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Development And Evaluation Of A Low-Cost Rice Milling Machine

[1]C.A. Popoola* and [2]R.A. Olabomi
[1] Department of Chemical Engineering, Federal University Wukari, Wukari, Nigeria.
[2]National Institute for Policy and Strategic Studies, Kuru, Nigeria
** Corresponding author e-mail: calebiodunchem@yahoo.com*

Abstract
A low-cost rice milling machine was designed, fabricated and evaluated to reduce post-harvest loss being faced by the peasant farmers using traditional methods and to meet up with the demand for high quality and well processed rice at a cheaper and avoidable price. The machine was designed to de-husk paddy rice, separate the husk and remove unwanted foreign materials. It consists of a hopper, sheller, cleaner, separator (sieve), delivery unit and the frame. The machine operates on the principle of impact using centrifugal force. Four cylinder speeds of 400 rpm, 450 rpm, 500 rpm and 550 rpm as well as four feed weights of 1 kg, 2 kg, 3 kg and 4 kg were used for performance testing. Results of the performance evaluation carried out on the machine showed the highest milling efficiency of 88% and cleaning efficiency of 91% at a speed of 550 rpm, while the highest seed loss of 27% was obtained at a speed of 400 rpm. The effectiveness of the machine was dependent on the paddy conditions, drum speed and milling duration.
Keywords: *Milling, rice, hopper, milling, cleaning, efficiency, performance evaluation*

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I. INTRODUCTION

Rice is generally considered as a semi aquatic annual plant, although it could survive as a perennial in the tropics or subtropics. It is grown widely in the tropics where rainfall is abundant because it is a cereal that requires plenty of sunshine and water. It remains the staple article of food for many countries and it is a basic food as well as a very important nutritional diet for the world population as it contains carbohydrates and its consumption pattern has been found to be increasingly important [1]. The belief is widespread that rice is of major importance as a crop only in countries where its consumption is high and where it is the basic energy food for the inhabitants. The processing, storage and marketing of rice if carried out efficiently will be of immense contribution to the fight against world hunger. Rice processing involves harvesting, drying, threshing and milling [2]. Each grain of rice is encased in an easily removed protective hull. Inside the hull is a kernel of brown rice, so-called because of the dark bran layers of pericarp covering the endosperm. Underneath the bran coating is a layer of protein-rich cells called the aleurone layer. Rice is milled to remove hull, bran and other foreign materials [3].

Milling, according to Gbabo and Ndagi (2014) [4], is a crucial step in rice production. Rice milling is as a process whereby the rice grain is transformed into a form suitable for human consumption. In the rice industry, milling can refer to either the overall operations in a rice mill; cleaning, shelling, bran removal and size separation or it can refer simply to the one operation of removal of the bran or outer layers from the brown rice to produce a whole grain white rice product. The purpose of rice milling is to remove the chaffs (husks) and other unwanted materials from harvested, dried rough rice and to produce white rice with a minimum of breakage and with a minimum of impurities such as weed seeds in the final products [4]. The chaffs and other unwanted (foreign) materials have to be removed from the grain during the cleaning processes in order to improve the quality of the product**.** Therefore, rice milling has to be done with utmost care to prevent breakage of the kernel and improve the recovery [3].

A common rice milling system, according to Alizadeh (2011) [5], is a multi-stage process where the paddy rice is first subjected to husking and then to the removal of the brownish outer layer, known as whitening. Traditionally, after harvest, in some rice growing areas rice milling is accomplished by very primitive methods such as pounding the rough rice in a wooden mortar with pestle and then winnowing to remove the chaff from the grain. During winnowing, some people spread a piece of cloth on the floor unto which gradually the mixture of the grain and chaff is poured from an elevated place so that the prevailing wind blows away the chaff. Others put a small quantity of the mixture on a tray and toss it up intermittently so that air can blow through it before it returns to the tray. In the natural progression of improvements, the mortars and pestles became layers, and arrangements were made for moving the pestles by animal power, windmills, or water power. These crude means, according to Gbabo and Ndagi (2014) [4], are insufficient due to the fact that lots of damages are done on the rice leading to rice wastage and labour lost. The method also involved enormous human energy and time.

