Design and fabrication of a motorized rice hulling machine

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Rice is one of the most important cereal crop in the world. This paper present the design and performance evaluation of a rice hulling machine fabricated for removing chaffs from paddy rice as the consumer’s demand for rice requires the most hygienic, easy and less time consuming process. The design was segmented into the hopper and housing (processing) unit, the frame support and the power transmission unit. The housing unit consists of the upper and lower body where the sieve, hulling blade and cylinder is enclosed. The machine is powered by a 3.0 H.P. 950 rpm electric motor via a V-belt mechanism which deliverers the power requirement to the shaft on which the hulling cylinder is mounted. The hulling cylinder presses the paddy rice against the hulling blade to remove the chaff. The paddy rice is fed into the housing unit for processing through the machine hopper. The probability failure of the machine during loading has been minimized by proper material selection and using a factor of safety of 4 in the design process. The machine was designed to process about 8 kg of rice for small scale production. Performance evaluation of the machine shows that its efficiency is within the range of 83 to 88%, the hulling capacity is within the range of 22 to 25 kg/h and the maximum efficiency is at 5 kg paddy rice hopper loading which is about 60% of the hoppers’ volume.

Key words: Rice, hulling, dehusking machine, paddy, fabrication.

INTRODUCTION

Rice (Oryza) is one of the most important cereal crop in the world. Rice grains were recorded to have sustained 2.5 billion people of the world’s population in Cristina and Cristina (2008). Oryza sativa and Oryza glaberima are the two common species of rice grown. O. sativa commonly known as Asian rice originated in the wet tropics of Asia while O. glaberrima commonly known as African rice originate from Niger river delta and extended to Senegal Maddox, (2006). Rice is normally grown as an annual plant, although in tropical areas it can survive as a perennial crop. A paddy is a whole seed of rice which contains one rice kernel and has many layers; the outermost layer is the husk. The husk consists of two interlocked half shells and each protects one half of the paddy. In Nigeria, rice can be grown in almost all states, a grain of paddy is oval in shape with 1.5 mm long and 0.9 mm wide. The average grain size and specific gravity are 1.18 and 1.47 respectively Osoro and Adio (2018). Rice is rich in vitamins and a great energy source. The nutritive value of rice includes protein, fat, carbohydrates,
ash, mineral and vitamins which play an important role in health benefits and disease prevention such as high blood pressure, cancer, Alzheimer’s disease and dysentery in mankind (Cristina and Cristina, 2008). Parboiled rice has about 345 calories per 100 g. It contains Calcium, Phosphorus, Iron, Potassium, Thiamine, Niacin of 60, 200, 2.9, 9, 0.44 and 3.5 mg respectively in 100 g (Deepak and Kirti, 2011).

Rice undergoes post-harvest process before consumption. Parboiling is a hydrothermal treatment carried out before milling to reduce grain breakage during milling as it brings about hardening of rice kernel and gelatinization of starch. Parboiling involves soaking paddy in cold water or lukewarm water to increase the moisture content, steaming paddy to achieve partial gelatinization and drying paddy to save the moisture content for storage and milling Kazuhiko et al. (1985). Dehusking or hulling is done to remove paddy husk from paddy kernel, sieving is done to remove chaff from rice grain and milling is done to remove all or part of the bran and germ from the rough rice.

