

# PHYSICO-MECHANICAL PROPERTIES AND DESIGN OF DESTONING MACHINE FOR SMALL SCALE RICE MILLS

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## ABSTRACT

*The quality of local rice is a major concern for the future of the Nigerian rice sector. The major problem being the appearance and cleanliness of the rice delivered to the market. They are characterized by high percentage of impurities like husk and stones as well as under size/broken grains which reduces its economic value and makes it difficult to compete favourably with imported ones. Therefore, one of the important quality additions is reduction of contaminants especially stones to the barest minimum. In this research work, a rice grain destoning machine was designed based on the physical, mechanical and aerodynamic properties of rice. The average dimensions of three rice varieties; Kano, Zaria, and Mario in terms of length, width and thickness were found to be 7.038mm, 2.193mm and 1.95mm. While the averages for aspect ratio, arithmetic mean, geometric mean, surface area and sphericity were found to be 3.6mm, 3.73mm, 3.07mm, 29.72mm<sup>2</sup> and 0.4372. The calculated destoning efficiency was 80% at a speed of 284 rpm and feed rate of 94 kg/hr. It was observed that physical properties like surface area, sphericity, and geometric mean diameter of rice increased with increase in moisture content from 10% to 16% with a regression coefficient of ( $R^2$ ) values of 0.96, 0.86 and 0.95 respectively. However, porosity of rice decreased with increase in moisture content with a regression coefficient of ( $R^2$ ) = -0.97. It was recommended that for enhanced separation of rice from stones the sieve tilt angle should allow rice have enough resident time on the sieves.*

**Keywords:** Destoner, Efficiency, Rice, Performance, Development

## 1 INTRODUCTION

Nigeria has ecologies suitable for the production of different rice varieties which can be harnessed to meet domestic and export requirements. The country has a potential land area of between 4.6 to 4.9 million hectares for food production with only about 35 % cropped to rice [1]. Locally produced rice is highly nutritious; however, the quality of its milled rice is usually poor. They are characterized by high percentage of impurities like husk and stones as well as under size/broken grains which reduces its economic value and makes it difficult to compete favourably with imported ones [2]. Separation of materials other than grain is essential to upgrade the quality of food material. Some of the methods employed for separating materials other than grains include winnowing (traditional method), aspiration, sieving and use of vertical air stream [3]. A survey carried out on rice milling industries in Nigeria only few millers were destoning their paddy before milling. The low utilization of destoners in rice milling operations could be the cause of high presence of stones in locally milled rice, which is the major reason consumers, refrain from purchasing local rice [4]. [5] Accomplished separation of stones and other contaminants using a combination of oscillating sieves and variable directional air stream at 160 rpm. [6] Improved on an appropriate technology cereal cleaner by [7] and obtained a higher cleaning efficiency of

71% for paddy. [8] Studied the optimum operating conditions for achieving a high degree of cleaning wheat grains from impurities. Their results showed that the combination of airstream velocity, specific feed rate, percentage of total impurities and samples moisture content affected significantly cleaning efficiency and grain losses. [9] Determined the terminal velocity of wheat, rice, and barley. They found that the terminal velocity ranged from 5.85 to 9.70 m/s for wheat varieties, from 7.88 to 8.54 m/s for rice varieties and from 7.49 to 9.95 m/s for barely varieties. [10] mentioned that separating and cleaning grains from material other than grain (straw, chaff, fine particles) could be improved by using a combined action produced, firstly from the formation of fluidized bed of these particles and secondly from the movement of the particles on tilted screen. [11] studied some engineering parameters affecting cleaning and separating efficiency such as type of motions (vibrating or rotary speeds), cells shape (rectangular, square and circle), position of rectangular cell (parallel or perpendicular with speed direction), sieve inclination and sieving time were considered for each machines type (vibratory and rotary machines). He found that the efficiency increased by increasing sieving time, oscillating and rotary speed. [12] Showed that cleaning efficiency and total losses were positively affected by air speed, and sieve tilt angle, but purity was negatively affected by moisture content, and feed rate. The total losses were negatively affected by moisture content and feed rate. Purity increased when using round-hole sieve compared with slotted sieve. The optimum performance was at air speed of 4 m/s, moisture content of 18 %, sieve tilt-angle of 0.03 rad (2 deg), round-shaped sieve, and feed rate of 1200 kg/h. Purity and total losses at these conditions were 98.98 and 0.21 % respectively. The literatures reviewed above were used to guide the development of the destoning machine.