The basic components of the rice milling process are grain cleaning (paddy rice is passed through coarse screens to remove all straw, stones and other objects that are larger than the rice), destoning (stones are separated from the rice), husking (husk is removed from the rice), paddy separation (separation of light paddy kernels from heavy brown kernels), broken removal and sorting (removal of defects). Gbabo and Ndagi (2014) [4] listed many factors that affect milling quality, which are grouped into two categories namely: engineering and variety factors. Engineering factors include harvesting, handling, drying, storage, transport and milling operations, while variety factors include physical and mechanical properties of the grain. Alizadeh (2011)[5] reported that the physical properties of rice significantly affect the milling process and also identified effective parameters that improve the performance of rice milling machines which include rotor speed, paddy moisture content, type of rolls clearance, screen size and blade-rotor clearance. Paddy with high moisture contents is too soft to withstand hulling pressure and those that are too dry become brittle resulting in kernel breakage. It is important that the paddy rice is milled at the proper moisture content to obtain the highest head rice. The performance of a rice milling machine in terms of milled yield and quality depends on moisture content of the paddy as reported by Gbabo and Ndagi (2014) [4].

Since rice will most likely remain the staple food of the ever-increasing world population, efforts need to be made to boost and increase rice production as well as reduce its post-harvest loss by developing an improved low-cost rice milling machine that will produce quality rice at a cheaper price.

II. MATERIALS AND METHODS

2.1 Design conception

In the design of the rice milling machine, the following design concepts were considered:

- Separation and cleaning should use a force field other than a gravitational force field.
- Separation and cleaning should be accomplished in the minimum possible space.
- The operation should be continuous.
- A positive means of supplying kinetic energy to crop material should be provided.
- The screen surface on which chaff moves should offer minimum mechanical resistance to the flow of chaff.
- The grain should move in a direction different from the motions of chaff in order to separate clean grain from a mixture of grain and chaff.

Other factors considered were: equipment portability, production and maintenance costs (cheap, bearable and affordable). The criteria for the choice of materials for construction included: bulk property e.g. strength, surface property e.g. corrosion resistance, ability to be fabricated, appeal to potential buyers and customers as well as economic competition with other alternative equipment.

2.2 Machine description

The milling machine is made up of the following units; the hopper, the shelling unit, the separating unit, the cleaning unit and the delivery unit as shown in Fig. 1. The hopper is made up of four welded mild steel sheets slanting towards the smaller opening which connects it to the shelling drum. The flow of paddy rice down the hopper was influenced by gravity. The shelling unit consists of the shelling drum, the drum shaft, and the concave and drum cover. The shelling drum which was made from mild steel has shelling studs that execute the shelling action when the drum is rotating. The drum shaft was made from an iron rod. The concave and drum cover housed the shelling drum. The concave is the lower half of the cylinder perforated to serve as discharge holes for the shelled materials and the upper half serves as the cover and carries the hopper. The separating unit consists of two components, a sieve and a sieve carrier made from mild steel sheets. The cleaning unit is made up of the space between the shelling unit and the separating unit. It is composed of the iron shaft and its housing together with the fan blade. The feed from the shelling unit on getting into the cleaning unit was separated into two compartments, rice and chaff as a result of air being blown to the seeds by the fan and this is due to difference of densities or specific gravities of the components. The denser particles (rice) fell down into the separating unit while the less dense particles (chaff) were carried away along the flowing air stream to the chaff delivery unit. The delivery unit consists of a rice delivery unit and a chaff delivery unit. The frame is the support on which the machine rests.

