# Design, Construction and Performance Evaluation of a Rice Winnowing Machine

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**Abstract:** A rice winnowing machine was designed, constructed from locally sourced materials and tested at three different level of feed rates (2 kg, 3 kg and 4 kg), three concave clearances (20 mm, 40 mm and 60 mm) and three different blower speeds (350 rpm, 630 rpm and 760 rpm). The maximum separation efficiency was attained at a clearance of 20 mm for all blower speed (350 rpm, 630 rpm and 760 rpm) with corresponding efficiencies of 89.76 %, 92.11 % and 91.59 % while the throughput capacities are 117.17 kg/hr, 115 kg/hr and 109.72 kg/hr respectively. It was observed that 630 rpm blower speed at a clearance of 20 mm is the most suitable for the operation of this machine, as it has a high separation efficiency of 92.11 % with throughput capacity of 115 kg/hr. It can be concluded, that the developed machine could reduce the drudgery involved in manual winnowing of rice.

***Keywords: Rice, Winnowing, Drudgery, Concave Clearance, Separation efficiency***

## 1. Introduction

Rice (*Oryza sativa)* is an increasing crop in Nigeria. It is relatively easy to produce and is grown for sale. In some areas there is a long tradition of rice growing. Rice has been considered a luxury food for special occasion only, with the increased availability of rice, it has become part of the day diet of many in Nigeria. Rice is a cereal cultivated mainly for human consumption and also finds use in the manufacturing of alcohol, starch, glucose, acetic acid and diet foods (Pirot, 1998).

Nigeria is currently the largest importer of rice in the world. Hitherto, Indonesia had until 2004 been the world's largest importer of rice but today she has with a sense of patriotism surpassed all odds to become self sufficient in the commodity. Nigeria still imports rice to the tune of 1.8 million dollars alone in 2002. The annual demand for rice in the country is estimated at 5 million tons, while domestic production is 3 million resulting in a deficit of 2 million tons (Chuma, 2008).

The north central zone is the largest producer of rice in Nigeria, accounting for 47 % of total output. This is followed by Northwest (29 %), Northeast (14 %), Southeast (9%), and the Southwest with 4 % of rice production. Kaduna State is the largest rice producing State in the country accounting for about 22 % of the country output, followed by Niger State (16 %), Benue State (10 %), and Taraba State with 7 % of total output (Chuma, 2008).

Market value of rice may drastically reduce due to poor harvesting and post harvesting handling methods which encourage the presence of contaminant such as stone, stick, chaff and leave stalk (Ogunlowu and Adesuyi, 1999). These unwanted materials must be significantly separated from the grains for good market value. Winnowing is one of the methods employed for the separation of this unwanted materials from grain.

Winnowing is the process of separating a lighter component (chaff) from a heavier component (grain) by throwing it from a height. The lighter material is blown away by wind and heavier component goes down.

Traditional method of winnowing grain used by Nigerian farmers cannot effectively handle the volume of rice produced in the country while at the same time the mechanical means available are too expensive for the local farmers. Winnowing machine is a contrivance, employed for separation by artificial current of air, the chaff from the grain, after it has been threshed out of the straw. Winnowing machine was invented like many other inventions to make the farmers work a little easy. All the farmer had to do is to keep feeding rice and chaff into the top of the machine through a set of wheels and pulleys that operated a big blower inside the machine and a set of shakers that the grain passed down through. The chaff would come out of the chaff outlet while the grains would fall down through the shakers and come out through the grains outlet (John, 2007).

Ogunlowu and Adesuyi, (1999) stated that mechanical method of separating rice from foreign materials depend on the difference in size, shape and specific weight. It was also observed that chaff-like materials were removed from cereals like wheat, rice and soybeans at air velocity of 3.05 m/s which is less than their terminal velocity.

### 1.1. Statement of the Problem

The traditional method of winnowing employed by the peasant farmers cannot effectively handle the increase in grain production and the mechanical means available are too expensive for the local farmers. Therefore a simple and effective winnowing machine becomes imminent.

