DOI : https://dx.doi.org/10.26808/rs.ed.i10v2.02
International Journal of Emerging Trends in Engineering and Development Issue 10, Vol.2 (Feb-Mar 2020)
Available online on http://www.rspublication.com/ijeted/ijeted_index.htm ISSN 2249-6149

Design, Development and Performance Evaluation of a Mobile Rice Threshing Machine

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ABSTRACT
Mobile motorized rice threshing machine comprises of the prime mover (combustion engine), the blower, the threshing unit, discharging unit, and threshing basket. It was developed using locally sourced materials to reduce drudgery in the threshing of rice, infiltration of stones and other debris, as well as breakage and enhance production of adequate quantity and quality of processed rice. Performance test analysis that was carried out, revealed average throughput and threshing efficiency for mobile motorized rice thresher are 82.9kg/hr and 92.7% respectively while manually powered rice thresher throughput is 33.3kg/hr and its threshing efficiency is 66.7%. Thus, the Mobile Motorised rice thresher is a veritable option for both medium and large scale rice production.

1.0 INTRODUCTION AND BACKGROUND

Rice is the seed of a grass species called Oryzasativa. It is a monocot crop normally grown for a year but in tropical areas, it can survive as a perennial crop (IRRI, 2009). Rice is a stable food for majority of the world's population. More than 40% of the rice consumption in West Africa is imported, which represents 2.75 million tons per year (Barris et al., 2005). Worldwide there are different varieties of rice species names like Oryzasativa, doongara, jarrah, kyeema, reizip are a few species (IRRI, 2015). It is estimated that rice sustains the livelihood of 100 million people and its production has employed more than 20 million farmers in Africa (WARDA, 2005). Rice crop production originated from China and was spread to countries such as Sri Lanka and India. Rice is a commodity with the third-highest worldwide production after sugarcane and maize (FAOSTAT, 2012). Rice consumption has been increasing over the years with population growth; hence rice continues to be part of the main diet in most homes due to its relative convenience in preparation and palatable recipes.

Nigeria is one of the countries that engage in rice production enabled by its soil and found to be rich in protein, carbohydrates, vitamins and minerals: for instance the Abakaliki rice, Ofola rice and the Igbemo rice in Ekiti State etc. This rice when processed would have passed through different stages of processing which threshing is involved. The threshing machine was first invented by a Scottish mechanical engineer by name Andrew Meikle (Correa et al., 2006). It was devised (c.1786) for the separation of grain from stalks and husks. Rice threshing machine can be put into two main categories with types. The motorized and manual rice threshers. Example is the ASI type for the motorized and the TCC/IDDS manual rice thresher (ARC, 2006).

Threshing is an integral part of post-harvest activities for rice processing but the manual system of threshing rice in Nigeria leads to low quality of paddy rice and grain loss. While the rice demand increases, the manual threshing consequently becomes arduous even with the already existing mechanized system, the rough nature of Nigerian farm terrain still poses a challenge to the harvested rice. The need to do different performance evaluation of rice threshing machines (rice thresher) with consideration of the terrains of the farmland in these areas becomes essential so as to address the challenges hampering the production of adequate quality and quantity of processed rice. The thresher reduces the drudgery associated with the manual harvesting of paddies with the winnower removing the premature grain and leaves by the help of a suction blower. These premature grains and leaves are often lighter thus leaving aside the massy grains that will be collected.

Currently, Nigeria spends Billions of Naira annually on rice importation to argument local demand. The country's self-sufficiency in rice production stands at about 40 per cent, leaving a shortfall of 60 percent. However, local farmers involved in rice production in Nigeria still use outmoded means of threshing. Thus, using wood logs as implement to aid in the threshing. Aside from being labour intensive, the post-harvest losses are huge. Studies has shown that threshing losses were higher (6.14%) when threshing was done using the "Bambam" box (a big locally made wooden box) than when bag beating method (2.45%) was used (Ramatoulaye, 2010). Hence, this research will give the design analysis, development, and as well evaluate the performance of a mobile rice threshing machine designed for Nigerian farmland.

1.1 Objectives and Scope of Study

Specific objectives of this study are to;

i. Design and develop a mobile rice threshing machine.
ii. Performance evaluation of the machine.