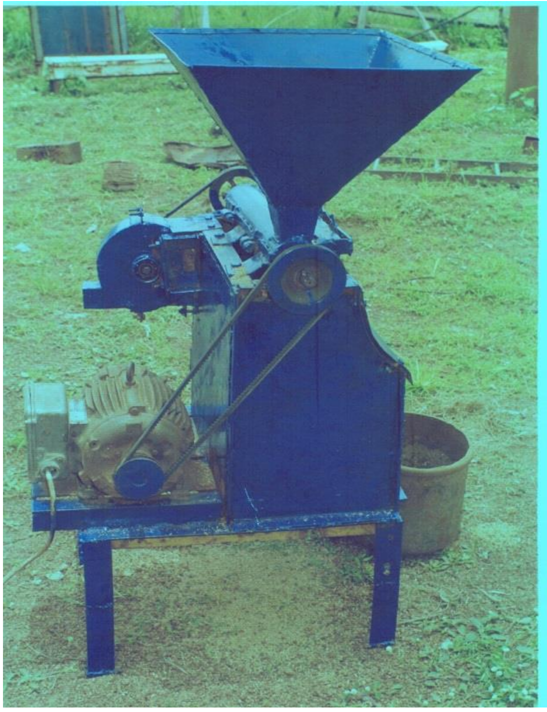

Fig. 1: Pictorial side view of the rice milling machine

2.3. Design calculations

The following calculations were made for some components of the machine.

2.3.1 The hopper

Since the machine was designed for small and medium scale users, the hopper was designed for a capacity of about 38,250 cm^3. This was achieved by making the upper part of the hopper to be 45 cm in length and 44 cm in breadth, while the lower part has a length of 45 cm and 6 cm in breadth with total height of 34 cm. The capacity of the hopper is the area of its side multiplied by the length of the hopper.

Therefore, Volume = $^1/_2\,(6 + 44)x\ 34\ x\ 45 = 38{,}250\ cm^3$

The hopper can contain 38,250 cm^3 of paddy rice.

2.3.2 The shelling unit

The principal parameters of the shelling drum were; the drum length, the drum diameter, number of beaters on the drum and the drum speed [6]. The drum length was obtained using this equation:

$$q = q_o LM \qquad \text{--------------------------------} \qquad (1)$$

Where: L= drum length (m); q = feed rate of thresher (kg/s); q_o= permissible feed rate (kg/s)

M = number of (row of) beaters.

According to Raji and Akaaimo (2005) [7], the permissible feed rate of threshers is 0.4-0.6kg/s, therefore for a q of 0.6kg/s and q_o of 0.4kg/s, the drum length (L) for 4 rows of beater was

$$L = \frac{q}{q_o M} = \frac{0.6}{0.4\ x\ 4} = 0.40\ m$$

The peripheral velocity of the drum was obtained using:

$$V = \frac{\pi D n}{60} \qquad \text{------------------------------} \qquad (2)$$

Where: V= peripheral velocity (m/s); D = drum diameter (m); and n = drum speed (rpm)

The drum shaft diameter was obtained from the equation of given below reported by Oladejo *et al.* (2016) [8]:

$$d^3 = \frac{16}{\pi S_s}[(K_b M_b)^2 + (K_t M_t)^2]^{½} \qquad \text{--------------------------------} \ (3)$$

Where d = shaft diameter, Ss = allowable shear stress for shaft (40 MN/m^2),

k_b = combined shock and fatigue factor applied to bending moment =1.5, M_b = Bending moment (Nm)

k_t = combined shock and fatigue factor applied to torsional moment =1.0, M_t = Torsional moment

2.3.3 The Separating Unit

Taking the screen to be punched, the efficiency is given as: $C_o = \frac{3\pi D^2}{2(D+d)^2}$

where: D = diameter of the sieve, d = diameter of a hole

For efficient screening Co = 40% = 0.4, therefore, $\frac{2C_o}{3\pi} = \frac{D^2}{(D+d)^2}$

$$0.2913 = \frac{D}{D+d}$$

$$0.2913d = D - 0.2913D \quad \text{--------- (4)}$$

Top Screen

Rice theoretical diameter (Dtheory) (geometric mean) = 0.379 cm

For cleaning purposes 0.1 was added to give 0.479 cm as rice actual diameter (Dactual)

From equation (4); 0.2913d = D – 0.2913D = 0.479 – (0.2913 x 0.479 = 0.3395

$$d = \frac{0.3395}{0.2913} = 1.17cm$$

Lower Screen

Dactual was 0.2cm. Therefore from equation (4)