## **2 MATERIALS AND METHODS**

### **2.1 Determination of rice physical properties**

Some selected physical properties of rice namely dimensions, sphericity, particle density, bulk density, terminal velocity, angle of repose, internal coefficient of friction, and equilibrium moisture contents were determined for three (3) rice varieties namely Kano, Zaria and Mario. The samples were measured at random from each rice variety using a micrometre screw gauge with (least count 0.01 mm) to determine the dimensions of rice grains. One hundred replications were taken at random and each parameter (length, width and thickness) determined, before embarking on the design and development of the rice destoner.

### **2.2 Design of the rice destoner**

The geometric characteristics and aerodynamic properties of the various material of rice impurity mixture were considered for effective design of the rice destoner. [6] Suggested that separation and cleaning should use a continuous force field rather than a gravitational force and must be accomplished within a minimum space. The aspect ratio that is major diameter/minor diameter, if greater than 2.0 imply that horizontal and vertical displacement will be required for the separation of the crop [7] was also adopted.

### **2.3 Sieve**

Here Sieve parameters like hole shape, size of opening and the co-efficient of opening,  $C_o$  were considered. And equations 1 and 2 adopted from [7] were used to estimate area for circular and oblong openings. For circular opening;

$$C_o = \text{open area/total area} = \frac{3D}{2} \times \frac{D^2}{(D+d)^2} \quad (1)$$

Where,  $D$  = diameter of hole,  $d$  = distance between two successive holes. (b) For Oblong opening.

$$C_o = \frac{DL - 0.22D^2}{D - d(L + d_1)} \quad (2)$$

Where,  $L$  = length of opening (mm),  $D$  = width of opening (mm),  $d_1$  = distance between adjacent lateral side (mm),  $d$  = distance between elongated sides (mm).

## 2.4 Sieve mechanism

The sieves were fixed inside the sieve housing inclined at an angle of  $15^{\circ}$  to the horizontal. The upper and lower sieves move together as a unit since they are both enclosed in the same casing. The sieves as a result of eccentric drive connection to the housing experiences horizontal oscillation and small vertical motion. The combined motion ensures that the grain move or slides down from the sieve and at the same time hops up to give the rice a sudden impact.

## 2.5 Power requirement for the machine

Theoretical power requirement for oscillation was estimated using equations 3 and 4.

$$\text{Vertical Hp}_1 = \frac{(W_s \times N \times 2 \times Y)}{4500} \quad (3)$$

$$\text{Horizontal Hp}_2 = \frac{W_s \times N \times 2 \times x \times \mu}{4500} \quad (4)$$

Where,  $W_s$  = weight of reciprocating unit along with materials on it kg,  $N$  = Speed in revolutions per minute,  $Y$  = Vertical displacement of the reciprocating assembly in meter per stroke,  $X \tan 15^{\circ}$ .  $X$  = Horizontal displacement of reciprocating assembly in meter per stroke,  $\mu$  = Co-efficient of friction between rice grain and metal. The determination of available power for blower equation 5 was used.

$$\text{Available power for blower} = \text{Electric motor Hp} - (\text{Hp}_1 + \text{Hp}_2) \quad (5)$$

## 2.6 Determination of Shaft Speeds

A photo type digital tachometer (Lutron DT-2234B 5 to 99,999 rpm) was used to determine the speed of the shaft. Air Velocity: Air velocity from radial blade centrifugal fan was determined using an anemometer. The anemometer was placed in the air stream between the upper sieve and the grain distributor when the machine was in operation. Feed Rate: The feed rate was computed as weight of crop fed into the machine per unit time (hr). Linear Velocity equation 6, for a rotating shaft with speed  $n$  and pulley of radius ( $r$ ).

$$V = \frac{2\pi rn}{60} \quad (6)$$

Where,  $n$  is speed in revolutions per minute (rpm) and Velocity is m/s. Sieve Oscillation Frequency: The sieve oscillation frequency,  $\alpha$ , was determined using equation 7.

$$\alpha = \frac{N}{t} \quad (7)$$

Where,  $N$  = number of reciprocations,  $t$  = time in seconds.