### 1.2. Aim and objectives of the Study

The aim and objective of this research is to design, construct and carry out the performance evaluation of a rice winnowing machine in respect to separation efficiency, grain recovery range, throughput capacity and percentage of blown grain.

## 2. Methodology

### 2.1 Determination of Size of Paddy Rice

A vernier calliper and a micrometer screw gauge were used for measuring dimensions and a beam balance was used for weighing the paddy rice. All the measurements were done at the Agricultural and Bioresources Engineering Laboratory, FUT, Minna, Nigeria.

### 2.2 Determination of Terminal Velocity

The terminal velocity of the grains (rice) was obtained from the following expression (Sitkei, 1986):

$$V_t = 1.74\left(\frac{gd_e(\rho_p - \rho_f)}{\rho_f}\right)^{\frac{1}{2}} \quad (1)$$

Where: $V_t$ = Terminal Velocity of rice, m/s; $\rho_p$ = Particle Density, kg/m$^3$; g = Acceleration due to gravity, m/s$^2$; $d_e$ = equivalent diameter, m; $\rho_f$ = air density, kg/m$^3$

The equivalent diameter of the rice grain, ($d_e$) is given (Sitkei, 1986) as:

$$d_e = (M_D I_D)^{\frac{1}{3}} \quad (2)$$

Where: $M_D$ = Mean major diameter, mm; $I_D$ = Mean intermediate diameter, mm; $M_d$ = Mean minor diameter

The volume particle ($V_p$), is given (Sitkei, 1986) as:

$$V_p = \frac{1}{6\pi}(d_e)^3 \quad (3)$$

The density of paddy rice was obtained from equation (4):

$$\rho_{pr} = \frac{mass\ of\ paddy\ rice}{volume\ paddy\ rice} \quad (4)$$

According to Tindall (1983), 30 seeds of paddy rice weighed a gramme, therefore mass (m) of a single seed will be = $^1/_{30}$ = 0.0339 g

The terminal velocity of rice (10. 41 m/s) is twice the peripheral velocity (4.56 m/s). Therefore, the grains will settle down without being blown off (John, 2007).

### 2.3 Design of the machine components

The design of the machine was based on physical and aerodynamic properties of paddy rice while the materials for construction were sourced locally. The materials are chosen on the basis of their availability, suitability, economy, viability in service among other consideration.

The main features of the rice winnowing machine are: the hopper, the frame, the blower, the electric motor, the chaff outlet, and the grain outlet.

#### 2.3.1 Hopper

The hopper forms the opening through which the rice is fed into the winnowing chamber. It is trapezoidal in shape and is made of 16 gauge mild steel with all sides slanting inwards at an angle of $60^0$.

#### 2.3.2 Frame

The frame which makes the mounting supports for all other units is made of 50 x 50 mm angle bar. The overall dimension is 973 mm x 493 mm x 750 mm.

#### 2.3.3 Blower

Blower unit consist of the fan made of blades, fan housing, and a shaft supported by bearings. The airflow is directed toward the winnowing unit, this help to separate grain effectively.

The factors considered in the design of the blower unit are the blade diameter, blade length and width, number of blade and the weight of the fan blades. Also considered is the required air discharge through the blower or the velocity of air required for separation.

### 2.4 Air Discharge through Blower

The required air discharge ($Q_A$) through the blower can be estimated from equations (4) and (5) (Sitkei, 1986):

Therefore the required ($Q_A$) air discharge is:

$$Q_A = V_a A_a \quad (5)$$

$$A_a = D_a W_a \quad (6)$$

Where: $Q_A$ =Actual air Flow, $m^3/s$; $V_a$ =Velocity of air, m/s; $A_a$=Cross Sectional area of blower, $m^2$, $D_a$ =Depth of air stream above the mouth of blower, m; $W_a$ = Width over which air is required, m

### 2.5 Blade Diameter Determination

The forward curved blade with $90^0$ blade tip is selected because it is simple to construct and has the ability to convey materials and deliver them at high pressure.

