



Design, construction and performance evaluation of a rice destoner

Aremu, A. K.¹, Oyefeso, B. O.¹, Ajao, T. O.^{1*}, Ojo, K.¹, Egbunu, J. O.¹

¹Department of Agricultural and Environmental Engineering, Faculty of Technology,
University of Ibadan, Ibadan, Nigeria

*Corresponding author: ajaotaiwooluwatoyin@gmail.com

ABSTRACT

The market price of local rice in the market is significantly determined by its quality which is dependent on the level of cleaning and some other processing operations. Hence, the need to improve the quality of rice, increase production and reduce human labour has brought about the development of rice destoning machine. Therefore, this study aimed at designing, fabricating and evaluating the performance of a rice destoner. The design was based on the principle of material separation and was constructed from locally-available materials. The machine was powered by a 2hp electric motor and three vibrating screens of varying apertures were used for the upper, middle and lower screens. The machine had an average capacity of 130 kg/h. The performance of the machine was evaluated with 10 kg of *Ofada* rice at 11, 21 and 25% moisture content (dry basis) and 10 kg of *Faro 55* rice at 14, 22 and 27% moisture content (dry basis). The results showed that separation efficiency decreased as the moisture content of rice decreased for both varieties. Cleaning of rice at low moisture content is recommended for optimum performance of the destoner.

Keywords: Rice, Cleaning, Quality, Destoner, Separation efficiency, Moisture content, Performance evaluation.

1. INTRODUCTION

Rice (*Oryza spp.*) is a staple food for more than half of the human race of a hundred million and is very competitive in the world trade. It belongs to the grass family, *Gramineae* (Sweeney and Mccouch, 2007) and has become the second most important cereal in the world after wheat in terms of production due to a decline in maize production (Selbut, 2003). It is highly nutritious with high calorie constituents thus providing more than one-fifth of the calories consumed worldwide by humans (Smith, 1998).

In Nigeria, rice is grown on 1.77 million ha and ranks sixth after sorghum, millet, cowpea, cassava and yam. On a social scale, it can be ranked first because it is no longer just a mere festival meal, but the staple food of most homes both in urban and rural areas (Selbut, 2003).

Locally produced rice in Nigeria has been found to contain some stones, sand particles, debris, chaffs and other impurities which have contributed to its low quality and poor consumer acceptance. The low quality of local rice is one of the factors militating against



its demand and prospect of being exported to generate foreign exchange for the country. These foreign materials or impurities in locally-produced rice are often introduced into rice during harvesting, threshing, handling, packaging etc (Selbut, 2003). Ogunlowo and Adesuyi (1999) reported that the harvest and post-harvest operations of local rice encourage the introduction of contaminants. Mud usually is attached to the stem of rice when uprooted from the soil and thereafter, it dries up to become sand and stones which can only be removed by cleaning. Also, after parboiling, drying is usually carried out under the sun on bare floor, platforms or slabs which could also result in stones and other dry impurities being introduced into rice. Hence, cleaning, as a preliminary operation, must be carried out to remove the unwanted materials or impurities from rice to increase the quality of locally-produced rice and make it more attractive to the consumers.

Cleaning of harvested rice includes operations such as winnowing (for separation of chaff and other light impurities) and destoning (removal of stones and sand particles from rice) which can be done either manually or mechanically with the use of a cleaning machine. Manual or traditional methods of cleaning are time consuming and laborious (Mohammed *et al.*, 2017). These limitations necessitate the need for appropriate technologies for cleaning locally-produced rice. This study therefore, developed a motorised rice destoner with a view to improving the quality of local rice, increasing productivity and reducing the drudgery involved in rice cleaning.

1.1 Review of existing rice destoning machine

Efforts have been made by researchers to design and construct rice destoners with varying separating efficiencies (Henderson and Perry, 1976; Osueke, 1998; Simonyan *et al.*, 2010; Adejuyigbe and Bolaji, 2012; Agidi *et al.*, 2015). Henderson and Perry (1976) designed a grain destoner which uses gravity and floating characteristics between the rice grains and stones. The destoner was made of a triangular shaped perforated table which is subjected to reciprocating motion that moves any material on it in the direction of conveyance due to gravity. Osueke (1998) also designed a rice destoner which separated small stones, sand and metallic impurities from the cleaned rice. Simonyan *et al.* (2010) designed a rice destoning machine on mechanical principles of reciprocating and vibrating sieves. The mixture of rice and stones was fed onto the reciprocating sieve through the hopper where stones smaller than the rice pass through and stones larger than the sieve size fall with the rice onto the vibratory sieve. The vibratory sieve sends the stones in the opposite direction of the flow of clean rice. Average rice and stone separation efficiencies obtained were 74.2 and 70%, respectively. Adejuyigbe and Bolaji (2012) incorporated two vibrating sieves into a destoning machine. The average capacity of the machine was 31,800 kg/h and the average efficiency was found to be 90%. Agidi *et al.* (2015) designed a rice destoner locally powered by a 2 Hp electric motor. The separation of stone from rice was achieved by the horizontal oscillation of the reciprocating screens and the results showed that the machine had 69 and 87% for stone and rice separation efficiencies respectively.