0.2913d = 0.2 – (0.2913 x 0.2) = 0.14174

$$d = \frac{0.1417}{0.2913} = 0.49cm$$

Terminal Velocity

Geometric mean Dtheory = 0.379 cm = 0.00379 m; Mass of particle Mp = 2.92 x 10^{-5} kg

Density of air ρ_f= 1.25 kg/m^3; Density of particle ρ_p = 577.43 kg/m^3

Volume of equivalent sphere $V = \frac{4\pi}{3}(\frac{0.00379}{2})^3 = 2.85 \ x \ 10^{-8} \ m^3$

Drag coefficient C = 0.44

Area of particle $A_p = \frac{\pi D^2}{4} = \frac{\pi(0.00379)^2}{4} = 1.128 \ x \ 10^{-5} \ m^2$

Terminal velocity $V_t = \sqrt{\frac{2 \ M_p(\rho_p - \rho_f)g}{\rho_p \rho_p A_p C}}$ -------------------------------- (5)

$$V_t = \sqrt{\frac{2 \ x \ 2.92 \ x \ 10^{-5}(577.43 - 1.25) x \ 9.81}{577.43 \ x \ 1.25 \ x \ 1.128 \ x \ 10^{-5} x \ 0.44}} = 9.59 \ m/s$$

2.3.4 Power requirement

Total power required to operate the machine was given by:

$P_T = P_r + P_b$ ---------------------------- (6)

Where: P_T = total power required; P_r = power required to shell the grain.

P_b = power required to operate the blower

Shelling Power (P_r)

The power required for shelling according to Raji and Akaaimo (2005) [7] was given as:

$P_r = T_r \ x \ W_r$ ------------------------------ (7)

Where: T_r = torque needed to shell the grain; W_r = speed of rotation of drum shaft and grain

But, $T_r = (M_p + M_s + M_h)g$ -------------------------------- (8)

Where: M_p = mass of pulley = 4kg; M_s = mass of shelling drum = 14kg

M_h = mass of grains in the hopper = 4kg

$$T_r = (4 + 14 + 4)9.8 = 215.6 \ N$$

Also, $W_r = \frac{\pi D_e N_e}{60}$ ----------------------------------- (9)

Where: D_e= diameter of pulley on electric motor = 10 cm =0.1m

N_e= rotational speed of motor = 1430 rpm

Therefore: $W_r = \frac{3.142 \ x \ 0.1 \ x \ 1430}{60} = 7.49 \ m/s$

Therefore, Power required for shelling (P_r) was:

P_r = 215.82 x 7.49 = 1616.49 W = 1.6165 kW

$$P_r = \frac{1.6165}{0.746} \ hp = 2.17 \ hp$$

Power required to operate the Fan (P_b)

Using: $P_b = \frac{\delta_f A V_t^3}{4}$

Where: δ_f = density of air = 1.25kg/m^3; A = discharge area = (0.51 x 0.2) m^2

V_t = terminal velocity of the grain = 9.6 m/s

Therefore, $P_b = \frac{1.25 \ x \ (0.51 \ x \ 0.2) x \ 9.6^3}{4}$ = 28.20 W = 0.0282 kW

$$P_b = \frac{0.0282}{0.746} \ hp = 0.04 \ hp$$

Therefore, total power required to operate the machine P_T was: $P_T = P_r + P_b = 2.17 + 0.04 = 2.21hp$

Factor of Safety

Using the factor of safety of 1.3, to allow for power loss due to friction and others, therefore, the power required was: P = 2.21 x 1.3 = 2.87 hp.

Therefore, an electric motor of **3 hp** was chosen to power the machine.