The diameter of the blade can be determined (Sitkei, 1986) from equation (7):

$$Q_t = \pi d_2 w_b V_{2r} \quad (7)$$

Where: $V_{2r}$=tangential components of absolute velocity; $W_b$= Width of blades; $d_2$ = diameter of impeller/blades

The air velocity $V_{2r}$ is 20 % of impeller velocity ($V_2$) of the impeller tip (Sitkei, 1986):

Given that impeller velocity,

$$V_2 = \pi d_2 N K \quad (8)$$

Therefore, the theoretical discharge $Q_A$ in equation (7) becomes:

$$Q_t = 0.2\pi^2 d_2^2 w_b NK \quad (9)$$

Also from equation (7), diameter of impeller becomes:

$$d_2^2 = \frac{60Q_t}{0.2\pi^2 w_b NK} \quad (10)$$

The peripheral velocity of blower $V_3$ expressed in terms of impeller diameter and shaft speed, becomes (Sitkei, 1986):

$$V_3 = \frac{\pi^2 d_2 N}{60} \quad (11)$$

This velocity is enough to blow rice husk and very light materials with terminal velocity below 4.56 m/s and allow the paddy rice grain with terminal velocity 10.41 m/s.

**2.6 Determination of mass of blade**

The area of the blade ($A_b$) = L x B, $m^2$

Where: L, B = length and breadth of the blade

While the volume of blade

$V_b$ = area x blade thickness (t) (12)

∴ The mass of blade $M_b = V_b \times \rho$ (13)

The blade is constructed from a guage 16 mild steel plate of thickness 1.5 mm. The density of mild steel was assumed to be 7850 kg/m$^3$ (Kurmi and Gupta, 2006).

**2.7 Fan Casing Design**

The radius of the fan casing is calculated using the formula (Kurmi and Gupta, 2006):

$$r = (1 + \frac{\theta}{360}) \quad (14)$$

Where:

r = radius of fan casing, mm; R = fan casing outlet radius, mm

$$\therefore R = \frac{\text{distance from centre of shaft to the tip of blade}}{\text{number of impeller}}, mm$$

**2.8 Determination of area of outlet casing**

The area of outlet casing ($A_c$) is gotten from the given relationship:

$$A_c = \frac{1}{2}(l + b)h \quad (15)$$

Where: L = length of blower casing mouth, m; b = breadth of blower casing mouth, m; h = height of blower casing, m

**2.9 Determination of the blower pulley diameter**

The transmission belt transfers drive from the electric motor to the power transmission shaft inside the blower housing/casing in which blades are attached with the aid of pulley:

The blower diameter becomes (Isyaku, 2005; Kurmi and Gupta, 2006):

$$D_b = \frac{N_m D_m}{N_1} \quad (16)$$

Where: $D_b$ = Diameter of blower pulley, m; $N_m$ = Motor pulley speed, rpm

$D_m$ = Diameter of motor pulley, m; $N_1$ = Speed of the blower, rpm;

**2.10 Determination of centre distance between blower and electric motor pulley**

The distance between the blower and electric motor pulley is given (Isyaku, 2005; Kurmi and Gupta, 2006) as:

The maximum centre distance $C_{max} = (D_m + D_b)$ (17)

The minimum centre distance:

$$C_{min} = \frac{D_m + D_b}{2} + D_m \quad (18)$$

**2.11Belt Selection**

Length of the belt between blower and electric motor (L) becomes (Kurmi and Gupta, 2006):

$$L = 2C + \frac{1.57(D_b + D_m)}{2} + \frac{(D_b - D_m)^2}{4C} \quad (19)$$

Therefore, the Centre distance becomes (Kurmi and Gupta, 2006):

$$C = \frac{2.5(D_b + D_m)}{2} \quad (20)$$

The length correction factor $K_L$, is obtained to be 0.84 (Dauda, 2001; Kurmi and Gupta, 2006). Therefore, the corrected belt length becomes:

$$l = 475.92K_l \quad (21)$$

**2.12 Determination of Arc of belt contact**

The arc of the belt contact (Ø) was computed from equation (22) (Kurmi and Gupta, 2006).