This study therefore, developed a rice destoning machine that incorporates three vibrating sieves for separating rice from small-sized and large-sized stones and a blower (centrifugal fan) to separate chaff and other light impurities from the cleaned rice.

2. MATERIALS AND METHODS

2.1 Development of the rice destoner: description of the machine

The rice destoner was constructed using 2 mm by 2 mm angle iron, galvanized metal and stainless steel of thickness 2 mm and 1.5 mm respectively. It comprises a centrifugal fan which blows off chaffs and lighter impurities and three set of sieves for better separation efficiency. It has two screens (uppermost and bottom) with circular apertures and a middle screen with oblong holes to trap stones that escape the uppermost screen. The screens were tilted at angles between 15° to 20° to the horizontal and the angles could be varied with respect to the speed and efficiency required. The two screens were connected together and mounted on the frame work which connects them to the shaft. The shaft has an auger which conveys rice grains over the upper sieve as it is being fed into it from the hopper. The separation is achieved by an eccentric drive which effects the reciprocation of the middle and lower screens causing it to move to and fro thereby, ensuring the separation of impurities from the rice grains. The rice destoner was powered by a 2 hp electric motor and operates at a speed of 360 rpm. The 3-Dimensional view of the machine is shown in Fig. 1.

2.2 Design considerations and calculations

2.2.1 Belt and pulley design for shaker mechanism

The belt and pulley were designed in accordance with Fenner industrial belt drive manual. A 2 hp electric motor rotating at 1440 rpm was chosen. V-belt type of A-section was selected for the machine.

2.2.2 Design for shaft diameter

The shaft diameter was determined according to Equation 1 (Khurmi and Gupta, 2005).

$$D^3 = \frac{16}{\pi S_s \sqrt{(K_b M_b)^2 + (K_t M_t)^2}} \quad (1)$$

Where: D = Diameter of shaft; M_b = Maximum bending moment, Nm ; M_t = Torsional moment, NM ; S_s = Allowable shear stress, MN/m^2 ; K_b = Combined shock and fatigue factor applied to torsional moment on rotating shaft (Hall, 1988).

The torsional moment was calculated using Equation 2 while the angle of wrap, linear velocity, mass of belt, weight of the pulley and volume of pulley on shaft were determined using Equations 3 to 7, respectively.

$$M_t = (T_1 - T_2) \times r \quad (2)$$

T_1 = Tension on tighter side of the belt on pulley (N); r = Radius of pulley (m)



T_2 = Tension on slack side of the belt on pulley (N);

$$\text{The angle of wrap: } \cos\left(\frac{\theta}{2}\right) = \frac{r_1 - r_2}{l} \quad (3)$$

$$\text{Linear velocity (ms}^{-1}\text{): } V = \frac{2\pi Nr}{60} \quad (4)$$

$$\text{Mass of belt (kg), } m = \rho bt \quad (5)$$



Figure 1. Three-Dimensional view of the rice destoner

$$\text{Weight of the pulley(kg), } W = V \times \rho \quad (6)$$

$$\text{Volume (V) of pulley on shaft} = \pi(R^2 - r^2) \times t \quad (7)$$

Where: θ = angle of wrap (degrees); r_1 = outer radius of the pulley (m);
 = inner radius of the pulley (m); N = rotational speed (rpm); r
 = radius of the driven pulley; ρ = density of steel (7800kg/m³).

The reactions on the shaft were determined using moment of forces and a maximum bending moment of 14.1 kNm was obtained. Hence, the diameter of shaft was obtained as 0.0299 m. Therefore, a shaft diameter of 30 mm was selected.

2.2.3 Design of shaft key for shaker mechanism

The shaft key size was determined using Equation 8.

$$T_s = \frac{S_s}{N} \times W \times L \times r \quad (8)$$



Where: T_s = shearing Stress; S_s
 = Allowable shear stress of 100Mpa for mild steel; N
 = Factor of safety; W = width of Key; L = Length of hub on pulley.