2.3.5 The belt

(i) Belt length from electric motor to the drum shaft

Pulley center $C = \frac{D_1+D_2}{2} + D_1$ ------------------------------ (11)

Where: D_1 = driving pulley = 10 cm and D_2 = driven pulley = 26 cm

Therefore, $C = \frac{10+26}{2} + 10 = 28\ cm$

Belt length $L = 2C + 1.57(D_1 + D_2) + \frac{(D_2 - D_1)^2}{4C}$ ---------------------------- (12)

$$L = (2\ x\ 28) + 1.57(10 + 26) + \frac{(26-10)^2}{4\ x\ 28} = 114.81\ cm$$

(ii) Belt length from electric motor to the fan

D_1 = driving pulley = 26 cm and D_2 = driven pulley = 30 cm

Pulley center $C = \frac{D_1+D_2}{2} + D_1 = \frac{26+30}{2} + 26 = 54.0\ cm$

Belt Length, $L = (2\ x\ 54) + 1.57(26 + 30) + \frac{(30-26)^2}{4\ x\ 54} = 195.99\ cm$

2.4 Machine Fabrication

a. Hopper

Hopper is frustum in shape which was made from mild steel. The flow of paddy rice down the hopper was influenced by gravity. It has a shutter at the bottom to regulate the flow of paddy into the milling chamber. The mild steel sheet of gauge 16 used was marked out using surface table, surface plate, tri square, rule, scriber and centre punch. The dimensions used for the upper part was 48 cm length and 46 cm breadth, while 48 cm length and 8 cm breadth was used for the lower part. The mild steel sheet was cut into sizes using a sheet metal cutting machine called a “Guillotine machine”. The plates were later welded together using an electric arc machine with the aid of electrodes. In order to have a very smooth surface, the welded components were grinded using a grinding machine, removing the burrs.

b. Shelling unit

i. Shelling drum

Shelling drum was constructed using a mild steel sheet of gauge 16. The mild steel sheet of dimensions $80\ cm\ x\ 100\ cm$ was rolled into cylindrical shape to form a drum of diameter 30 cm. It has shelling studs that execute the shelling action when the drum is rotating.

ii. Drum shaft

This was made of an iron rod of 2 cm diameter and 68 cm long which was cut at a distance of $10\ cm\ and\ 12\ cm$ from one end. An eccentricity radius of 5 cm was welded to it, after a bearing and its housing had been inserted at the center of the 6 cm iron that was cut out. The connecting rod which was made from an iron rod of 2 cm diameter and length 40 cm was welded on the bearing housing inserted at the middle of the drum shaft and a hole was drilled at the other end to take the hitch under the sieve carrier. The shaft has a 26 cm pulley mounted on it which was driven by 10 cm diameter pulley connected to a motor running at 1430 rpm. Therefore, the shaft speed was calculated as:

$$\text{Shaft speed} = \frac{1430\ x\ 10}{26} = 550\ rpm$$

iii. Concave and drum cover

The concave is the lower half of the cylinder perforated to serve as discharge holes for the shelled materials and the upper half serves as the cover and carries the hopper. The concave and drum cover housed the shelling drum. They were made from a horizontal cylinder of 30 cm diameter and 42 cm long. The dimensions were marked out using rule and scribe; it was then cut according to the inscribed line on the sheet using the sheet metal cutting machine.

c. Separating unit

This consists of two components, sieves and sieves carrier.

i. Sieves

These were made of a mild steel plate of $60\ cm\ x\ 45\ cm$ which were punched or drilled to different holes diameter.

ii. Sieves carrier

It was made of a mild steel plate of $90\ cm\ x\ 55\ cm$. The plate was bent upward at a distance of $30\ cm$ to both ends. The furrow in which the sieve slide was made of two iron bars of length $60\ cm$ long welded to the inner side of the bent part a distance of $6\ cm\ and\ 20\ cm$ from the upper end. The carrier has the seed drain attached at the front of the sieve at an elevation lower than the plane of each sieve it serves. At the middle of the carrier but at a distance $35\ cm$ to its back is located the hitch on which the connecting rod.

