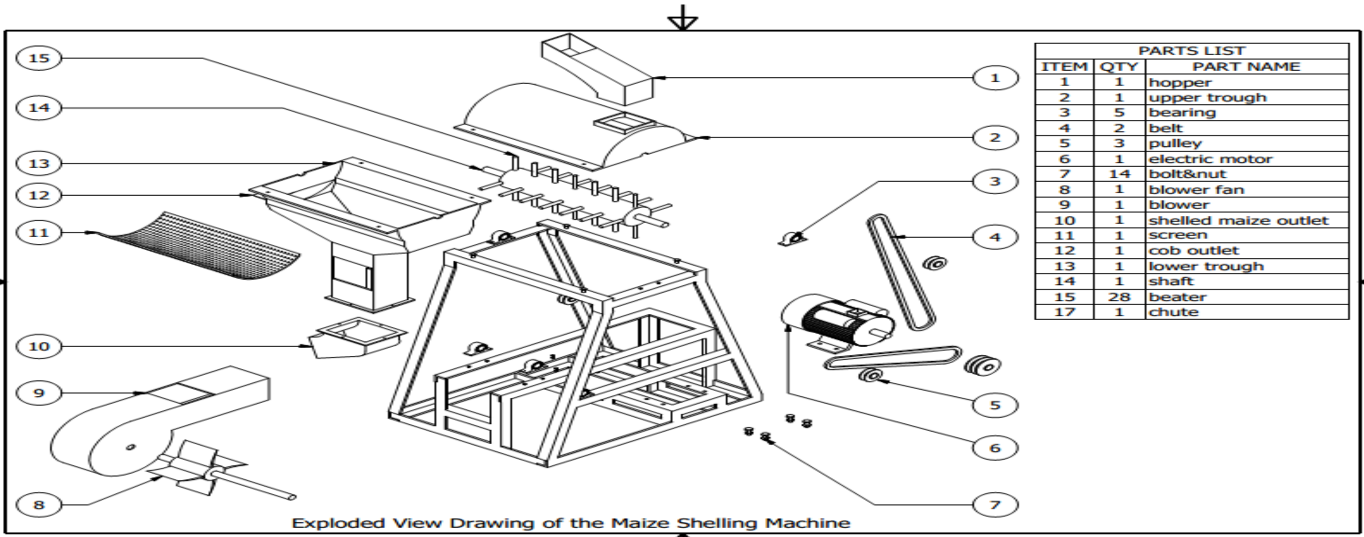

Fig 1 The Exploded Drawing of the Machine.

Fig 2 The Combined Shelling and Winnowing machine

C. Machine Performance Test

The evaluation of the combined maize shelling and cleaning machine was carried out at the workshop of Agricultural and Bio-Environmental Engineering Technology Department of Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria. Based on the literature, the machine was evaluated at varying speed of 400, 500, and 600 rpm and moisture content of 11 %, 12 % and 13 % wet basis. The moisture content of each sample was determined using the method described by ASABE (2006). The machine capacity and efficiency were calculated using the following equations;

$$\text{Capacity of the Machine} = \frac{input\ load}{Time\ taken}\frac{kg}{s}$$

$$\text{Machine Efficiency \%} = \frac{ws}{wi} \text{ X } 100$$

Where: Ws is weight of cleaned grains (kg) and Wi is initial weight of grains (kg)

IV. RESULTS AND DISCUSSION

The result of the test carried out on the machine to determine its performance discussed based on the following:

A. Capacity of the Machine

Figure 3 gives the implication of machine speed for maize cobs at various moisture content on machine capacity. From the graph, shows that, for all the maize cobs at different moisture content, as the machine speed increases machine capacity also increases, thus, at 400rpm, 500rpm and 600rpm for 11%, 12% and 13% moisture levels, we have machine capacity of 215kg/h 242kg/h 263kg/h, 205kg/h 232kg/h 253kg/h and 198kg/h 219kg/h 234kg/h respectively

B. Efficiency of the Machine

Figure 4 gives the implication of machine speed for maize cobs at various moisture level on the efficiency of the machine. From the graph, it shows that that increase in machine speed result to increase in machine efficiency. At 11% moisture content, more maize were shelled per time but more damage (breakage) were also done to the maize because of low moisture content level, also at 13% moisture content, the machine recorded least efficiency because of high moisture content. The machine performed optimally at 12% moisture content and at 500rpm, thereby recording 88% efficiency.