2.2.4 Torsional rigidity of shaft design

Torsional rigidity of solid shaft was determined based on the permissible angle of twist given in Equation 9 (Hall et al., 1988).

$$\theta = \frac{584Mt \times L}{Gd^4} \quad (9)$$

Where: Mt = Torsional moment on shaft; θ = angle of twist (0); L
 = Length of the shaft between point and the applied load and resisting torque (mm); G
 = Torsional modulus elasticity given as 80×10^4 N/m² and d
 = Shaft diameter (mm).

2.2.5 Critical speed of shaft

The critical speed of shaft was determined from Equation 10.

$$W_c = \sqrt{5/4(g/\delta_{max})} \quad (10)$$

Where: W_c = Critical speed in rpm; g
 = Acceleration due to gravity (9.8m/s); δ_{max}
 = Maximum static deflection for a single attached mass.

2.2.6 Bearing Design

Equivalent load on the bearing was determined according to Equation 11 (Hall et al, 1988)

$$\text{Equivalent load, } P = X_o \times F_r + Y_o \times F_a \quad (11)$$

Where: F_a = Thrust load (N); Y = Thrust = 1.48; X = Radial factor = 0.56; Equivalent load factor = 1; F_r = Radial force = 90N (determined).

A bearing corresponding to 145 kN dynamic load (No: P206) was therefore, selected from the bearing chart.

2.2.7 Sieve Design

Osueke (1998) classified the sand particles found in rice into two categories namely, sand and stones. He further classified the sands into fine and coarse, with particle size ranging from 0.2 to 2 mm and 0.02 to 0.2 mm, respectively. The stones ranged from 2.25 to 4.0 mm and the bulk density was given as 1.33 g/cm³. These parameters were the basis on which the sieve sizes were selected.

The upper screen was chosen to be a round-hole sieve with a diameter of 4 mm based on the effective diameter of rice grains which was determined to be 3.8 mm. This would therefore, enable the separation of sand particles larger than 4 mm and permit the grains to fall onto the middle screen. The distance between the holes was determined using the coefficient of open area (C_o) according to Equation 12.

$$C_o = \frac{D^2}{(D+d)^2} \quad (12)$$



Where: width of opening (mm);

d = distance between the elongated sides of the opening (mm)

The middle screen had oblong holes at distance of 3 mm between the adjacent lateral sides of the openings. This would enable the rice grains to pass through unto the lower sieve due to its shape and stones of particle sizes above 3mm were trapped. The coefficient of opening of this sieve was determined using Equation 13.

$$C_o = \frac{DL - 0.22D^2}{(D-d)(L+d_1)} \quad (13)$$

Where: L = length of opening (mm);

d_1 = Distance between the adjacent lateral sides of the opening, mm.

A round hole sieve was selected for the lower screen with a diameter of 2 mm. This sieve is expected to trap the rice grains since the effective diameter of rice is 3.8 mm (Akintunde and Tunde-Akintunde, 2007) and allow the passage of the sand particles of sizes less than or equal to 2 mm. The coefficient of opening was also determined using Equation 12 as in the uppermost screen.

2.2.8 Fan Pulley and Belt drive design

The belt was designed in accordance to the Fenner standard industrial belt drives for a one step pulley. On the assumption that machine will run for less than 10 hrs per day, a service factor of 1 was chosen. Belt designed power was determined as 1.5 kW and the belt section of 80 mm. At 1:1.6 speed ratio, diameters of 100 and 160 mm were selected for the driving and driven pulleys, respectively. The center distance was calculated using Equation 14.

$$C = 2 \times \sqrt{(D + d) \times d} \quad (14)$$

Using a correction factor = 0.87, V belt A1250 was selected.

2.2.9 Auger design

The auger was designed using rapid screw conveyor design chart. The flight diameter, screw diameter, rubber pad diameter, shaft diameter and housing diameter were 78, 240, 5, 30 and 258mm respectively. The screw clearance of 13mm was chosen.

2.3 Performance Evaluation

The performance of the rice destoner was evaluated in terms of separation efficiency. The machine was operated at a speed of 360 rpm and its using 10 kg of the locally produced *Ofada* rice at 11, 21 and 25% moisture content (dry basis) and 10 kg of Faro 55 rice at 14, 22 and 27% moisture content (dry basis) to determine the influence of moisture content on the separation efficiency of the machine. The efficiency of the machine was calculated using the procedure used by Okunola *et al.* (2015).

