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Design and Development of Double Spindle Rice Threshing Machine

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ABSTRACT

The Double spindle rice threshing machine was designed to ease the suffering of local farmers during harvesting as a result of the higher cost, low output and loses associated with the traditional method of rice farming. The combination of its operational mechanisms makes it unique as compared to the existing once based on the different variety of rice threshed and the level of moisture content of the product. Jamila rice variety has the highest threshing efficiency of 96% while Faro 52 has the lower efficiency with 85% with the power requirements is 4.0 Kw. Operationally the rice paddy is fed in to the threshing chamber through the hopper, the grains are collected at the grain discharger and the chaff (straw and husk) is blown away through the husk discharge unit. The Machine which is supported on two rear wheels and two support jacks at the front and a towing bar for easy transportation to even the remotest farm fields can be easily adopted by Small and Medium Scale Farmers.

Keywords: Rice thresher, Design, Double spindle, Farmers, Moisture content

1.0 INTRODUCTION

A rice threshing machine is machine used to bring out rice grain from rice straw in the farm which will be ready for further processing known as milling. It has been observed that one of the most important cereals across the sub Saharan Africa and even the entire population of the Asia is rice products. Rice is cultivated in almost all parts of the globe including Nigeria. By 2015, it has been estimated that over three-fifth of the world population will depend on rice as their staple food (Echiegu, 2009). Rice in Nigeria is primarily an urban middle-class product. The total market is an estimated 5 million tons in 2007, approximately two-third of which is urban and the rest rural. Estimated annual production is 3.4 million and the rest is imported. Again approximately two-third of urban demand is met by imports (KPMG, 2019). There is a growing market for rice in Nigeria. This is as a result of a growing population of about 195 million people (estimated) and an average annual growth projection of 2.6% over the last 10 years. With rapid population growth expected to exceed 200 million by 2019, it is expected that the demand for rice will be sustained and increased in the foreseeable future. Rice is cultivated in all Nigeria's agro-ecological zones, from the mangrove swamps of the Niger Delta to the dry zones of the Sahel in the North. However, the North West accounts for 72% of total rice production. A total land area of 3.2 million hectares was harvested by 1.43 million farmers in the 2018/2019 season. (KPMG, 2019).

Rainfed lowland is the most predominant rice production environment covering 47% of cultivated area and accounting for over 50% of the total rice produced in Nigeria, while rainfed upland rice (30% cultivated area, 17% domestic production), irrigated systems (17% cultivated area, 27% domestic production), deep water and mangrove swamp environments (6% cultivated area, 4% domestic production) are the rice production environments in Nigeria. Rice is an essential cash crop for small-scale farmers who commonly sell 80% of total production and consume only 20%. Rice generates more income for Nigerian farmers than any other cash crop in the country. The two types of rice mainly cultivated in Nigeria are the African Rice (Oryza glaberrima) and the Asian rice (Oryza sativa). In recent times however, new hybrid varieties have been introduced such as NERICA (KPMG, 2019).

Half of local the rice is channeled through the small-scale processors and medium commercial processors. The major steps involved in rice processing after harvesting include threshing, pre-cleaning, destoning, parboiling, milling/dehusking, husk separation, whitening, polishing, grading, colour sorting and bagging. Rice threshing is the first and important unit operation carried out on the paddy straw to remove paddy from the straws after harvesting (Sarafadeen et al, 2021). National rice production growth is 15% per annum (FAO) and growth of national demand is 20% per annum. Imported rice sets the standard in the market in terms of price and quality (in terms of cleanliness,whiteness, consistency, breakage and being free of stones). In principle locally produced and processed rice can compete with imports at an estimated sales price of NGN 300/measure (vs. NGN 450/measure for imports) by improving the quality of local rice (Propcom DFID, 2010). However, the present inflation makes the price per measure of rice grain to become NGN 2700 (vs. NGN 3500/measure for imports). The genus oryze signifies the family with satia in Asia and glaberima in Africa. However, rice threshers developed are not affordable or easily accessible and varies from the manually operated to the more advanced machines used in large government and commercial installations. Mechanized threshing has the potential to significantly improve productivity and develop to an industry capable of producing rice of acceptable quality (Adefidipe & Adetola, 2022). In rural areas, only some organized personnel involve in the manual threshing with sticks and drum. This is because there no means of getting the mechanized threshing method, or even if there are, it is not affordable by common farmers. In this work, locally available materials were sourced and basic engineering principles were applied to design and construct a portable and affordable rice thresher for our local farmers. Therefore, we looked at previous studies which are not affordable to our local farmers because of the high cost of importation and maintenance, coupled with large size of the designs and huge materials demand for fabrications. To bridge this gap, we employ a novel approach of reducing the size by making some workable assumptions in the design of the present work. This has given us the opportunity to design and construct a small, affordable and efficient product that contributed to the agricultural value chain. This innovation has contributed to the boost in agricultural activities in our communities.