## 2.7 The Rice Destoner

The principal components of the machine are the hopper with its metering device at the base, grain distributor, a centrifugal blower, the sieve assembly and collection unit, the supporting frame and the drive components. The frame is made of (25x5mm) angle iron sections while the grain hopper is made of (2mm) sheet metal. The support linkage of the sieve assembly causes it to oscillate, moving the grain over the sieve. The machine is loaded through the hopper, which is regulated at the base by a slider unto the sieve assembly via the grain distributor. Then air from the blower is directed over the falling rice grains and materials other than grains (MOG) larger, light impurities, chaffs, and dust are blown out of the machine. While rice grains, denser materials and small stones pass through the openings (holes) in the upper sieve onto the second sieve which has smaller.

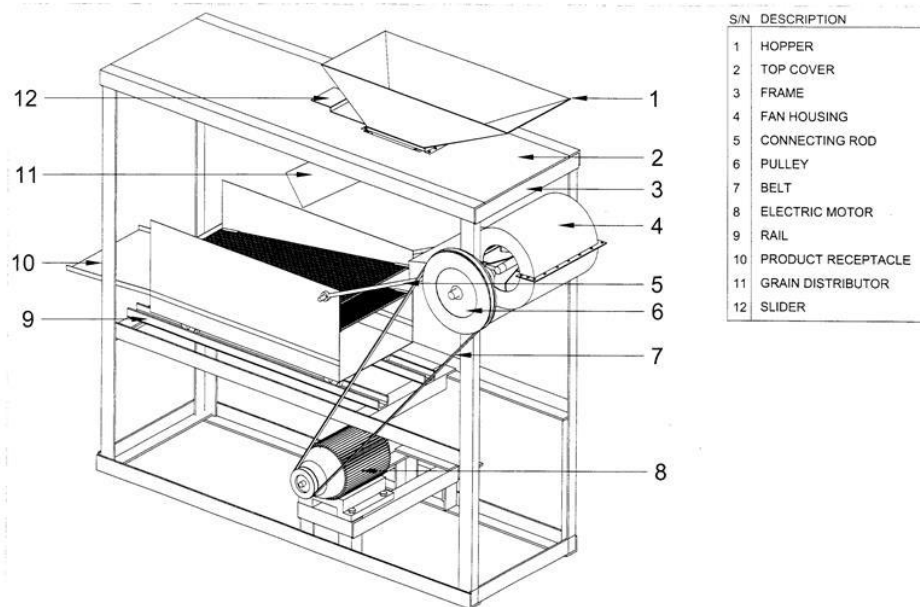


Figure 1. Isometric projection of the rice destoner

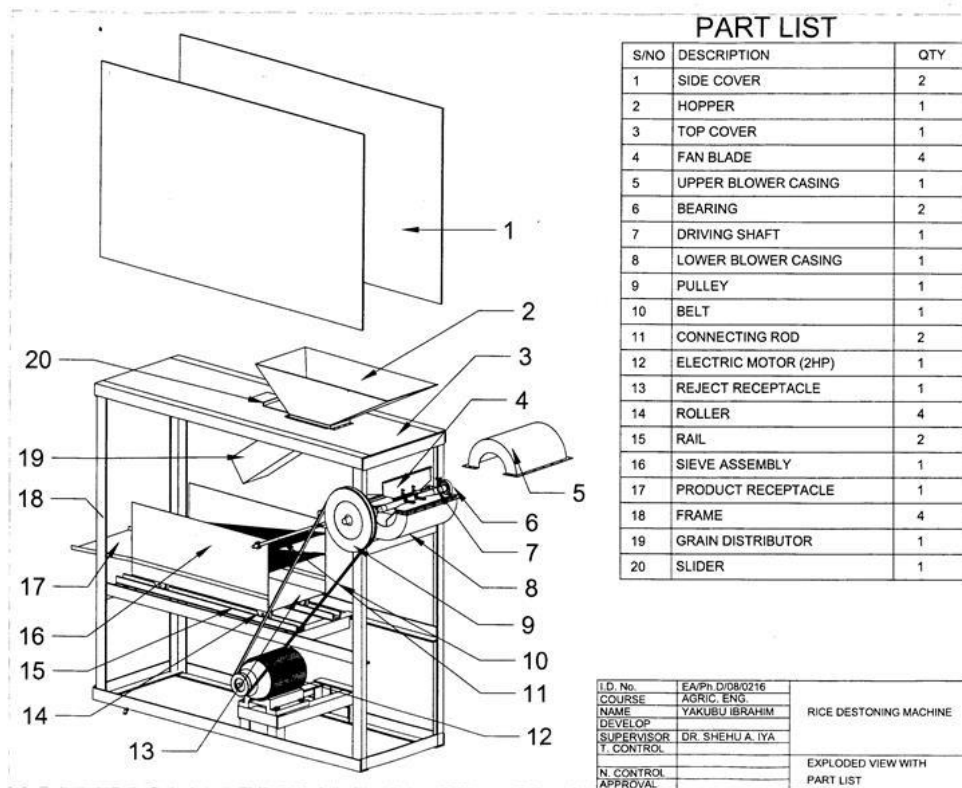


Figure 2. Exploded view of the machine

Holes diameter openings that allows only materials that are less than 2mm in diameter to pass through. The thorough shaking of the material as a result of the to and fro motion of the sieve assembly causes such materials to pass through the hole openings on to the reject receptacle. The destoned rice grains are then held on the second sieve because of their size and flow out to the product receptacle for collection.