$$\phi = \sin^{-1}\frac{(D_b - D_m)}{2C} \quad (22)$$

While motor pulley arc ($\alpha_1$):

$$\alpha_1 = 180 + 2\phi \quad (23)$$

The driven blower pulley arc ($\alpha_2$):

$$\alpha_2 = 180 - 2\phi \quad (24)$$

**2.13 Determination of Belt Tensions**

A – Type V-belt with cross sectional area of 75.29 mm$^2$ and mass of belt, 0.1009 kg/m is used in the determination of belt tension.

The tension on the slack side of the belt ($T_2$) is given as (Kurmi and Gupta, 2006):

$$T_2 = \frac{T_1 - T_c}{e^{\mu\pi / \sin^1/2^\theta}} + T_c \quad (25)$$

Where: $T_1$ = Tension on the tight side of the belt, N; $T_c$ = Centrifugal force on the pulley, N

But, $T_c = MV^2$ (26)

Where: M = mass of the belt, kg/m; V = impeller velocity, m/s

Impeller velocity becomes (Kurmi and Gupta, 2006):

$$V = \frac{\pi D_b n}{60} \quad (27)$$

The centrifugal force on the pulley becomes:

$$T_c = M(\frac{\pi D_b n}{60})^2 \quad (28)$$

The maximum allowable stress of a leather belt is between 2 and 3.5 MPa, then, taking the average, 2.73 x $10^{-6}$ N/m$^2$ as the tensile stress on the tight side ($T_1$) (Kurmi and Gupta, 2006).

**2.14 Power transmitted to the blower (P)**

The power transmitted to the blower is given as (Kurmi and Gupta, 2006):

$$P = (T_1 - T_2)V \quad (29)$$

Where: P = Power, kW; $T_1$, $T_2$ = are tensions on tight and slack sides of the belt respectively; V = velocity

**2.15 Design**

Shaft design primarily is about the determination of the correct diameter to ensure satisfactory strength and rigidity, when the shaft is transmitting power under various operating loading conditions. Shafts are usually circular in cross section and may be hollow or solid. A solid shaft is selected (Kurmi and Gupta, 2006).

**2.16 Determination of Blower shaft Diameter**

According to Kurmi and Gupta (2006) the required diameter of shaft from the ASME loading is given as:

$$d^3 = \frac{16}{\pi T_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad (30)$$

Where: $d$ = blower shaft diameter, m; $T_s$ = Maximum allowable shear stress, 40 x $10^6$ N/m$^2$; $M_b$ = Maximum bending moment, Nm; $M_t$ = Torsional moment (torque), Nm; $K_b$ = Combine shock and fatigue factor bending = 1.5; $K_t$ = Combine shock and fatigue factor for twisting 1.0

**2.17 Blower bearing design and selection**

The machine has pair of thrust bearing located at the both end of blower shaft. Static and dynamic conditions as well as the life requirement are to be considered in selecting these bearing for combined radial and axial load. Therefore, the equivalent load ($P_o$) becomes (Kurmi and Gupta, 2006):

$$P_o X_o V F_r + Y_o F_a \qquad (31)$$

Where $P_o$ = Equivalent load; $X_o$ = Radial load factor = 0.56; V = Rotational factor = 1; $F_r$ = Radial load on shaft

The required radial load rating, ($C_r$) is given as (Kurmi and Gupta, 2006):

$$C_r = F K_l K_s \qquad (32)$$

Where: F = design load, N; $K_L$ = Life factor; $K_s$ = Speed factor

Where:

$$K_l = \left(\frac{L_D}{L_c}\right)^{\frac{1}{3}} \qquad (33)$$

$$K_s = \left(\frac{n_d}{n_c}\right)^{\frac{1}{3}} \qquad (34)$$

Where: $L_D$ = desire life of bearing, hrs; $L_c$ = Catalogue life of bearing, hrs; $n_d$ = rotational speed of bearing, rpm; $n_c$ = Catalogue rotational speed, rpm

The various parts were assembled as an integral unit (Fig.1) after all the necessary construction processes.