The basic ways of hulling include traditional method, animal powered miller, use of pedal powered rice miller, mechanized method and use of rubber rolls to separate the chaff from the seed grains. Traditional method of hulling involves the use of a mortar and pestle. It is tedious, has low efficiency and separation of chaff from grains is done by winnowing (Poonam, 2014). The rice hulled through the use of mortar and pestle are known to have stones due to the insanitary environment where the process is done and this predisposes consumer to health risk such as appendicitis as well as low milling efficiency due to breakage of rice during the hulling process. Bisen et al. (2014) developed a mini pedal powered rice mill with a capacity of 25 kg/h and milling efficiency of 82.6% consisting of chain drive and gear amplification mechanism that turn huller shaft in housing filled with rubber materials on husking dynamics of paddy rice, the application of rubber rolls to husk rice involves passing it between two rubber rollers that are rotating with a surface speed differential. The resulting normal pressure and shear stress causes the husk to be peeled away from the kernel. Baker et al. (2012) studied the effect of different rubber materials on husking dynamics of paddy rice, the husking performance of different rubbers was compared for changes in the applied normal load. It was found that grains rotate between the rubber counter-faces on initial motion before being husked. Harder rubbers were found to husk a higher proportion of entrained grains at lower applied normal load. By measuring the coefficient of friction between rice and rubber samples, the shear force required to husk a given percentage of grains could be calculated and was shown to be constant regardless of rubber type. Firouzi et al. (2010) studied the effect of rollers differential speed and paddy moisture content on performance of rubber roll husker. The experiment was conducted at six levels of rollers differential speed (1.5, 2.2, 2.9, 3.6, 4.3 and 5 m/s) and three levels of paddy moisture content (8-9, 10-11 and 12-13% w.b.). Average broken kernel percentage increased from 13 to 14.61% while husking index decreased from 71.64 to 61.81% as paddy moisture content increased from 8-9 to 12-13%. It was observed that amount of broken rice decreased from 18.83 to 9.97%, when rollers differential speed varied from 1.5 to 5 m/s, while the husking index initially increased and then started to decrease. It was concluded that rollers differential speed of 2.9 m/s and moisture content of 8-9% was the most appropriate combination.

dehusked unit. The paddy grain is separated from the chaff by passing the mixture through a current of air supplied by a fan. The machine dehusked 1 kg of paddy in 3 min with an efficiency of 85-90%. Brian et al. (2016) developed a rice milling and grinding machine after fabricating a prototype of a rice huller that can efficiently husk and bran of the rice using the principle of friction resulting from the rotating motion of the steel roll. A vacuum fan was also installed to suck the remaining light husk at the exhaust of the rice huller. The resulting output from the rice huller with vacuum fan had a husk to rice ratio of less than one cup of husk per 30 cups of rice. Dauda et al. (2012) conducted performance evaluation of a locally developed rice hulling machine. The milled rice was collected at grain outlet and examined for milled, unmilled and broken grains. From the performance test carried out, the milling efficiency, cleaning efficiency, input capacity, output capacity and average percentage of head rice yield obtained were 90.22, 90.2, 27.3 and 16.47 kg/h, 44.2% respectively. Total losses, grain recovery range, capacity utilization, milling index, milling intensity, milling rate, milling recovery and co-efficient of husking were 2.5, 97.5, 60.3 and 53%, 0.137 and 14.8 kg/h, 48.8 and 94.8% respectively. The effectiveness of the milling machine was reported to be dependent on the paddy varieties and sizes, paddy conditions, milling duration, speed of burr and operator’s skill. The application of rubber rolls to husk rice involves passing it between two rubber rollers that are rotating with a surface speed differential. The resulting normal pressure and shear stress causes the husk to be peeled away from the kernel.
Milling of rice involves several stages, Odior and Oyawale (2011) developed and applied a time study model in a rice milling firm. The time was represented by structural equations which are characteristics of the rice milling firm studied. The study revealed that the time it takes to mill a 50 kilograms’ bag of rice is directly proportional to the number of production stages involved and the time spent at each of these production stages. The aim of this paper is to carry out design, fabrication and performance analysis of a local rice hulling machine with high ease of maintenance which will overcome the problems of food contamination, rice grain breakage, high machine and operation cost.

MECHANISM OF OPERATION

Power is transmitted to the rotor shaft of the hulling machine via a 3HP electric motor connected to the rotor shaft with a pulley and belt transmission system. The electric motor is connected to power supply of 220V, when the huller runs paddy rice is introduced into the hopper. The rotor shaft which is located below the hopper in form of an Auger as pushes the rice to the other end of the rotor. When the grains of the non-husked rice arrive at the hulling blades, the movement is restricted between the rotor and the blades and as the blades opposes the rotation of grain, the chaff and the bran surrounding it then rub along the edge of the hulling blades and the elevations of the rotor leading to their separation of the grain by necking and scouring. This is the principle of dehusking the rice paddy. The level of scouring is set by the opening of the exit for the husked rice and the pieces in which the bran and the chaff are cut are small enough to pass through the sieve.