### 2.8 Performance Evaluation of the Rice Destoner

Small stones of different sizes similar to the once dominant in rice were selected by sieving. The selected stones were washed to remove very fine sand and other unwanted particles and dried. After drying the stones were sprayed with a dark coloured paint and allowed to dry to enhance easy identification in rice. In preparing each sample, 1kg of rice, approximately 40,000 grains based on an average thousand grain weight of 25g [13] was measured and 20 coloured stones were introduced and mixed with it. This admixture was then passed through the destoner and the time to separate the admixture was recorded using a stop watch. A digital tachometer was used to measure shaft revolution per minute. The number of stones removed out of twenty deliberately introduced into every kilogramme of rice and the amount of rice retained on the screen and discharged with the stones were recorded. Each test was carried out five consecutive times and their averages obtained. Separation Efficiency: the separation efficiency was determined using equation 8.

$$E_s = \left(1 - \frac{S_r}{S_t}\right) \times 100 \tag{8}$$

$S_r$  = no. of stones retained in the rice,  $S_t$  = total no of stones introduced into the rice. Equation 9 was used to estimate wastage.

$$\text{Wastage, (w) \%} = \frac{G_{wr}}{G_i} \tag{9}$$

Where  $G_{wr}$  = weight of rice at rubbish outlets,  $G_i$  = weight of rice at input.