2.0 MATERIALS AND METHODS

2.1 Materials

The materials required are sourced locally and are readily available for use in our market. They are: - Sheet metal (Mild steel), Angle iron (Mild steel).

2.2 Methods

Locally available materials were used for the construction and some mechanisms were incorporated to thresh rice plant in to a fine finished crop ready for milling. The construction involved the following operations; Measurement, Cutting Joining, Folding, Drilling and Welding. The construction was done in the following phases. Construction of threshing chamber, feeding unit, separation system and drive mechanism. Design analysis is the most important aspect in a project work, therefore we first considered the theoretical analysis. The thresher was design to carries two shaft which comprises the threshing shaft and the winnowing shaft. When power is delivered to the shaft, torque is set up within shaft and permits power to be transmitted (Khurnu & Guptar, 2011). In this work, solid shaft of mild steel was required with a predetermine length of 1500mm based on the width of frame of the thresher. Also the following specification are predetermined in the design consideration due to the requirement for low cost of production, local material utilization and portability for our local farmers. Therefore the consideration and assumptions are:-

i. Height of thresher 1000mm

ii. Width of thresher 800mm

iii. Spike diameter 340mm

iv. Combine spike and shaft length 1400mm

v. Length of spike drums 945mm

vi. Length of drum 1000mm

vii. Diameter of drum 510mm

2.2.1 Components

Hopper, Shaft, Bearing, Spike Drum, Grain Discharger, Husk discharge, Support frame, Blower, Sieve, Fan blade, Pulley, Flat bar, bitters

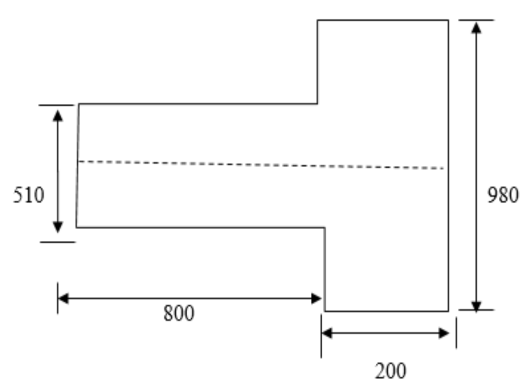


Figure 1. The threshing chamber

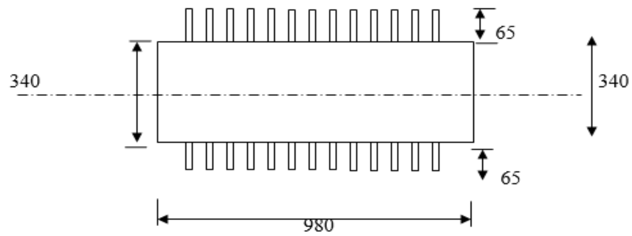


Figure 2. The spike drum

2.2.2 Design Analysis and Calculation

The arrangement of bitters was made in a sinusoidal form to give an easy transportation of the straw out of the chamber. There were 60 bitters on the threshing drum. The Arrangement of bitter was done using the equation below

$$circumference\ of\ spike\ drum = \frac{\emptyset}{360}\ \pi D \tag{1}$$

The spike drum consists of 12 bitters on each flat bar, there are 5 flat and 2 end plate to aid the threshing process. Therefore, Volume of spike materials analyze as follows:

Volume of flat bar = (LBH)5 and Volume of flat bitter = (LBH) 64 (2)

$$Volume\ of\ plate\ = \frac{\pi d^2 t}{2} = \frac{\pi 470^2 6}{2} \tag{3}$$

Total volume of spike material = TVs, therefore TVs = volume of flat bar + volume of bitter + volume of plate

$Density = \frac{mass}{volume}$ But density of mild steel is 7850Kg/m^3

The drum is considered a cylindrical material as shown in the diagram below.

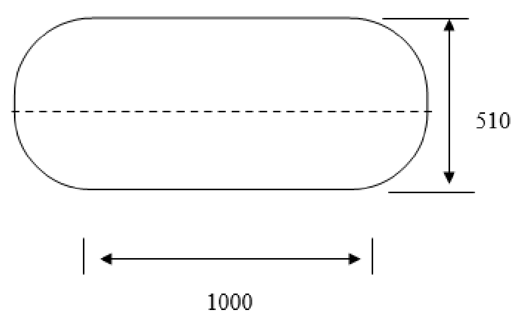


Figure 3: Drum material

Therefore, Volume of cylinder = Area x length. But

$$Area = \frac{\pi D^2}{4} \tag{4}$$

$V_S = 0.2033$ m^3. Therefore, the mass that the threshing chamber can hold at a time is given as;

$Mass = density \times volume$ =0.2033x194 = 39 kg. Where 194 Kg/m^3 is the density of rice straw.

2.2.3 Design calculation:

For 39 Kg mass of rice straw to be threshed at a time. 60 bitters were considered to be used on the spike drum and four (4) fan blades were used on the upper blower.

Work required in threshing (W_R) Let W_R = f x d (5)

Where d = distance and the Power required is

$$P = \frac{W_R}{T} \tag{6}$$

Where T = time and

$$F = mg \tag{7}$$

Where m = mass of threshing material = 39Kg g = acceleration due to gravity = 9.8ms^{-2}

Work required in threshing (W_{R1}) From equation 1 work required is given as

W_R = f x d, therefore $W_{R1} = 39 \times 9.8 \times D$

Where m=39kg and D = 470mm (0.47m)

$W_{R1} = 39 \times 9.8 \times \pi \times 0.47 \times 60$ $W_{R1} = 33864.60Nm$

Work required in separating (W_{R2}), $W_R = M \times g \times d$ i e W_R=20753.46Nm

Work required on discharging chaff 2meter away (W_{R3})from chaff exit

$W_{R3} = mgd$ =48921.6Nm

Total work required = $W_{R1} + W_{R2} + W_{R3}$ = 103539.66N

Also, $Power = \frac{TW_R}{time} = 1725.66Nm/s$

Hence power, P = 1725.66watts = 1725.66Nm/s

The most efficient form of engines are direct injection diesels, which may achieve an efficiency of approximately 40% in the engine speed range of idle to around 1,800 rpm. Although the diesel cycle itself is less efficient at equal compression ratios, engines that use it are typically more efficient. Beyond this speed, efficiency begins to decline due to air pumping losses within the engine. However, the coefficient of friction between the belt and pulley is 0.3 (khurmi and Gupta, 2011). For the purpose of this design, a multiple pulley and single pulley was adopted. Coefficient of friction= 0.3 × 3= 0.9 But, Power factor = energy required for work × coefficient of friction =

1725.661× 0.9 = 1553.1watts.Therefore, power required to do the work = energy needed + power factor =3278.8watts. There is vibration, friction and noise associated with moving parts. This loses are approximated at a power factor of 0.3 of the power requirement which is thus 3278.8× 0.3 = 983.6watts. The total power required to do the whole work is thus 3278.8+ 983.6 = 4262.4watts. Based on the results of the power required, a 4.0 Kw engine was chosen as the prime mover for this project.