While revolving around the rotor, the rice also advances towards the exit, driven by the rice still located in the feed hopper. Once it arrives at the exit, it can escape through the opening at the outlet. The position of the release is placed relatively high, which allows the last separation between the rice and the chaff which has not yet been evacuated by the sieve. The grains of the rice because of its weight, is projected onto the exit by inertia while the lighter chaff remains in the body of the huller and continues to turn until it exits through the sieve.

MATERIALS AND METHODS

Hopper design analysis

The design of the hopper was made to be filled in a vertical position only. It shape is like a funnel. The top and the bottom sections are cuboids with rectangular faces. The middle section is in the form of a frustum of a pyramid truncated at the top, the top and bottom faces of the midsection have rectangular shapes as shown in Figure 1. The material used for the construction is mid steel sheet metal, which is readily available in the market and relatively affordable. The volume of the top section \( V_t \) in the form of a cuboid is given by:

\[
V_t = L_1 + B_1 + H_1 \]

=0.00465 m\(^3\)

The Volume of the mid-section \( V_m \) in the form of a frustum of a pyramid is given by:

\[
V_m = \frac{H_m}{3} \left( L_1 B_1 + L_2 B_2 + \sqrt{L_1 B_1 \times L_2 B_2} \right) \]

=0.008223670 m\(^3\)

The Volume of the bottom section \( V_b \) in the form of a cuboid is given by

\[
V_b = L_2 B_2 H_2 \]

=75 mm \( \times \) 70 mm \( \times \) 55 mm =288.750 m\(^3\)

The Total Volume of the hopper \( V \) is given by

\[
V = V_t + V_m + V_b \]

=0.01316 m\(^3\)

Where \( L_1 \) =Length of top section of hopper=310 mm; \( L_2 \) =length of bottom section of hopper=75 mm; \( B_1 \) =Width of top section of hopper=300 mm; \( B_2 \) =Width of bottom section of hopper=70 mm; \( H_1 \) =Height of top section of hopper=50 mm; \( H_2 \) =Height of Bottom section of hopper=55 mm; \( H_m \) =Height of mid-section of hopper=205 mm

Weight of un-husked rice in hopper

\[
W_1 = \rho_B \times V \times g \]
Figure 2. The housing unit.

Where

\[ \rho_b = \text{Bulk density of the unhusked rice} = 0.642 \text{ g/ml (642 kg/m}^3) \]

\[ V = \text{Volume of the hopper} = 0.01316 \text{ m}^3 \]

\[ g = \text{Acceleration due to gravity} = 9.81 \text{ m/s}^2 \]

\[ W_1 = 82.88 \text{ N} \]

This implies the hopper can contain 8.45Kg of unhusked rice at full capacity.

Weight of Hopper \((W_2)\):

\[ W_2 = \text{Total surface area of hopper sheet} \times \text{thickness of sheets} \times \text{density of sheets} \times \text{acceleration due to gravity} \]

The total surface area of hopper sheets is approximately

\[ A_s = 2(L_1H_1 + B_1H_1 + L_2H_2 + B_2H_2) + H_m(L_1 + L_2) + H_m(B_1 + B_2) \]

\[ = 265.700 \text{ mm}^2 \]

\[ = 0.2657 \text{ m}^2 \]

The thickness of the sheet \((t) = 2 \text{ mm} = 0.002 \text{ m}; \) The density of mild steel sheets \( = 7850 \text{ kg/m}^3; \) The mass of the hopper \((M_h)\) is given by:

\[ M_h = \text{Density of mild steel sheet} \times \text{Total surface area of sheet} \times \text{thickness} \]

\[ = 7850 \times 0.2657 \times 0.002 = 4.168 \text{ kg} \]

From Equation 6 the weight of the hopper is:

\[ W_2 = 40.92 \text{ N} \]

Housing unit, hulling cylinder, hulling blades and sieve

The housing is important part of the hulling unit. The hopper is directly mounted on top of the housing unit as shown in Figure 2. It contains the upper and lower body in which the hulling cylinder and hulling blades is enclosed. The abrasive hulling blades with high speed touch the rice paddy against the hulling cylinders responsible for dehusking. The housing is made of mild steel plate of about 3 mm. The bottom part of the housing is circular and contains the sieve. The blade support made of cast iron provides the link between the blade and adjustment screw permits the release of the blade, and avoids in most cases to breaking of parts that are more difficult or expensive to replace. At both ends of the blade is a screw to allow the adjustment of the distance between the hulling blade and the hulling cylinders this distance should be slightly higher than the diameter of hulled rice to avoid breakage of rice grains, but lower than that of the paddy rice for dehusking to take place. The sieve has a grid whose holes are big enough to allow the chaff and bran to cross, but also small enough to not allow the hulled rice to cross the grid.