1.2 Justification

The development of the mobile rice threshing machine will definitely make the processing of rice more economical in terms of labour, time and cost since drudgery will be reduced. Moreover, the profit margin of rice investor will be enhanced because excessive waste of unthreshed rice which characterized this sector will be totally phased out. This will also provide employment for the populace and increase the external trade potential of Nigeria, as the prospect of mass production of Nigerian local rice and their exportation will be enhanced.

2.0 DESIGN ANALYSIS AND SPECIFICATIONS OF THE MOBILE RICE THRESHING MACHINE

2.1 Design Concepts and Considerations

1. The machine was designed to separate the rice grains from the stalks in a manner to minimize absolutely their breakage and enhance the production of adequate quality and quantity of processed rice.
2. The effective moving system that will suit Nigerian farm terrain was incorporated as well as the air separating unit to separate the rice grains from the stalks.

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2.2 -Determination of Torque Required to Comb off Grains from the Stalk

Torque; T = Fr

(1)

Where T is torque, F is force and r as radius respectively.

Assuming that force acts per unit length of tong, taking force per 10mm segment of length.

2.3 Determination of Power Required to Thresh off Grains from Stalk

The power is determined as 16.19W from the equation 2,

P = Tω

(2)

Where ω is angular velocity in rad/s, T is torque and P as power respectively.

2.4 Determination of Feed Roller Speed

$$N_f = \frac{r_1}{r_2} \text{ x } N_{cs} \quad (3)$$

Where N_f is feed roller speed

$\frac{r_1}{r_2}$ is speed ratio of pulley on comb shaft to the pulley on feed roller shaft,

N_{cs} is speed of radial comb

2.5 Shaft Design Consideration and Analysis

The diameter, *d* of the rice threshing machine transmission shafts was determined from the maximum stress relations given by Khurmi and Gupta (2005) in equation 4.

$$d = \left[\frac{16}{\pi\tau}\sqrt{(k_b m_b)^2 + (k_t m_t)^2}\right]^{1/3} \quad (4)$$

Where; τ= allowable shear stress for steel shaft with provision for keyways = 50N/mm^2; m_t= maximum twisting moments on the shafts; m_b= maximum bending moment on the shaft; k_b= combined shock and fatigue for bending; k_t= combined shock and fatigue factor for twisting. The maximum twisting moments on the threshing drum shaft and blower shaft where determined respectively using the Equation given by Khurmi and Gupta (2005) in equation 5.

$$M_t = (T_i - T_j)\frac{D_2}{2} \quad \text{--} \quad (5)$$

The maximum bending moment on the driving conveyor shaft was computed as 10217.34N-mm using its force diagram shown in Fig. 1;

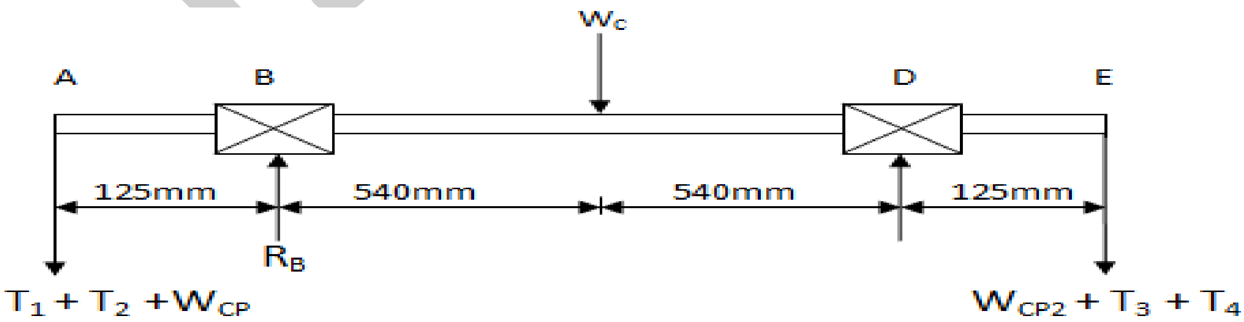

Fig 1: Force diagram of the driving conveyor shaft

Where, the shaft/roller weight, W_c = 328.44N, rolling peeler/conveyor driven pulley weight, W_{cp} = 17.05N, tight side tension of conveyor/feeder drive belt, T_1= 169.93N while its slack