d. Cleaning unit

This is made up of the space between the shelling unit and the separating unit. It is composed of the iron shaft and its housing together with the fan blade. The feed from the shelling unit on getting into the cleaning unit was separated into two compartments, rice and chaff as a result of air that was blown to the seed by the fan and this was due to difference of densities or specific gravities of the components. The denser particles (rice) fell down into the separating unit while the less dense particles (chaff) were carried away along the flowing air stream to the chaff delivery unit. Fan was made up of an iron shaft of $2.5\ cm$ diameter on which an iron bar of length $5\ cm$ was welded at right angle and at four equal distances marked apart on the lathe machine. This iron bar was drilled to allow for bolting of the fan blade. The fan blade was made of a mild steel sheet of dimensions $12\ cm\ x\ 50\ cm.$ The shaft was mounted at both ends on the bearing. The fan housing was made up of a mild steel sheet of dimensions $60\ cm\ x\ 41\ cm$ which was cut accordingly and folded into cylindrical shape. An air delivery channel of $50\ cm\ x\ 16\ cm$ was welded to the part where the cylinder would have joined. The convergence of the air delivery channel was made to make the air concentrate and increase its strength of removing chaff from the grains.

e. Delivery unit

This consists of rice delivery unit and chaff delivery unit

i. Rice delivery unit

This unit is like an inverted frustum and it can be bolted on the separating unit. The rice after separation from impurities fell down into the container placed underneath the delivery unit. It was made of a mild steel plate of gauge 16 with dimensions $20\ cm\ x\ 14\ cm$. It was welded to the cleaning unit.

ii. Chaff delivery unit

Chaff delivery area was made of mild steel plate of gauge 16 with dimensions $30\ cm\ x\ 35\ cm.$ It was welded to the cleaning unit. It has a box with open ends and some portions of it are slanted for the outflow of the chaff. The upper face part of this unit was covered with wire net so that air from the cleaning unit can be allowed to escape. The speed of the chaff was then reduced to zero immediately after impact on the wire net and can then fall down under gravity or slide down on the wall of the unit into the chaff container.

f. Frame

Putting the dimensions of the shelling drum, drum shaft, concave and drum cover into consideration, the frame of the machine was designed to the operating convenience of a man of average height. As such it was $34.5\ cm$ high, $70\ cm$ long and $67.55\ cm$ wide. It was made from angle iron of dimensions $5\ cm\ x\ 5\ cm\ x\ 0.3\ cm.$ For stability during operations, the legs of the frame were opened at an angle of 70^{o}.

Bearing Selection

The bearings were designed using the loads resulting from the belt tension and stainless steel ball bearings of 6 cm bore diameter, 10 cm outside diameter and 4cm width with load rating of 650 N were selected to withstand such loads.