Weight of the Hulling cylinder \(W_3 = m_c \times g \)

Where \(m_c = \) mass of hulling cylinder \(= 14.15 \text{ kg} \)

\[ g = \text{Acceleration due to gravity} = 9.81 \text{ m/s}^2 \]

\[ W_3 = 138.81 \text{ N} \]

The weight of the Housing Unit including cover plates

\[ W_4 = m_h \times g \]

Where \(m_h = \) mass of housing unit \(= 5.26 \text{ kg} \)

\[ g = \text{Acceleration due to gravity} = 9.81 \text{ m/s}^2 \]

\[ W_4 = 51.60 \text{ N} \]

Frame and bearings for support

The frame provides support on which all other components are mounted on. Components which include the motor engine, housing unit, pulley and other accessories. The frame which is made of low carbon steel and is joined together through welding. The bearings have a bore of 30 mm to accommodate the shaft.

Speed and power transmission components

Electric motor

An electric motor connected to power supply was used to transmit torque to the rotor shaft for hulling. The motor is rated 3 HP 720 rpm

Pulleys diameter

For the selected motor of 3HP 950 rpm, the diameter of pulley chosen is 100 mm for the motor pulley and 112 mm for the driven pulley. For the selected motor speed of 950 rpm the speed on shaft or driven pulley, using standard equation can be determined as follow:

\[ d_1N_1 = d_2N_2 \]
Where: $d_1$ is the diameter of the driver pulley = 100 mm
$d_2$ is the diameter of the driven pulley = 112 mm
$N_1$ is the speed of motor pulley=950 rpm
The speed on shaft or driven pulley

$$N_2 = \frac{100 \times 950}{112} = 848.2 \text{ rpm}$$

### Belt size and grade

The centre distance $(C)$ between the motor pulley and shaft pulley was determined to be 535 mm for best performance and in order for proper resting of the motor on the frame to avoid unnecessary vibrations. The belt length can be determined using

$$L = \frac{\pi}{2} (d_1 + d_2) + 2C + \frac{1}{4c} (d_1 + d_2)^2$$

After inputting the value, the length of belt required was 1402 mm.
For Class A belts the inside length can be gotten by subtracting 36 from the pitch length. The inside length=1402 – 36=1366 mm; A standard belt was then chosen as the nearest match is 1372 mm which is type A54belt.

### Contact angles of belt

First we determine the angle of contact $(\theta)$ for both the driver and the driven pulleys from the pulley geometry presented using the equation below:

$$\sin \alpha = \frac{d_2 - d_1}{2c}$$

Inputting the values, $\alpha = 0.64^\circ$ then angle of contact for the driver pulley will be