side tension, T_2 = 14.34N, T_3 =169.19N and T_4 = 2.97N are the respective tight and slack side tensions of the rolling peeler/conveyor drive belt. The reactions at B and D were therefore computed by taking moment about B as 215.74N and 203.03N respectively. The bending moments on this shaft were computed as 0 at A and E; 3072.97N-mm at C and 10217.34N-mm at D. Thus, the shaft diameter was computed as 13.6mm using Equation (10) since it involves gradual loading, k_b = 1.5 and k_t=1.0 (Khurmi and Gupta, 2005). Hence, standard 15mm diameter mild steel solid shafts were selected and used for operating the conveyor belt.
Figure 2 shows the loads on the feeder shaft where W_F (28.84N) is the shaft/roller weight, W_{pF} (17.11N) is conveyor/feeder shaft driven pulley weight.

The shaft is cylindrical with circular cross sections and sprockets and bearings on them. The shaft will be subjected to fluctuating torque and bending moments, and therefore combined shock and fatigue factors taken are taken into account.

i. Shaft subjected to twisting moment only

Torsion equation,

$$\frac{F_t}{r} = \frac{T}{J} = \frac{C\theta}{L} \qquad (6)$$

Where, f_t = torsional shear stress
R = distance from neutral axis to outermost fibre,
T = twisting moment (or torque) on shaft
J = polar moment of inertia
C = modulus of rigidity of shaft material
L = length of shaft
θ = angle of twist in radius on length, l
(ASME 1995).

Polar moment for round solid shaft

$$J = \frac{\pi}{32} \times d^4 \qquad (7)$$

For $r = \frac{d}{2}$ and $f_z = f_t$

$$\frac{T}{\pi 32} \times d^4 = \frac{ft}{\frac{d}{2}}$$

$$T = \frac{\pi}{6} \times f_t \times d^3 \qquad (8)$$

Twisting moment, t can be obtained from

$$P = \frac{2\pi NT}{60} \qquad (9)$$

Where, N = speed of shaft in rpm in the case of belt drive,

$$T = (T_1 - T_2)R \qquad (10)$$

Where, T_1 and T_2 are tensions on the right side and slack side of the belt respectively
R = radius of pulley
From P = Tω in equation (2);

But $T = \frac{\pi d^3 ft}{16}$

ii. Shaft subjected to bending moment only,

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Bending equation is given by

$$\frac{M}{I} = \frac{F_b}{Y} \quad (11)$$

Where, M = bending moment

I = moment of merits of cross-sectional area of the shaft about axis of rotation.

f_b = bending stress

y = distance from neutral axis to outermost fibre

$$\text{but } I = \frac{\pi d^4}{64} \quad (12)$$

$$\text{then } M = \frac{f_b}{y} \times I$$

$$= \frac{f_b}{y} \times \frac{\pi d^4}{64}$$

$$\text{But } y = \frac{d}{2}$$

$$M = \frac{\pi d^3 f_b}{32} \quad (13)$$

(for solid shaft)

For bending moment M = Torque T

iii. Shaft subjected to combined twisting and bending moments based on maximum shear stress theory.

$$F_x(\max) = \frac{1}{2}\sqrt{(f_b)^2 + 4(f_t)^2} \quad (14)$$

$$\text{but } f_b = \frac{My}{I} = \frac{32M}{\pi d^3}$$

$$\text{and } f_x = \frac{16T}{\pi d^3}$$

Substituting into the previous equations;

$$F_s(\min) = \frac{1}{2}\sqrt{\left(\frac{32M}{\pi d^3}\right)^2 + 4\left(\frac{16T}{\pi d^3}\right)^2} \quad (15)$$

$$d = \frac{16\sqrt{M^2+T^2}}{\pi f_s} \quad (16)$$

2.6 Determination of Belt Length

The belt length, L required were respectively computed as 1590mm and 1200mm combustion engine/threshing drum shafts, and feeder/blower shafts, from the following relations given by Sharma and Aggarwal (2006) as;

$$L = 2C + 1.57(D_1 + D_2) + \frac{(D_2 - D_1)^2}{4C} \quad (17)$$

Since, none of the drives transmits more than 3.75kW each, type ‘A’ v-belts were selected and used in each of them. Thus, belts of standard pitch lengths were selected based on IS: 2494-1974 for the combustion engine/threshing drum shafts and feeder/blower shafts respectively. Consequently, the exact centre distances between the adjacent pulleys used in the fabrication of this machine were also determined 275mm, and 365mm for the combustion engine shaft, threshing drum shaft, feeder shaft and blower shaft respectively (Khurmi and Gupta, 2005) from Equations (17).