2.4 Shaft Speed

If the speed of engine is to be reduced to about $^1/_3$ as the shaft speed, a pulley of 270mm will be attached to the shaft, therefore

$N_1D_1 = N_2D_2$, N_1 = speed of engine, N_2 = speed of shaft, D_1 = diameter of pulley in engine and D_2 = diameter of pulley in shaft. The speed of shaft is then given = 480r.p.m.

2.5 Shaft Diameter

From the relation $P = \frac{2\pi NT}{60 \times 1000}$ $where:$ N = revolution per minute, T = average/mean torque in Nm while P = power $T = \frac{P\times 60\times 1000}{2\times\pi\times N}$ therefore $T = 79.56Nm$ Also, $T = \tau \times \frac{\pi}{16} \times D^3$
$if\ the\ shear\ stress\ considered\ is\ \frac{40MN}{m^2}\ then,\ the\ diameter\ of\ shaft\ is\ calculated\ as$

$$D = \sqrt[3]{0.00001012858}$$

$$= 0.0216m \cong 22mm$$

For this design, the minimum shaft diameter required is 22mm. However, for the sake of reducing risk of failure; a 30 mm shaft diameter was adopted.

2.6 Tension on tight and loose side

Let T_1 = tension on tight side and T_2 = tension in shaft side and Diameter of pulley = 270mm. The radius R = 135mm N = 480r.p.m, T = 79.56Nm, μ = 0.3 and ϕ = 180x2α

$$\alpha = \frac{\sin^{-1}(D_1 - D_2)}{x} \tag{8}$$

Km = 1.5; K_l = 2.0; ɽ = 40MN/M2; X = 2 ($^{D-d}/_1$) Therefore,

$$\alpha = \frac{\sin^{-1}(270 - 90)}{360} = \sin^{-1} 0.5$$

$$\propto = 30$$

$$\theta = 180 + 2 \times 30 = 240\,°$$

$\theta = 240 \times \frac{\pi}{180} = 4.18rad$,from$\frac{T_1}{T_2} = e^{\mu}\theta$

$$T_1 = T_2 \times e^{0.3}240$$

$$T_1 = 3.3 \times T_2$$

M_T = Let tensional moment be 9950Kw/N (khurmi and Gupta 2011)

Also, $M_T = (T_1 - T_2)r_1 = (3.3T_2 - T_1)r_1$ and $M_T = 27638Nm$

$$T_2 = \frac{27638}{252.548}$$

$T_2 = 109.4N$, $Therefore\ T_1 = 3.3 \times T_2$ therefore, $T_1 = 3.3 \times 109.44$

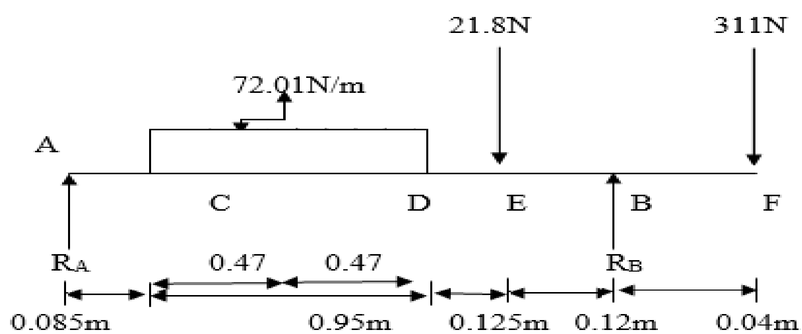
$= 361N$,

$Also, T = T_1 - T_2 = 361 - 109$

$T = 252N$

The weight of pulley acting on shaft is thus $W_P = \rho \times volume = \rho\pi\frac{d^2}{4} \times t_P$ = 6.3Kg = 61.7N