### 3 RESULTS AND DISCUSSION

Results obtained from laboratory measurements of physical dimensions are presented blow. Table 1 shows the means of the physical properties of three rice varieties major, intermediate and minor diameters and calculated values of aspect ratio, arithmetic mean diameter, geometric mean diameter, sphericity and surface area. It can be seen that length of rice is between 6.50 - 7.38 mm, width between 2.13 - 2.24 mm, while thickness is between 1.81 - 2.15 mm for Kano and Mario rice variety respectively. These values are within the published range of 5.25 - 7.49 mm for length, 2.10 - 2.89 mm for width and 1.71 - 2.03 mm for thickness of Abakaliki and Akeze rice varieties respectively as obtained by [14]. The measured equivalent diameter ranged between 3.52 - 3.91mm which are similar to the range of values of 3.48 - 3.90 mm obtained for sadri rice variety. The sphericity values for Kano, Zaria and Mario rice varieties are 0.45, 0.42 and 0.44 respectively. These values are higher than the value of 0.41 obtained by [5] for local rice variety ITA 257. The surface area ranged between 27.17 - 39.90mm<sup>2</sup> for Kano and Mario rice variety respectively, indicating that the larger the grain dimension the larger the surface area. Table 2 shows the mean values of physical properties and characteristics of the three rice varieties, minimum values, maximum values and standard deviation. In this study minimum value for length obtained for the three rice varieties was 6.50mm and the maximum value was 7.38mm, width ranged between 2.13 to 2.24mm and thickness between 1.81 to 2.15mm. [14] Determined the dimensions of Abakaliki and Akeze rice, where 72% of grain lengths are between 6.00 mm and 7.24 mm, 23.3 % have lengths between 5.25 mm and 5.99 mm, 5 % have lengths between 7.25mm and 7.99 mm. They found that 99 % of grains have thickness less than 2 mm, which are within the range of values obtained in this study.

Table 1. Physical properties of three rice varieties

Rice variety	Length (L) mm	Width (W) mm	Thickness (H) mm	Ra	Da	Dg	Sphericity	Surface area (mm <sup>2</sup> )
Kano	6.503	2.24	1.807	3.6094	3.5167	2.9376	0.4524	27.1714
Zaria	7.235	2.125	1.895	3.8179	3.7517	3.0427	0.4206	29.0881
Mario	7.377	2.216	2.148	3.4344	3.9137	3.2360	0.4387	32.9022
Average.	7.038	2.193	1.95	3.6206	3.7273	3.0721	0.4372	29.7206

Mean of 300 replications

The bulk density of rice ranged between 720 to 780 kg/m<sup>3</sup> which is higher than values of 726.06 kg/m<sup>3</sup> - 734.60 kg/m<sup>3</sup> for Tarom and Farj rice variety obtained by [15]. While values of true density lie between 1218.20 to 1282.01kg/m<sup>3</sup> whose values are higher than the true density of Tarom and Farj rice varieties with 1108.98 to 1144.68 kg/m<sup>3</sup> obtained by [15]. Plywood has higher angle of repose than galvanized iron this may be due to the smooth surface of the galvanized iron sheet relative to plywood. Angle of repose for the three rice varieties lies between 31<sup>0</sup> - 35<sup>0</sup> on the galvanized iron surface. Therefore, the data on frictional properties was used in hopper design for gravity flow, since the angle of inclination of the hopper walls should be greater than angle of repose to ensure continuous flow of the material. The terminal velocity of rice in this study lies between 5.22m/s – 6.52m/s, which are higher than mean values of 5.06 to 5.19 m/s obtained by [16] for terminal velocities of some rice varieties grown in South West Nigeria. It was also less than the values of 7.88 to 8.54 m/s obtained by [17] for some rice varieties. Mass of 1000 rice grains for the three rice varieties ranged between 21 to 23g, which are higher than values of 17.84 to 23.61g for Farj and Ramezani rice variety by [15].

Table 2. Dimension and physical characteristics of the three rice varieties

Property	No. of observation	Mean value	Standard deviation	Min. value	Max. value
Length (mm)	300	6.94	0.44	6.50	7.38
Width (mm)	300	2.19	0.06	2.13	2.24
Thickness (mm)	300	1.98	0.17	1.81	2.15
Geometric mean diameter (mm)	300	3.09	0.15	2.94	3.23
Sphericity (%)	300	43.65	1.16	42.05	45.24
Aspect ratio	300	3.63	0.20	3.43	3.82
Surface area (mm <sup>2</sup> )	300	30.04	2.87	27.17	32.90
Bulk density (kg m <sup>-3</sup> )	15	750.21	30.21	720.01	780.41
True density (kg m <sup>-3</sup> )	15	1250.11	31.91	1218.20	1282.01
Porosity (%)	15	43.5	1.5	42.00	45.00
Thousand weight of grains (g)	15	22.00	1.00	21.00	23.00
Angle of repose (degree)	15	33	2	31	35
Terminal velocity	15	5.87	0.65	5.22	6.52