2.3.1 Procedure for Evaluation

The initial moisture content of the rice grain was determined using oven drying method. This involved drying of a sample of known weight in the oven at a temperature of about 103⁰C until three consecutive weights were constant. The moisture content was determined using Equation 15.



$$MC = \frac{W_w - W_d}{W_d} \times 100 \quad (15)$$

Where: *MC* is the moisture content (% dry basis);
W_w is the wet weight of the sample (g) and *W_d* is the dry weight of sample (g).

The initial moisture content of the two varieties of rice was varied by using Equation 16 (International Rice Research Institute, 2009).

$$Q = \frac{A(b-a)}{100-b} \quad (16)$$

Where: *Q* = Mass of water to be added (kg); *A* = Initial mass of sample (kg);
a = Initial moisture content of sample (% dry basis);
b = Final moisture content of samples (% dry basis)

The required mass of water was mixed with the appropriate mass of rice available to obtain the desired moisture content. Separation Efficiency (SE) of the machine was calculated using Equation 17.

$$SE = \frac{\text{Good Product}}{\text{Total Product}} \times \frac{\text{Bad reject}}{\text{Total reject}} \quad (17)$$

3. RESULTS AND DISCUSSION

3.1 Results of performance evaluation of the machine

The evaluation was carried out by destoning two different varieties of rice at three different moisture contents. The separation efficiency obtained for *Ofada* rice and *Faro 55* rice at different moisture contents are presented in Tables 1 and 2, respectively.

Table 1. Results obtained for *Ofada* rice

Moisture content (%)	Efficiency (%)	Time taken (mins)	Capacity (kg/hr)
11	81.16	4.42	135
21	77.41	4.98	120
25	68.72	5.17	116

Table 2. Results obtained for *Faro 55* rice

Moisture content (%)	Efficiency (%)	Time taken (mins)	Capacity (kg/hr)
14	85.96	4.00	150
22	77.42	4.50	133
27	74.41	5.00	120

3.2 Effect of moisture content on machine efficiency separation

The separation efficiency of the machine decreased as the moisture content of the rice being destoned increased for both varieties of rice. Variations in separation efficiency with



moisture content are presented in Fig. 2 and for Faro 55 and *Ofada* rice, respectively. It can thus be deduced that the machine performed better at lower moisture content of rice for both varieties of rice. The highest separation efficiencies of 85.96 and 81.16% were obtained for Faro 55 and *Ofada* rice, respectively. Reduced efficiencies as the moisture content of rice increased may be as a result of excessive clogging of the screens at higher moisture levels.

3.3 Effect of moisture content on capacity

An increase in the moisture content results in a longer destoning time which invariably decreased the capacity of the machine. There existed increased difficulty of the grains to slide on the sieve as the moisture content increased due to increasing coefficient of friction and angle of repose of both rice varieties on the surface of the screens (Aghajani, 2012). This increase in time taken can also be attributed to clogging of the screens in the machine which can also reduce the screening efficiency of the vibratory screens in the machine (Ortega-Rivas, 2012).

4. CONCLUSIONS

Rice destoner has been designed and constructed from locally-available materials. The machine was evaluated to determine its performance on rice at different moisture levels. Higher separation efficiencies and machine capacities were obtained at lower moisture contents for Faro 55 and *Ofada* rice varieties. The total cost of the machine was ₦200,000 which can be considered to be relatively more affordable for rice farmers when compared to the imported ones.