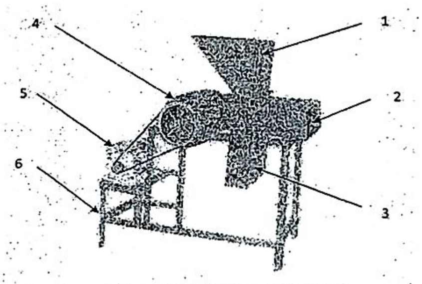


Fig. 1: The Rice Winnowing Machine

Legend: 1 -- Hopper
2 – Chaff outlet
3 – Grain outlet
4 – Blower Unit
5 – Electric Motor
6 - Frame

**2.18 Performance Evaluation of the Machine**

The machine was first run under no - load condition using an electric motor of 2 hp (1.5 kW) with speed rating of 760 rpm. The no-load test was carried out to ascertain the smoothness of operation for the machine's rotating parts. The actual test was conducted using paddy rice at a feed rate of 2 kg, 3 kg and 4 kg and at a blower speed of 350 rpm, 635 rpm and 760 rpm and a clearance of 20 mm, 40 mm and 60 mm respectively.

Essentially, the performance evaluation was done to determine the separation efficiency, throughput capacity, percentage blown grain and grain recovery range (Hyeston, 2000).

**2.19 Separation efficiency $S_e$ (%):**

$$S_e = 100(\frac{W_T - W_C}{W_T}) \quad (35)$$

Where: $W_T$ = total mixture of grain and chaff received at the main outlet, kg: $W_c$ = weight of the chaff at the main outlet of the machine, kg

**Grain recovery range (GRR), %:**

GRR = 100 - % total losses (36)

**Throughput capacity, ($T_C$) (kg/h):**

$$T_C = \frac{Q_S}{T} \quad (37)$$

Where: $Q_S$ = quantity of material that pass through the grain outlet, T = Time taken to complete operation, Sec.

**Percentage of blown grain $B_G$ (%):**

$$B_G = 100(\frac{W_G}{Q_T}) \quad (38)$$

Where: $W_G$ = weight of cleaned grain at chaff outlet, kg: $Q_T$ = total grain input, kg

The technical characteristics of the developed rice winnowing machine are shown in Table 1.

Table 1: Technical Characteristics of the Rice Winnowing Machine

| S/No. | Technical characteristics | Determined values |
|---|---|---|
| 1 | Volume of hopper | 0.0075 $m^3$ |
| 2 | Terminal Velocity | 10.41 m/s |
| 3 | Peripheral velocity of blower | 4.6 m/s |
| 4 | Diameter of impeller | 60 mm |
| 5 | Theoretical air discharge (30 % of the actual discharge) | 0.072 $m^3$/s. |
| 6 | Blade weight | 4.85, N |
| 7 | Radius of the fan casing | 155 mm |
| 8 | Area of outlet casing | 0.0345 $m^2$ |
| 9 | Diameter of blower pulley | 280 mm |
| 10 | Diameter of blower shaft | 25 mm with F 205 ball bearing (carbon steel) |
| 11 | Power required to operate the mixer | 1.1 kW, therefore an electric motor of 2 hp (1.5kW) was selected |
| 12 | Maximum centre distance | 1050 mm |
| 13 | Belt length | 1050 mm |
| 14 | Number of belts | 1 |
| 15 | Mean values of major, intermediate and minor Diameters of paddy rice | 9.65 mm; 2.53 mm and 2.01 mm respectively |

## 3. Results and Discussion

The average performance parameters (separation efficiency, throughput capacity, percentage blown grain and grain recovery range) obtained from the test carried out to ascertain the performance of the machine at a speed of 350 rpm, 635 rpm and 760 rpm, using a clearance of 20 mm, 40 mm and 60 mm respectively and a feed of 2 kg, 3 kg and 4 kg are shown in Table Tables 2, 3, 4 and 5.