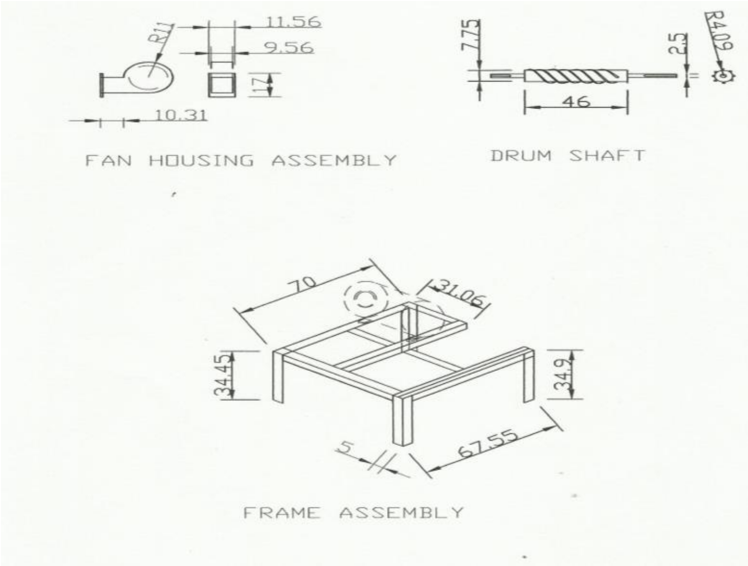

Fig.2: Components assembly

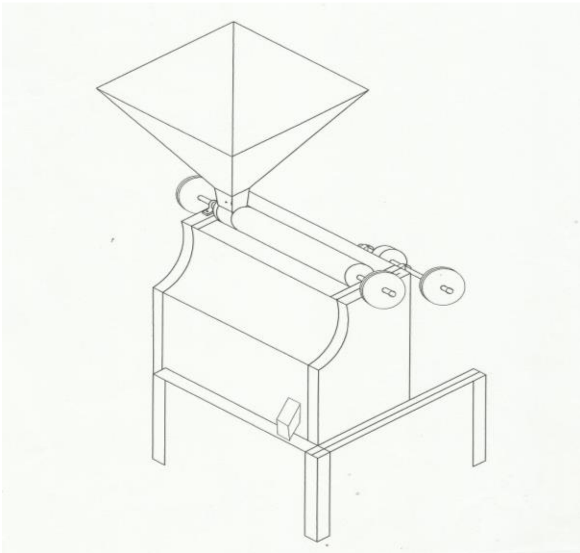

Fig. 3: Schematic representation of the rice milling machine

DESCRIPTION	QTY	Item	DESCRIPTION	QTY
BLOWER ASSEMBLY	1	10	FRAME ASSEMBLY	1
TRANSMISSION BELT	2	9	ELECTRIC MOTOR	1
DRUM SHAFT	1	8	DISCHARGE CHUTE	2
HOPPER SHELLING DRUM	1	7	BODY ASSEMBLY	1
HOPPER	1	6	PULLEY	4

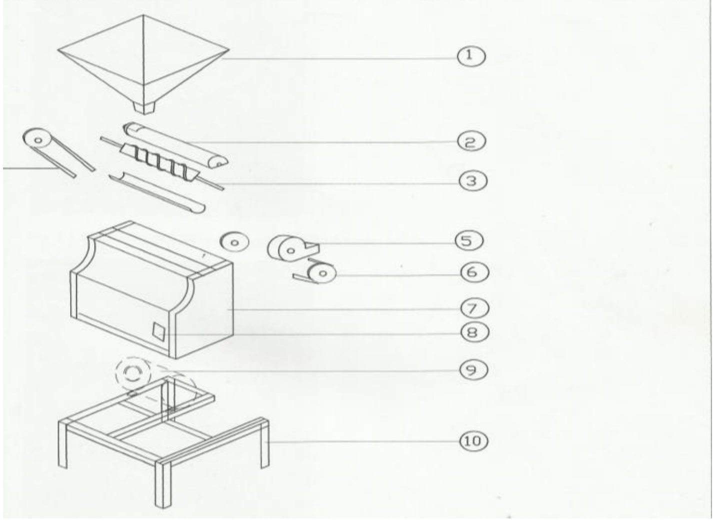

Fig. 4: Various component of the rice milling machine

III. TESTING AND EVALUATION

3.1 Testing

To ascertain the performance of the machine, tests were conducted on it. The purpose of these tests was to determine the effectiveness to mill the rice and evaluate the effects of speed on the performance of the machine. The grains were fed manually into the machine. The output from the seed outlet and the chaff outlet were collected and weighed. Grains not milled were fed back into the machine. Four cylinder speeds: 400rpm, 450rpm, 500rpm and 550rpm were used and these were obtained by changing the sizes of the pulley on the milling cylinder. Four feed weights: 1kg, 2kg, 3kg and 4kg were selected for the tests.

3.2 Evaluation

Milling efficiency (ME), cleaning efficiency (CE) and seed loss were used to evaluate the performance of the rice milling machine as reported by Adekunle *et al.* (2009) [6] and Dauda *et al.* (2012) [3].

$$Milling\ efficiency\ (ME)(\%) = \frac{Weight\ of\ milled\ seed\ (kg)}{Total\ weight\ of\ seed\ (kg)}\ x\ 100$$

$$Cleaning\ efficiency\ (CE)(\%) = \frac{Weight\ of\ chaff\ collected\ at\ the\ chaff\ outlet\ (kg)}{Total\ weight\ of\ chaff\ (kg)}\ x\ 100$$

Adding up the total weight of seeds collected at the chaff outlet and the weight of un-milled grains, and expressing this as a ratio of the total grain weight give the seed loss.

$$Seed\ loss\ (SL)(\%) = \frac{Weight\ of\ seeds\ that\ escaped\ with\ the\ chaff\ (kg) +\ weight\ of\ un - milled\ seeds}{Total\ weight\ of\ seeds\ (kg)}\ x\ 100$$