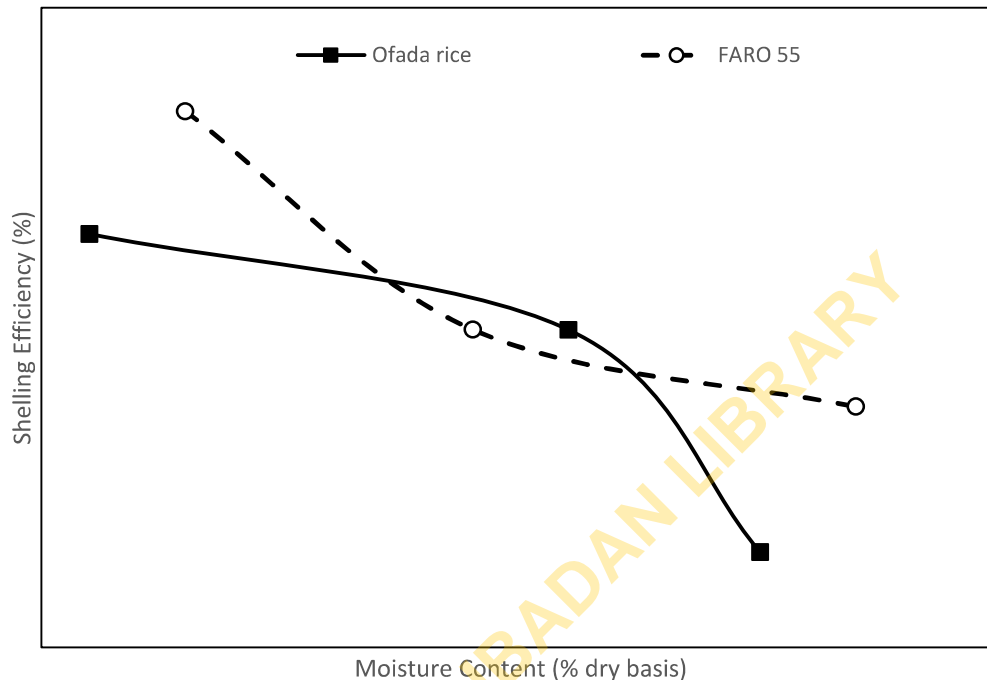


Figure 2: Separation Efficiency for Ofada and Faro 55 rice

5. REFERENCES

- Adejuyigbe, S. B. and Bolaji, B. O. 2012. Development and Performance Evaluation of a Rice Destoning Machine Using Vibrating Sieves. *Journal of Natural Science, Engineering and Technology Agricultural Mechanization in Asia, Africa and Latin America*, 30(1): 20-24.
- Aghajani, N., Ansaripour, E. and Kashaninejad, M. 2012. Effect of Moisture Content on Physical Properties of Barley Seeds. *Journal of Agricultural Science and Technology*, 14: 161-172.
- Agidi, G., Ndagi, B., Kuku, A. M., Abdullahi, L. 2015. Development and Testing of a Rice Destoning Machine; *International Journal of Engineering Research and Science and Technology*, 4(3): 134-141.
- Akintunde, B. O. and Tunde-Akintunde, T. Y. 2007. Effect of moisture content and variety of selected properties of benniseed. *Agricultural Engineering Internals: The CIGR E-Journal manuscript, FPO 7021, Vol. IX*.
- Hall, A.S., Holowenko, A.R., Laughlin, H. G. 1988. Theory and problems of machine design, Schaum's Outline Series. S.I. (Metric) Edition, McGraw-Hill Book Company, New York.



The Proceedings 12th CIGR Section VI International Symposium 22 –25 October, 2018

- Henderson, S. M. and Perry, R. L. 1976. *Agricultural Process Engineering* 3rd Edition. The Avi Publishing Company, Incorporated, Westport, Connecticut. Pp. 170 – 189.
- International Rice Research Institute. 2009. Measuring quality of paddy. Rice knowledge bank. <http://www.knowledgebank.irri.org>
- Khurmi, R. S. and Gupta, J. K. 2005. *A textbook of machine design*, 25th Edition. S. Chand and company Ltd, New Delhi.
- Mohammed, G. Y., Adeshina, F., Kail, K. K. and Ucheoma, O. C. (2017). Performance evaluation and Modification of an existing rice destoner. *International Journal of Engineering Technologies*, 3(3): 169-175.
- Ogunlowo, A. S. and Adesuyi, A. S. 1999. A low cost rice cleaning/destoning machine. *Agricultural Mechanization in Asia, Africa and Latin America*, 30(1): 20-24.
- Okunola, A. A., Igbeka, J. C. and Arisoyin, A. G. 2015. Development and evaluation of a cereal cleaner; *Journal of Multidisciplinary Engineering Science and Technology*, 2(6): 1587-1592.
- Ortega-Rivas, E. 2012. *Unit operations of particulate solids: Theory and practice*. CRC, Taylor and Francis Group, 6000 Broken Sound Parkway NW, Suite 300, Boca Raton, USA.
- Osueke, C. O. 1998. Design and Construction of a Rice Destoner. Unpublished M.Eng. Project, Department of Mechanical/Production Engineering, Enugu State University of Science and Technology, Enugu State, Nigeria.
- Selbut, R. L. 2003. Rice production in Nigeria. Literature Review. Multi-agency partnerships in West African agriculture: a review and description of rice production systems in Nigeria. <http://www.odi.org>
- Simonyan, K. S., Emordi, I. S. and Adama, J. C. 2010: Development of a locally designed rice destoning machine; *Journal of Agricultural Engineering and Technology* 18(1): 74-80.
- Smith, B. D. 1998. *The Emergence of Agriculture* Scientific American Library, A Division of HPHLP, New York, ISBN 0-7167-6030-4.
- Sweeney, M. and Mccouch, S. 2007. The complex history of the domestication of rice. *Analns of Botany*, 100: 951-957.