Considering fig. 2.

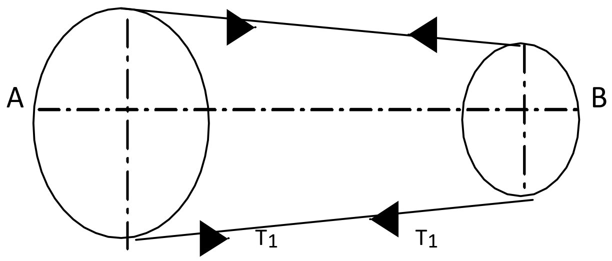

Fig.2 Power transmitted by belt

Effective driving (turning) force, is given by

$T_1 = T_2$

Power transmitted is given by, $P = (T_1 – T_2)V$ (18)

Where;

T_1 is Tension in the tight side in N

T_2 is Tension in the slack side N

V is velocity of belts in m/s

2.7 Determination of drum (flange) diameter

The drum or flange was determined as 404837mm using the equation below

$$D = \frac{UAT_S N_b}{\pi} \quad (19)$$

Where D is Diameter of drum/flange

U is peripheral velocity of the drum, 4mm/s

N_b is number of beaters, 60

AT_s is time interval per successive strikes, 5.3×10^3 sec and π= 3.142

2.8 Determination of drum (flange) speed

The drum speed was determined as 1040rpm from the equation below:

$$VR = \frac{N_1}{N_2} = \frac{D_2}{D_1} \quad (20)$$

Where; N_1 is speed of rotation of smaller sprocket, 2600rpm

N_2 is speed of rotation larger sprocket,

D_1 is diameter of smaller sprocket (combustion engine pulley), 100mm

D_2 is diameter of larger sprocket (threshing drum shaft pulley), 250mm

2.9 Determination of blower speed

The speed of the blower speed is determined to be 1600rpm from the equation below

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \quad (21)$$

2.10 Selection of Drive Pulleys and Belts

The rice threshing machine uses a total of four pulleys for its drives, one each mounted on the combustion engine, threshing drum shaft, feeder shaft, and the last on the blower shaft. Due to its availability, cost and performance, mild steel pulleys were selected. The respective diameters of the selected driver and driven pulleys for the combustion engine shaft, threshing drum shaft, feeder shaft, and blower shaft are 100mm, 250mm, 200mm and 130mm respectively. The speed of the combustion engine is 2600rpm, thus, the speed of the driven pulleys of the threshing drum shaft, and blower shaft are determined as 1040rpm and 1600rpm respectively from the relation given by Khurmi and Gupta (2005) in equation 22.

$$N_1 D_1 = N_2 D_2 \tag{22}$$

Where N_1 and N_2 are the respective driving and driven pulleys' speeds while D_1 and D_2 are the corresponding diameters of the pulleys. The centre distances, C between the driving and driven (adjacent) pulleys were determined from Equation (23) as 475mm, and 365mm for the combustion engine shaft, threshing drum shaft, feeder shaft and blower shaft respectively (Khurmi and Gupta, 2005) in equation 23.

$$C = \frac{D_1 + D_2}{2} + D_1 \tag{23}$$

2.11 Determination of the Velocity Ratio of the Pulleys

The velocity ratio of the pulleys is defined as the revolution per minute of the driven divided by the revolution per minute of the driver. The velocity was determined as 34038.33 using the formula below;

Velocity Ratio, V.R = dist. moved by Effort /dist. moved by Load = distance moved by Driven Pulley/dist. moved by Driver Pulley

$$V.R = \frac{\pi DN}{60} \tag{24}$$

Where; N and D are Speed of prime mover and diameter of pulley respectively.

3.0 DEVELOPMENTAL PROCEDURE/DESCRIPTION OF THE MOTORIZED MOBILE RICE THRESHING MACHINE

The major components of the developed rice threshing machine (Fig. 3) include prime mover (combustion engine), blower, threshing basket, sieving and threshing units. The detailed production drawings for this machine fabrication are contained in the Appendix.