Table 2: Performance data of the rice winnower at 350 rpm blower speed

| Feed (kg) | Clearance (mm) | $W_T$ (kg) | $W_o$ (kg) | $W_c$ (kg) | $W_g$ (kg) | $Q_L$ (kg) | $Q_T$ (kg) | $T_o$ (S) | $S_e$ (%) | $T_c$ (kg/hr) | $B_G$ (%) | GRR (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 20 | 1.7 | 1.5 | 0.2 | 0 | 0 | 1.5 | 54 | 88.24 | 113.30 | 0 | 100 |
| 3 | 20 | 2.75 | 2.5 | 0.25 | 0 | 0 | 2.5 | 81 | 90.10 | 122.22 | 0 | 100 |
| 4 | 20 | 3.48 | 3.2 | 0.28 | 0 | 0 | 3.2 | 108 | 91.95 | 116 | 0 | 100 |
| Mean | 20 | 2.64 | 2.40 | 0.27 | 0 | 0 | 2.40 | 81 | 90.35 | 117.17 | 0 | 100 |
| 2 | 40 | 1.85 | 1.5 | 0.35 | 0 | 0 | 1.5 | 38 | 81.08 | 175.26 | 0 | 100 |
| 3 | 40 | 2.88 | 2.5 | 0.38 | 0 | 0 | 2.5 | 57 | 86.81 | 181.89 | 0 | 100 |
| 4 | 40 | 3.65 | 3.2 | 0.45 | 0 | 0 | 3.2 | 76 | 87.67 | 172.89 | 0 | 100 |
| Mean | 40 | 2.79 | 2.40 | 0.39 | 0 | 0 | 2.40 | 57 | 85.19 | 176.68 | 0 | 100 |
| 2 | 60 | 1.90 | 1.5 | 0.4 | 0 | 0 | 1.5 | 32 | 78.9 | 213.75 | 0 | 100 |
| 3 | 60 | 2.92 | 2.5 | 0.42 | 0 | 0 | 2.5 | 48 | 85.62 | 219 | 0 | 100 |
| 4 | 60 | 3.68 | 3.2 | 0.48 | 0 | 0 | 3.2 | 64 | 86.96 | 207 | 0 | 100 |
| Mean | 60 | 2.83 | 2.40 | 0.43 | 0 | 0 | 2.40 | 48 | 83.83 | 213.25 | 0 | 100 |

Table 3: Performance data of the rice winnower at 638 rpm blower speed

| Feed (kg) | Clearance (mm) | $W_T$ (kg) | $W_o$ (kg) | $W_c$ (kg) | $W_g$ (kg) | $Q_L$ (kg) | $Q_T$ (kg) | $T_o$ (S) | $S_e$ (%) | $T_c$ (kg/hr) | $B_G$ (%) | GRR (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 20 | 1.65 | 1.5 | 0.15 | 0 | 0 | 1.5 | 54 | 90.99 | 110 | 0 | 100 |
| 3 | 20 | 2.7 | 2.5 | 0.20 | 0 | 0 | 2.5 | 81 | 92.59 | 120 | 0 | 100 |
| 4 | 20 | 3.45 | 3.2 | 0.25 | 0 | 0 | 3.2 | 108 | 92.75 | 115 | 0 | 100 |
| Mean | 20 | 2.60 | 2.40 | 0.20 | 0 | 0 | 2.40 | 81 | 92.11 | 115 | 0 | 100 |
| 2 | 40 | 1.8 | 1.50 | 0.30 | 0 | 0 | 1.5 | 38 | 83 | 170.53 | 0 | 100 |
| 3 | 40 | 2.82 | 2.50 | 0.32 | 0 | 0 | 2.5 | 57 | 88.65 | 178.11 | 0 | 100 |
| 4 | 40 | 3.6 | 3.20 | 0.40 | 0 | 0 | 3.2 | 76 | 88.89 | 170.53 | 0 | 100 |
| Mean | 40 | 2.74 | 2.40 | 0.34 | 0 | 0 | 2.40 | 57 | 86.85 | 170.06 | 0 | 100 |
| 2 | 60 | 1.85 | 1.5 | 0.35 | 0 | 0 | 1.5 | 32 | 81.08 | 208.15 | 0 | 100 |
| 3 | 60 | 2.88 | 2.5 | 0.38 | 0 | 0 | 2.5 | 48 | 86.81 | 216 | 0 | 100 |
| 4 | 60 | 3.63 | 3.2 | 0.43 | 0 | 0 | 3.2 | 64 | 88.15 | 204.19 | 0 | 100 |
| Mean | 60 | 2.79 | 2.40 | 0.39 | 0 | 0 | 2.40 | 48 | 85.35 | 209.48 | 0 | 100 |