2.7 The free body diagram of the mechanism is as shown below



$$R_B = \frac{474.12}{1.28} = 370.4N \text{ and } R_A = 30.8N$$

3.0 RESULTS AND DISCUSSION

3.1 Results

Height of thresher = 1000mm Width of thresher = 800mm

Spike diameter = 340mm Combine spike and shaft length = 1400mm

Length of spike drum = 980mm Length of drum = 1000mm

Diameter of drum = 510mm

Work required in threshing (W_{R1})= 33864.60Nm

Work required in separating (W_{R2}) =20753.46Nm

Work required on discharging chaff 2meter away (W_{R3})from chaff exit =48921.6N

Total work required = $W_{R1} + W_{R2} + W_{R3}$

= 103539.66Nm Power needed $= 4262.4$watts

Engine capacity required 5.6Hp = 4.0Kw

3.2 Testing

After assemblage, the rice threshing machine was tested. This test was carried out in phases

i. Free rotation test (unloaded)

ii. Full load test (loaded)

In free rotation test (unloaded). Here the engine was run without loading. This was done to check unnecessary vibration and noise. In full load test, having done all the necessary touch up in the machine after free test, the machine was tested and some quantity of rice straw was fed in to the hopper and the machine was set to operates .During the full testing, the following items were used.

1. A weighing device
2. Stop watch
3. Containers for collection of grains

Figure 4: Fabricated rice thresher

Table 1.0: Result of Measured Performance Evaluation of the Designed and Developed Thresher

Variety	Moisture Content of the rice (%)	Weight of rice straw fed (kg)	Weight of Rice Collected (kg)	Threshing time (min)	Weight of straw chaff (kg)	Throughput Kg/h	Efficiency %
Jamila	14.6	40	38.2	3.29	1.7		96
	14.6	40	38.7	3.33	1.3		97
Ave	14.6	40	37.9	3.25	2.1		95
	14.6	40	38.3	3.29	1.7	Ave. 648	96
Faro 52	17.3	40	33.6	4.20	6.4		85
	17.3	40	34.5	4.22	5.5		86
	17.3	40	33.9	4.23	6.1		85
Ave	17.3	40	34.0	4.22	6.0	Ave. 552	85
Faro 59	15.4	40	36.4	3.40	3.4		92
	15.4	40	37.2	3.45	2.8		93
	15.4	40	36.2	3.43	3.8		91
Ave	15.4	40	36.6	3.43	3.4	Ave. 632	92
Faro 61	14.9	40	37.5	3.32	2.5		95
	14.9	40	38.1	3.38	1.9		95
	14.9	40	37.7	3.35	2.3		94
Ave	14.9	40	37.8	3.35	2.2	Ave. 640	95

3.3 Discussion

From Table 1. The results of the performance evaluation showed that the machine has an efficiency of above 85% based on the different variety of rice threshed and the level of moisture content of the product. With a threshing efficiency of 96%, the Jamila rice variety has the highest, while Faro 52 has the lowest, at 85%. Even though, this is attributed to the moisture content of the rice variety during threshing, it could also be attributed to the nature of the rice physicochemical properties. A study of the physicochemical properties will give a complete information of the varieties. The efficiency also shows significant changes of the throughput with about 648kg/h for Jamila rice and 552kg/h for faro 52. This again shows the importance of moisture content toward overall yield during processing. However, attention must be given to the level of moisture in the product because if the moisture content is low, it tends to break the rice during threshing and this will affect the quality of the threshed rice. During the threshing process, it was observed that Jamila rice variety has about 8.1 bag/hour on 80kg bag size yielding a throughput of 648kg/h. On the other hand, Faro 52 was threshed at 6.9 bags/hour giving a throughput of 552kg/h. This information is very essential for investors in the agro allied industries towards boosting the agricultural sector.

4.0 CONCLUSION

The Rice thresher was designed, fabricated and tested for the local farmers in our society. Results obtained showed that the thresher has a threshing capacity of 85% to 96% depending on the moisture content of the rice variety threshed. This has contributed to the threshing capability of our local farmers and improves our productivity in the agricultural value chain.

Acknowledgement

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Conflicts of Interest

The authors declare that there is no conflict of interest in the process and completion of the projects

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