$$\theta_1 = 180^\circ - 2\alpha = 178.72^\circ = 3.12 \text{ rad}$$

And to determine the angle of contact for the driven pulley

$$\theta_2 = 180^\circ + 2\alpha = 181.28^\circ = 3.16 \text{ rad}$$

### Belt tension

Mass of the belt/meter length = 0.1 kg/m

$$\text{Belt Speed} = \frac{\pi d_1 N_1}{60}$$

$$= \frac{\pi \times 0.112 \times 950}{60} = 5.571 \text{ m/s}$$

$$P = (T_1 - T_2)V_s$$

Where $P$=power of the motor=3Hp=2.238KW $V_s$= Belt speed=5.571 m/s

$$T_1 - T_2 = 402N$$

$$T_1 = Tension in Tight side of belt$$

$$T_2 = Tension in Slack side of belt$$

$$\mu = \frac{\mu \theta}{T_2}$$

### Coefficient of friction of cast iron to leather

$\mu = 0.25$

$\theta = Angle of lap = 3.12 \text{ radians}$

$\beta = Semi groove angle = 17.5^\circ$es

$e = \text{logarithmic exponent} = 2.71828$

$$T_1 = e^{\beta \sin \beta} = 13.38$$

Solving equation 14 and 15 simultaneously we get

$$T_1 = 435 \text{ N}, T_2 = 33 \text{ N}$$

### Shaft design

A shaft is a rotating element which is used to transmit power from one place to another. The power is transmitted by some tangential force and the resultant torque (or moment) setup within the shafts permits the power to be transferred to various machine or its element linked up to the shaft. In other to transfer the power from the shaft, the various members such as pulleys, bearings, hulling cylinders are mounted on it. The members along with the forces exerted upon them causes the shaft to bending. In other words, we may say the shaft is used for the transmission of torque and bending moment. The various members are mounted on the shafts by means of keys/Splines (Khurmi and Gupta, 2011).

### Determination of torque on shaft

The torque on the shaft $T = \frac{60P}{2\pi N}$

$$T = \frac{60 \times 2238}{2 \times 950} = 22.496 N\text{m}$$

### Load analysis and determination of maximum bending moment

Consider the space diagram of the shaft carrying the loads shown in Figure 4. The total vertical load on shaft:

$$(P) = \text{Weight of unhusked rice}(W_1) + \text{Weight of hopper}(W_2) + \text{Weight of Hulling cylinder}(W_3) + \text{Weight of Housing Unit}(W_4)$$

$$P = 88.28N + 40.92N + 138.81N + 51.60N = 319.61N$$

The uniformly distributed load $(w)$ over the 400 mm length of the
\[ F = R_A - 0.8(x - 60) \]

At \( A, x = 60 \)
\[ F = +86.5 - 0 \]
\[ F = +86.5N \]

At \( B, x = 460 \)
\[ F = +86.5 - 0.8 \times 400 \]
\[ F = -233.5N \]

Shear Force at \( B \)
\[ F = -233.5 + R_B \]
\[ F = -233.5 + 711.3 \]
\[ F = 477.8N \]

The shear force remains constant between \( B \) and \( D \) since no force acts on the shaft along \( B \) and \( D \).

Shear force at \( D \)
\[ =477.8 - W = 477.8 - 477.8 = 0N \]

Bending Moment at \( A = 0 \)

Bending Moment at any section between \( A \) and \( B \) at a distance \( x \leq 60 \)
\[ M_x = R_A \times x \]
\[ M_x = 0 \] at \( x = 0 \);
\[ M_x = +86.5 \times 60 \] at \( x = 60 \);
\[ M_x = +5190Nmm \]

Bending Moment at any section between \( A \) and \( B \) at a distance \( 60 < x \leq 460 \)
\[ M_x = R_A \times x - 0.8 \times (x - 60) \times \frac{x - 60}{2} \]
\[ M_x = +68.5 \times 460 - 0.8 \times 400 \times 200 \]
\[ M_x = -24,210Nmm \]

Bending Moment at any section between \( A \) and \( B \) at a distance \( x > 460 \)
\[ M_x = R_A \times x - 0.8 \times 400 \times (x - 260) \]
At \( x = 460 \),
\[ M_x = +86.5 \times 460 - 0.8 \times 400 \times 200 \]
\[ M_x = +86.5 \times 460 - 24,210Nmm \]
At \( B, x = 520 \)

\[
M_B = +86.5 \times 520 - 0.8 \times 400 \times 260
\]

\[
M_B = -38,220 Nmm
\]

At \( D \)

\[
M_D = R_A \times 600 + R_B \times 80 - 0.8 \times 400 \times 340
\]

\[
M_D = +86.5 \times 600 + 711.3 \times 80 - 0.8 \times 400 \times 340
\]

\[
M_D = 0
\]

Maximum Bending Moment is negative at \( B \), \( M = 38,220 Nmm \)

The equivalent twisting moment \( T_e \) is given by

\[ T_e = \sqrt{M^2 + T^2} \]

\[ T_e = \sqrt{38,220^2 + 22946^2} = 44349 Nmm \]

\[ T_e = \frac{\pi}{15FOS} \times \tau \times d^3 \]