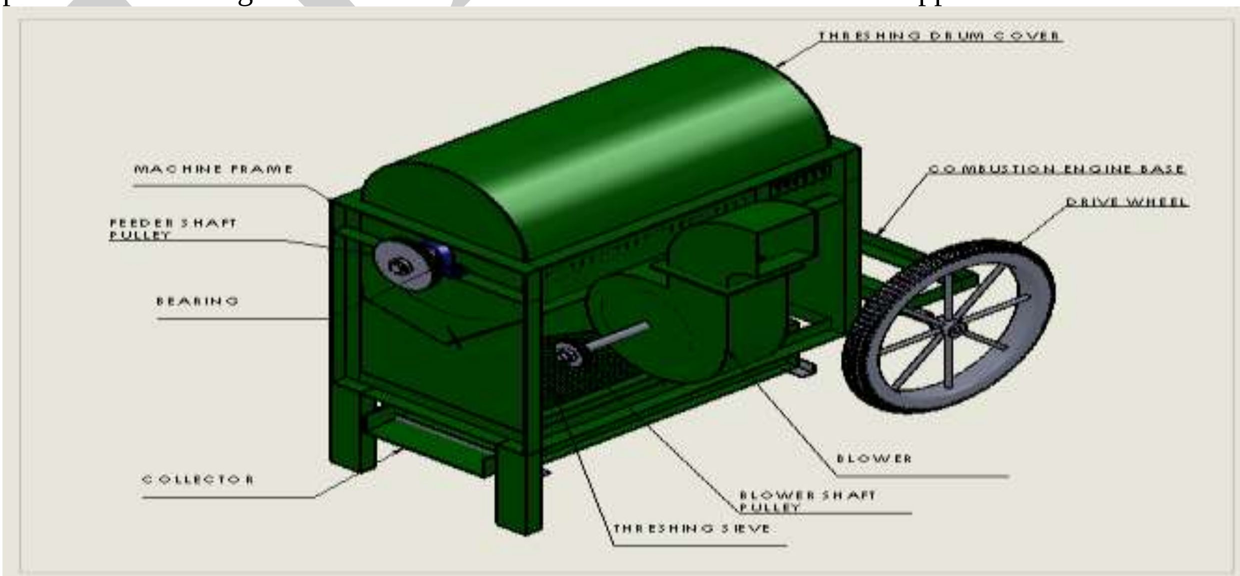

Fig. 3: Motorized Mobile Rice Threshing machine

These components were assembled on a structural frame made from a 50mm mild steel angular bar. The prime mover (combustion engine) drives the primary shaft of the threshing unit which in turn drives the feeder shaft unit that turns the blower shaft.

The motorized rice powered by combustion (diesel) engine as prime mover of power 4.41kw and at a speed of 2600r/min. The dimension of the rice thresher reads 1020 × 650 × 800 mm. The threshing unit consists of a rotating cylinder called the threshing drum with a diameter of 320mm and 960mm by length. It has flange on which a flat bar of 960mm x 50mm x 5mm is welded on it. On top of it is a threshing pin of diameter 12mm at 75mm length. The configuration of the threshing pin is in spiral form to also act like a conveyor, directing the straw through the outlet. Below the threshing drum is the threshing basket of 5mm spacing through which threshed paddy is collected. The rice threshing machine comprises three main units; the feeder chamber, the threshing chamber and the separation chamber.

The feeder chamber – this unit comprises of the hopper with the internal having a conveyor like attachment to give direction to the rice stalk while being threshed on the rotation of the shaft.

The threshing chamber – this comprises of the threshing pin which is made up of a shaft running through a flywheel with a flat bar welded across each flywheel from one end to another, which small rods are bolted on in a line at intervals in spiral direction. Each of the small rods is bent at the tip. The shaft is held by a bearing at each end with a pulley attached to the ends of the shaft for drive. The pulley/shaft rotates in the direction of carve of the threshing pin. Under the tip of the threshing pin is a threshing basket with an external slant called a sloppy tray that slopes downwards into a sieve. The sieve is attached with a cam to the main frame of the thresher so as to enable it to swing with vibrations for final collection of threshed rice grain.

The blower chamber – the blower is located under the threshing barrel at a point opposite the sloppy tray. It is a suction blower which takes the stalks or empty pods off from the system by sucking as separation is by gravity since the massy rice grains weighs more than the stalk.