Table 4: Performance data of the rice winnower at 760 rpm blower speed

| Feed (kg) | Clearance (mm) | $W_T$ (kg) | $W_o$ (kg) | $W_c$ (kg) | $W_g$ (kg) | $Q_L$ (kg) | $Q_T$ (kg) | $T_o$ (S) | $S_e$ (%) | $T_c$ (kg/hr) | $B_G$ (%) | GRR (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 20 | 1.55 | 1.4 | 0.15 | 0.1 | 0 | 1.5 | 54 | 90.32 | 103.33 | 9.68 | 90.32 |
| 3 | 20 | 2.55 | 2.35 | 0.2 | 0.15 | 0 | 2.5 | 81 | 92.16 | 113.33 | 7.84 | 92.16 |
| 4 | 20 | 3.25 | 3.0 | 0.25 | 0.2 | 0 | 3.2 | 104 | 92.31 | 112.5 | 7.69 | 92.31 |
| Mean | 20 | 2.45 | 2.25 | 0.2 | 0.15 | 0 | 2.40 | 81 | 91.59 | 109.72 | 8.40 | 91.60 |
| 2 | 40 | 1.6 | 1.4 | 0.2 | 0.1 | 0 | 1.5 | 38 | 87.5 | 151.58 | 12.5 | 87.5 |
| 3 | 40 | 2.62 | 2.37 | 0.25 | 0.13 | 0 | 2.5 | 57 | 90.46 | 165.47 | 9.54 | 90.45 |
| 4 | 40 | 3.35 | 3.05 | 0.3 | 0.15 | 0 | 3.2 | 76 | 91.04 | 158.58 | 8.96 | 91.04 |
| Mean | 40 | 2.52 | 2.27 | 0.25 | 0.13 | 0 | 2.40 | 57 | 89.33 | 158.58 | 10.33 | 89.66 |
| 2 | 60 | 1.75 | 1.5 | 0.25 | 0 | 0 | 1.5 | 32 | 85.71 | 196.88 | 0 | 100 |
| 3 | 60 | 2.86 | 2.5 | 0.36 | 0 | 0 | 2.5 | 48 | 87.41 | 214.5 | 0 | 100 |
| 4 | 60 | 3.55 | 3.2 | 0.35 | 0 | 0 | 3.2 | 64 | 90.14 | 199.69 | 0 | 100 |
| Mean | 60 | 2.72 | 2.40 | 0.32 | 0 | 0 | 2.40 | 48 | 87.75 | 203.69 | 0 | 100 |