Where \( FOS = \) Factor of safety = 4

\( \tau = \) Permissible shear stress taken for mild steel = 42 MPa

\[ 44349 = \frac{\pi}{16 \times 4} \times 42 \times d^3 = 27.81 mm \]

Say diameter of shaft \( (d) \) is 30mm

**RESULTS AND DISCUSSION**

**Performance evaluation**

In conducting the performance evaluation of the fabricated rice huller, three test runs were carried out on the rice huller. The hopper was designed for a maximum of 8.45 kg of unhusked rice. Different masses of unhusked rice paddy were fed per time. The mass of completely hulled rice, mass of chaff, mass of broken grains, time taken as well as hulling efficiency were recorded in the Table 1 and Figures 7 and 8.

The machine does not dehusk when started from rest, it gathers momentum first before it is loaded. It makes use of both gravitational movements of paddy rice as well as gradual loading during hulling. Bearing breakage and other related problems were eliminated through proper alignment in the assembly by ensuring, Figure 3 (hulling cylinders) mounted on the shaft was parallel between the adjacent bearings using a spirit level. Table 1 shows the results of the three test runs on the fabricated rice huller with 3, 5 and 8 kg of rice paddy. As shown in Figure 7 the hulling efficiency increases from 83 to 88.8% while the broken grains percentage decreases from 6 to 4.2% as the mass of paddy increases from 3 to 5 kg. The hulling efficiency drops to 75.75% while the broken grains percentage rises to 5% as the mass of paddy rice loaded increases from 5 to 8 kg. The hulling efficiency is maximum while the percentage of broken rice grains is minimum at 5 kg paddy rice. This implies that the increase in quantity of the paddy rice up to 8 kg tends to subject
the hulling cylinder mounted on the shaft to such a loading which the slows down the hulling mechanism and is responsible for the little additional quantity of paddy rice which breaks and that which escapes the dehusking process between the hulling cylinders and hulling blades. As shown in Figure 8 the hulling capacity is maximum for
Table 1. Result of test runs.

<table>
<thead>
<tr>
<th>Test runs</th>
<th>Mass of paddy rice (kg)</th>
<th>Mass of completely hulled rice (kg)</th>
<th>Mass of chaff (kg)</th>
<th>Mass of broken grains (kg)</th>
<th>Time taken (min)</th>
<th>Hulling efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>2.49</td>
<td>0.33</td>
<td>0.18</td>
<td>8.1</td>
<td>83.00</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>4.44</td>
<td>0.35</td>
<td>0.21</td>
<td>12.6</td>
<td>88.80</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>6.06</td>
<td>1.52</td>
<td>0.40</td>
<td>19.2</td>
<td>75.75</td>
</tr>
</tbody>
</table>

Figure 7. Mass of paddy rice fed into hopper, corresponding hulling efficiency and broken grains percentage.

Figure 8. Mass of paddy rice fed into hopper and corresponding hulling capacity.

8kg loading (25.2 kg/h), moderate for 5 kg loading (24 kg/h) and minimum for 3 kg loading (22 kg/h). However, in continuous production it has been observed that 5 kg/h showed higher labour productivity as it maintains a
balance between time taken and number of times required for operator to refill the hopper with paddy rice.

**Conclusion**

The rice hulling machine was developed to dehusk paddy rice. The machine is powered by a 3.0HP 950 rpm electric motor via a V-belt mechanism which delivers the power requirement to the shaft on which the hulling cylinder is mounted. The hulling cylinder presses the paddy rice against the hulling blade to remove the chaff. The paddy rice is fed into the Housing unit for processing through the machine hopper. The machine was designed to process < 8 kg of the rice for small scale production. The design was segmented into the hopper and housing (processing) unit, the frame support and the power transmission unit. Performance evaluation of the machine shows that its efficiency is within the range of 83-88%, the hulling capacity is within the range of 22-25 kg/h and the maximum efficiency is at 5 kg paddy rice hopper loading which is about 60% of the hoppers' volume.

**CONFLICT OF INTERESTS**

The authors have not declared any conflict of interests.

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