Table 3 presents the values of static coefficient of friction measured on plywood surface and on galvanized iron surface at 10% moisture content wet basis. The static coefficient of friction was higher on plywood surface than on galvanized iron surface. This can be attributed to the surface roughness which is highest on plywood. The static coefficient showed that the galvanized iron surface had the minimum amount of static friction coefficient compared to plywood surface. Moisture had a significant effect on friction properties of tested rice varieties with an increase of moisture from 10 to 16%, the friction coefficients of surface materials (plywood and galvanized iron) increased. This is similar to the work of [18] on the effect of moisture on some physical properties of two varieties of rough rice, which reported that moisture had a significant effect on the static friction coefficient. Hence, galvanized iron sheet was selected for use as machine component due to its lower friction coefficient when compared to plywood to enable free flow of rice grains in the hopper.

Table 3. Static coefficients of friction of the three rice varieties on two surfaces

Surface	Number of observations	Mean	Standard deviation	Minimum value	Maximum value
Plywood	15	0.4425	0.0150	0.4275	0.4574
Galvanized iron	15	0.3942	0.0247	0.3695	0.4189

Table 4 shows the mass, geometric mean diameter, and sphericity values of some impurities found in the three rice varieties. It can be seen that the geometric mean diameter of the impurities ranged between

2.74 – 2.88mm, these values are similar to the geometric mean diameter of rice varieties measured. Though their sphericity values are higher than that of rice, it may present a serious problem during separation of rice from stone. [5] determined the size, shape, density and suspension velocity of admixtures of ITA 257 rice variety and other impurities like stones and sticks and found the sphericity of ITA 257 rice variety to be 0.41. These measurements are important to enable complete separation of rice from its basic impurities.

Table 4. Mass, geometric mean diameter and sphericity of impurities in rice

Type of impurities	Mass of impurities (g)			Geometric mean diameter of impurities (mm)			Sphericity of impurities		
	Kano	Zaria	Mario	Kano	Zaria	Mario	Kano	Zaria	Mario
Millet	0.02	0.01	0.01	2.74	2.88	2.70	0.62	0.65	0.66
Small stone (1-2) mm	0.02	0.004	0.01	1.43	1.55	1.48	0.88	0.96	0.94
Medium stone (2-3) mm	0.03	0.014	0.02	2.58	2.17	2.41	0.73	0.77	0.85
Big stone (3- 4.25) mm	0.05	0.04	0.20	3.18	3.10	3.45	0.80	0.79	0.87

Table 5 presents principal dimensions of the three rice varieties at four levels of moisture content. Indicating that there is an increase in axial dimensions as moisture content is increased. This may be due to the fact that as moisture content increases, rice grains tend to swell due to moisture absorption. The effective diameter of rice was found to be higher than the thickness of the grains. Similar findings were reported for millet by [19] sweet corn and maize by [20].

Table 5. Principal dimension of rice varieties at different moisture contents

Rice variety	Kano			Zaria			Mario		
Moisture content (%)	Principal dimensions (mm)			Principal dimensions (mm)			Principal dimensions (mm)		
	length	Width	Thickness	length	Width	Thickness	length	Width	Thickness
10	6.34	1.98	1.68	6.88	2.00	1.69	6.78	1.89	1.96
12	6.50	2.24	1.81	7.24	2.13	1.90	7.38	2.22	2.15
14	7.02	2.44	1.94	7.52	2.34	2.02	7.52	2.52	2.25
16	7.32	2.50	1.98	7.58	2.38	2.26	7.56	2.54	2.30

#### 4 CONCLUSIONS

The physical and mechanical properties of three rice varieties namely Kano, Zaria and Mario were determined and used in the design of a prototype rice destoning machine. However, Buckingham Pi ( $\pi$ ) theorem was used to obtain a functional relationship between the cleaning efficiency and independent variables like feed rate, acceleration due to gravity, amplitude, frequency of oscillation, speed of machine, terminal velocity, bulk density, moisture content and sieve hole diameter.

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