3.3 Discussion

Effects of speed on the milling efficiency, cleaning efficiency and seed loss were investigated. As speed increases, milling efficiency (SE) and cleaning efficiency (CE) increased, while there was reduction in seed loss as drum speed increased (Fig. 5). The maximum milling and cleaning efficiencies were obtained at a speed of 550rpm as 88% and 91% respectively. At lower speeds, more number of seeds escaped with the chaff, but there was reduction in seed loss with increase in speed. The highest seed loss of 27% was obtained at a drum speed of 400rpm. These results were in line with the findings of previous researchers that milling efficiency, cleaning efficiency and seed loss is dependent upon the speed of the machine [3].

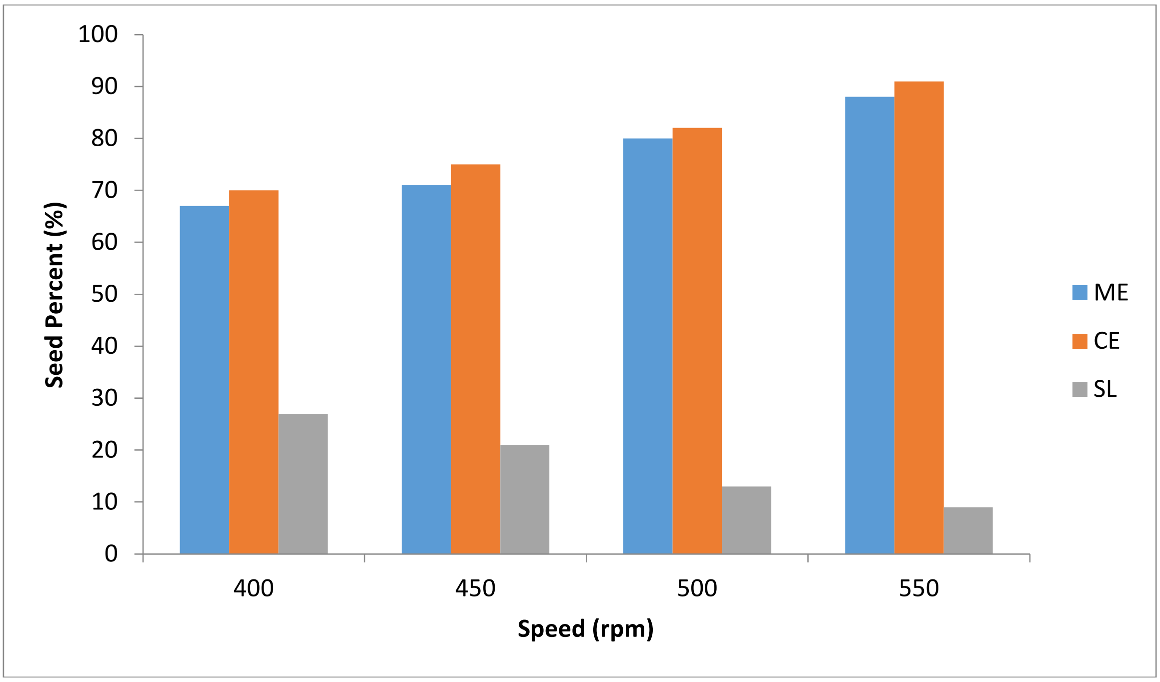

Fig. 5: Effect of speed on machine performance

IV. CONCLUSION

A low-cost rice milling machine was developed and evaluated. The operational mode of the machine is simple with high efficiency. Evaluation results show that milling efficiency, cleaning efficiency as well as seed loss is dependent on the speed of the machine. The best performance was obtained at a speed of 550 rpm which has highest milling efficiency (88%) and cleaning efficiency (91%) with minimal seed loss (9%). The fabricated machine will reduce cost of rice processing and promote the production of quality rice at low cost. It will also reduce post-harvest loss being faced by the peasant farmers using traditional methods and eliminate the drudgery involved. Therefore the mass production of this low cost machine should be encouraged. Future research would be directed towards modeling the machine performance on the basis of machine speed, feed rate, and rice moisture content.

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