The blower consists of am impeller shaft, volute casing and hose. The impeller is an open type fabricated from a 2mm thick mild steel plate with six vanes (each made from 1.5mm slitted plate) which created suction in the blower. The impeller shaft is a 400mm long mild steel rod with a diameter of 30mm. The casing which houses the impeller was formed using a 1.5mm thick, 20mm width squared formed mild steel plate with an 'eye' diameter of 18mm for atmospheric air intake and air vent width of 800mm through which a 2mm thick, 35mm long curved and 20mm diameter metal hose that connects the blower to the metal valve below the slating trays was fixed. The developed rice threshing machine requires two operators and can be operated manually or powered with a prime mover.

3.1 Performance Testing Procedure

Un-threshed rice varieties collected from the Abakaliki areas will be used for evaluation of the machines. Evaluations of the machines will be carried out at speeds 1040rpm. The engine power was designed to be 4410W. The shaft diameter and length are given to be 50mm and 1330mm respectively. The un-threshed rice will be weighed to determine the weight before loading into the machine. The weighed samples of un-threshed rice will be fed through the hopper into the threshing chamber. The threshed rice will be weighed after threshing to know the quantity of threshed rice and the threshed yield was calculated to obtain the total losses, threshing efficiency, cleaning efficiency, input and output capacities, grain recovering range (GRR), capacity utilization (CU), threshing index

(TIX) and threshing intensity (TIN) in accordance with the draft Nigeria standard test code for grain threshers (NCAM 1990). The performance evaluation will be carried out more times to obtain the average performance of the machine

3.2 Thresher efficiency and Throughput

This is the ratio of mass collected at the outlet to the mass inputted into the thresher

$$\text{Threshing Efficiency} = \frac{M_{tr}}{M_{tr}+M_{utr}} \times 100 \quad (26)$$

$$\text{Throughput (1hr)} = \frac{M_{tr}+M_{utr}}{\text{time (hr)}} \quad (27)$$

It is given

Where η (%) = Threshing efficiency

M_{tr} =Mass of Threshed Rice after Threshing

M_{uta} = Mass of Un-threshed Rice after Threshing

M_{tb} = Mass of Un- threshed Rice before Threshing

4.0 RESULTS AND DISCUSSION

The Rice Threshing machine performance test results shown in Tables 1 showed that its respective throughput and efficiency at a fixed speed of 1000rpm is 170.2kg and 62.5.% and its throughput and efficiency at variable speeds is 82.9kg and 92.7% when electrically powered. And when manually powered, its throughput and efficiency is 33.33kg and 66.7% respectively. Thus, the developed motorized mobile rice threshing machine has a very good throughput, cleaning efficiency and threshing efficiency for mass production. It is also affordable and energy saving.

Table 1: Comparative Analysis of the Performance of Mobile Rice Thresher (Motor Powered) and Rice Thresher (Manually Powered)

	Mobile Rice Threshing Machine (Motor Powered) at Variable speeds	Mobile Rice Threshing Machine (Motor Powered) at Fixed Speed of 1000rpm	Rice Threshing Machine (Manually Powered)
(%) of Un-threshed Grain	2.22	5.00	20.00
Percentage cracked & broken grain	1.11	1.25	6.60
Cleaning efficiency (%)	98.89	99.0	83.30
Threshing efficiency (%)	92.70	62.5	66.70
Sieve loss (%)	1.11	6.2	6.66
Total losses (%)	4.44	12.7	33.26
Grain Recovery Range (%)	98.00	96.67	90.00
Capacity Utilization (%)	90.00	53	66.60
Threshing Index ($kwkg^{-1}$)	0.045	0.0241	0.025
Threshing Intensity	4.90	5.50	4.41
Throughput (kg/hr)	82.90	170.20	33.33

4.0 CONCLUSION AND RECOMMENDATION

A mobile rice threshing machine was designed, developed and its performance evaluated at Enugu State University and Technology, Enugu using locally sourced standard materials. The machine eliminates drudgery and tedium in the processing and production of local rice as well as the excessive loss of rice grains during production. The machine equally reduced the breakage of rice grains and enhanced the production of adequate quality and quantity of processed rice. Adoption of this machine is recommended to facilitate mass production of rice as well as its possible exportation.

ACKNOWLEDGEMENTS

Funds and facilities support received from ESUT/Tertiary Education Trust Fund, Abuja, Nigeria is well acknowledged with gratitude.

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