Table 5: Average performance parameter of a rice winnowing Machine

| Speed (rpm) | Clearance (mm) | Feed (kg) | $S_e$ (%) | $T_c$ (kg/hr) | $B_g$ (%) | GRR (%) |
|---|---|---|---|---|---|---|
| 350 | 20 | 2<br>3<br>4 | 90.35 | 117.17 | 0 | 100 |
| | 40 | 2<br>3<br>4 | 85. 19 | 176.68 | 0 | 100 |
| | 60 | 2<br>3<br>4 | 83.83 | 213.25 | 0 | 100 |
| 638 | 20 | 2<br>3<br>4 | 92.11 | 115 | 0 | 100 |
| | 40 | 2<br>3<br>4 | 86.85 | 173.06 | 0 | 100 |
| | 60 | 2<br>3<br>4 | 85.35 | 209.48 | 0 | 100 |
| 760 | 20 | 2<br>3<br>4 | 91.59 | 109.72 | 8.40 | 91.60 |
| | 40 | 2<br>3<br>4 | 89.33 | 158.58 | 10.33 | 89.66 |
| | 60 | 2<br>3<br>4 | 87.75 | 203.69 | 0 | 100 |

Where:

$S_e$ = Separation efficiency, %;

$T_c$ = Throughput capacity; %,

$B_g$ = Blown grain, %;

GRR = Grain Recovery Range, %;

$W_T$ = Total mixture of grains and chaff at the grain outlet, kg;

$W_o$ = Weight of the grain collected at the grain outlet, kg;

$W_c$ = weight of the chaff at the grain outlet, kg;

$W_g$ = Weight of the clean grain at the chaff outlet, kg; $Q_L$ = Weight of the grain scattered around the winnower, kg;

$Q_T$ = Total grain input, kg;

$T_o$ = Time of operation, sec.

The analysis of the results obtained from table 5 shows that at 350 rpm blower speed, the separation efficiency decreases from 90.35 % to 83.3 % as the clearance increases from 20 mm to 60 mm. It is obvious from this result that concave clearance is inversely proportional to separation efficiency; however a clearance of 20 mm gave the best separation efficiency of 90.35 % at a blower speed of 350 rpm. In the case of throughput capacity, it was observed, that as concave clearance increases from 20 mm to 60 mm, the throughput capacity too increases from 117.17 kg/hr to 176.68 kg/hr. The grain recovery range (GRR) was observed to be 100 % for all the clearance. This is an indication that no grain was blown off.

At a blower speed of 638 rpm the trend was similar to what was observed at a blower speed of 350 rpm. Separation efficiency decrease from 92.11 % to 85.35 % as the clearance increased from 20 mm to 60 mm. However a 20 mm clearance gave the best separation efficiency of 92.11 % at a blower speed of 638 rpm and the throughput capacity increases from 115 kg/hr to 209.48 kg/hr as the clearance increase from 20 mm to 60 mm. At 760 rpm blower speed, it was also observed that the separation efficiency decrease from 91.59 % to 87.79 % as a result of increase in clearance from 20 mm to 60 mm. The throughput capacity was observed to increase from 109.72 kg/hr to 203.69 kg/hr as the clearance increased from 20 mm to 60 mm. At 20 mm clearance the grain recovery range was observed to be 91.60 % with a loss of 8.40 %. Also at 40 mm clearance, grain recovery range was observed to be 89.66 % with a loss of 10.33%. It was also observed that at 60 mm clearance the grain recovery range was 100 %.

For all speed tested in the experiment (350 rpm, 630 rpm and 760 rpm), the maximum separation efficiency was attained at a clearance of 20 mm with corresponding efficiencies of 89.76 %, 92.11 % and 91.59 %. At this point, the throughput capacities are 117.17 kg/hr, 115 kg/hr and 109.72 kg/hr respectively. It was observed that 630 rpm blower speed at a clearance of 20 mm is the most suitable for the operation of this machine, as it has a high separation efficiency of 92.11 % with a corresponding throughput capacity of 115 kg/hr.

## 4. Conclusion

A rice winnowing machine was successfully designed, constructed from locally sourced materials and tested. It was observed that 630 rpm blower speed at a concave clearance of 20 mm is the most suitable for the operation of this machine, as it has a high separation efficiency of 92.11 % with throughput capacity of 115 kg/hr. The separation efficiency decreases as the clearance increases. The concave clearance is inversely proportional to the separation efficiency and exhibits a linear relationship with throughput capacity.

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