Table 1 Machine Speed (RPM) Versus Capacity of Machine (Kg/hr)

Machine Speed (rpm)	**Machine Capacity (Kg/hr) at Various Moisture Contents**		
	13 %	12 %	11 %
400	198	205	215
500	219	232	255
600	234	253	263

Table 2 Machine Speed (RPM) Versus Efficiency (%)

Machine Speed (rpm)	Efficiency (%) at Various Moisture Contents		
	13 %	12 %	11 %
400	79	83	78
500	77	88	77
600	75	84	76

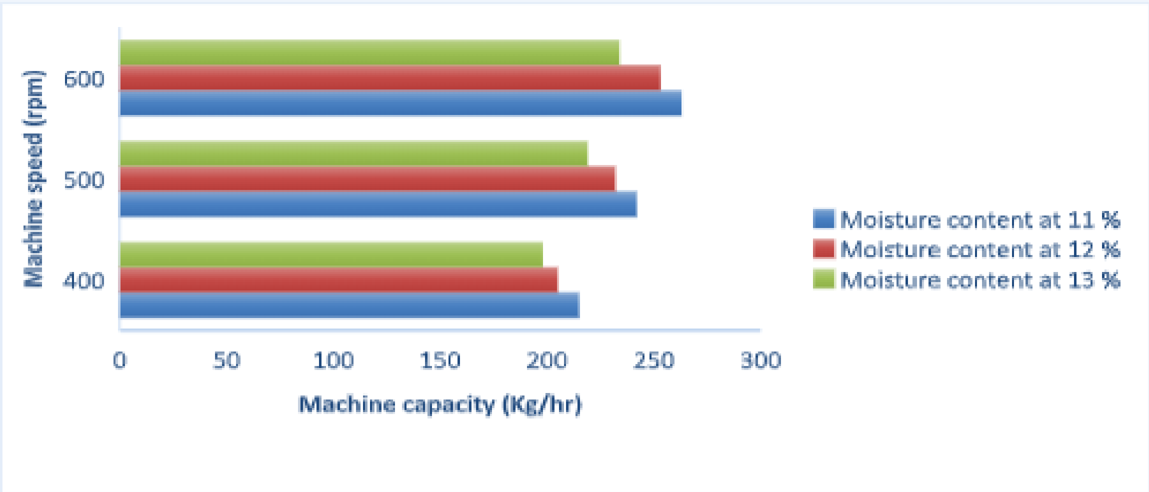

Fig 3 Effects of Machine Speed on Machine Capacity at Different Moisture Level

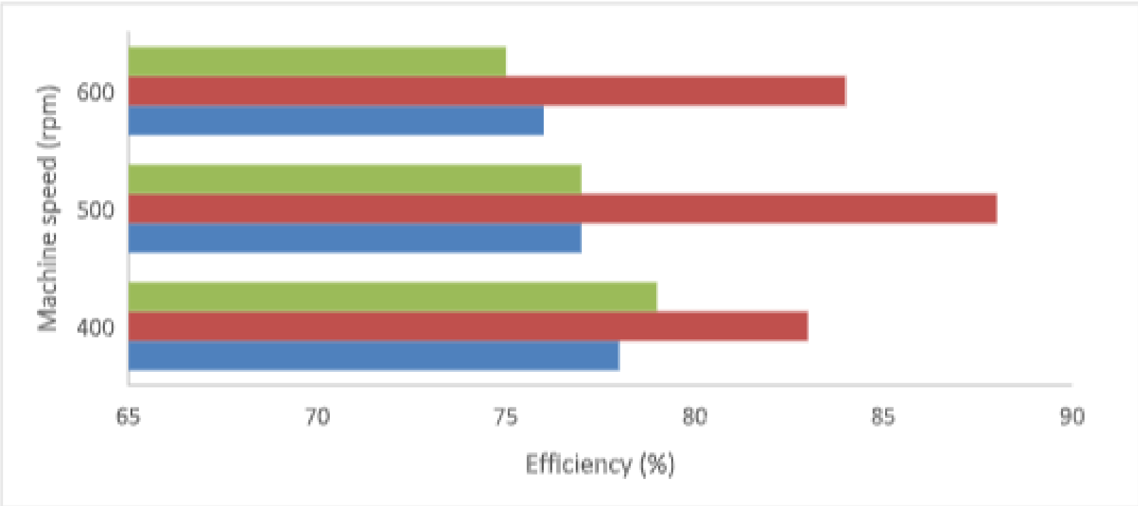

Fig 4 Effect of Machine Speed Efficiency of the Machine at Different Moisture Level

V. CONCLUSION AND RECOMMENDATION

A. Conclusions

The combined maize shelling and cleaning machine was developed in Agricultural and Bio-Environmental Engineering Technology Department. Three different moisture level (11%, 12%, and 13%) of maize cobs were used to evaluate the machine at different speed of 400rpm, 500rpm and 600rpm respectively. The outcome of the machine indicate that as speed increases, the machine capacity and efficiency also increase, and time of operation reduces. But at 600rpm, the maize breaks. The machine recorded highest efficiency of 88% at 500rpm and at 12% moisture content. Therefore, the machine performed optimally at 500rpm and at 12% moisture content.

B. Recommendation

The machine "combined maize shelling and cleaning machine" is operator's friendly as it can be operated by even a layman, the machine is a dual purpose one as it can shell and clean in one single operation. it has economic advantages over other existing shelling machines as it can be used to shell and clean maize at the same time and it also produced from local materials. The adoption of this machine by our peasant and medium scale maize farmers is advised as it will reduced the patronage of imported shelling machine of high cost

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