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DESIGN AND PRODUCTION OF A RICE THRESHING MACHINE TO ENHANCE RICE HARVESTING IN NIGERIA

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ABSTRACT: The work ‘’Design and Production of a Rice Threshing Machine to Enhance Rice Harvesting in Nigeria’’ has been carried out with the intent of boosting rice production in Nigeria. The work started with structural design of the machine using AutoCAD. This was followed by detail machine parts design, design calculations, materials specification and selection, detail parts production, and assembly. After the assembly process the machine was subjected to performance evaluation and testing, the outcome showed that the research work designed, and produced a rice threshing machine for rice threshing, after rice harvest. The research work evaluated the cost of producing a unit of the machine and put the cost at ₦450,000 ($331.6), while the performance evaluation cost was put at ₦100,000 ($73.69). The study evaluated the performance of the produced rice threshing machine and measured parameters such as stripping efficiency, threshing efficiency, cleaning efficiency, total weight of chaff, separation efficiency, grain losses and threshing throughput capacity. The study carried out DOE and analysis of data. The research study revealed that the stripping efficiency of the rice threshing machine was 3.23%, the threshing efficiency was 80.72%, the cleaning efficiency was 85.72%, and the separation efficiency was 81.11%. The research work showed that grain losses were as follows: drum losses 19.28%, cleaning losses 4.42%, and separation 6.16%. The study showed that the weight of grain produced decreased with increased efficiency. The study developed model equations for cleaning efficiency, separation efficiency, cleaning losses, separation losses and total grain loss. The study observed that the throughput capacity of the rice thresher was significantly affected by the threshing time. The ANOVA results showed that the model for the throughput capacity was highly significant (P = 0.0000) with an exceptionally high R2 value of 99.92%. This indicates an excellent model fit. Threshing time was found to be extremely significant (P= 0.0000), whereas moisture content was not significant (P = 0.375). This confirms that throughput capacity is primarily determined by the rate at which the machine processes material over time.

Keywords: *Rice thresher, Design of Experiment, production, Design, Efficiency, Machine capacity.*

1. INTRODUCTION

Rice (*Oryza sativa*) is a cornerstone of global food security, serving as the second most vital cereal crop and providing the primary staple food for the majority of the world's population (Yahaya *et al.,* 2024). Over the years, rice has remained one of the staple foods in the world. Roughly one-half of the world population, including virtually all of East and Southern Asia, is wholly dependent upon rice (Fukagawa and Ziska, 2019; Liste, 2024; Tagliapietra *et al.,* 2024). It is cooked by boiling or grounded into flour. It is eaten alone and with a great variety of soups, side dishes, and main dishes in Asia. Other products in which rice is used are breakfast cereals, noodles, as well as alcoholic beverages like the Japanese sake (Britannica, 2024). The cultivated rice plant is an annual grass and grows to about 1.2 meters (4 feet) in height. The leaves are long and flattened and are borne on hollow stems. The fibrous root system is often broad and spreading. The panicle (flower cluster), is made up of spikelets bearing flowers that produce the fruit or grain. Varieties differ greatly in the length, shapes, and weight of the panicle and the overall productivity of a given plant.

According to statista.com (2023), the 2022/2023 forecast showed that the global production volume of milled rice was 512.96 million metric tons and in a year, it has increased by a million, peaking at 513.5 million metric tons. Having the highest rice consumption in the world, China’s consumption was around 154.9 million metric tons in marketing year 2022/2023 (Yihan Ma, 2023). In the US, rice is one of the most popular grains, with Americans consuming around 4.6 million metric tons of rice, and in relation to the amount produced, rice has dropped by over 67 million pounds (lbs), equivalent of 30.42 million kg between 2020 and 2022, reaching 160.4 million pounds (lbs) in 2022. Rice production recovered significantly in 2023, reaching almost 218.3 million pounds (lbs) equivalent of 99.1 million kg, that year (Shahbandeh, 2024). In Nigeria, the volume of rice produced amounted to around 8.34 million metric tons in 2021. In the previous year, a lower quantity was produced, which was about 8.17million metric tons. Generally, rice production varied within the period under review. Rice is indigenous to Nigeria and has been cultivated for the past 3500 years (Hardcastle, 1959).

Rice is one of the most consumed staples in Nigeria, with a consumption per capita of 32kg. Nigeria consumes almost 7 million tonnes of it a year. In spite of the oil, agriculture remains the base of Nigeria's economy, providing the main source of livelihood for most Nigerians. The sector faces many challenges, notably an outdated land tenure system that constrains access to land (1.8 ha/farming household), a very low level of irrigation development (less than 1 percent of cropped land under irrigation), limited adoption of research findings and technologies, high cost of farm inputs, poor access to credit, inefficient fertilizer procurement and distribution, inadequate storage facilities and poor access to markets have all combined to keep agricultural productivity low (average of 1.2 metric tons of cereals/ha) with high post-harvest losses and waste.

Even though agriculture still remains the largest sector of the Nigerian economy and employs two-thirds of the entire labour force, the production hurdles have significantly stifled the performance of the sector. Given the importance of rice as a staple food in Nigeria, boosting its production has been accorded high priority by the government in the past 7 years. Significant progress has been recorded; rice production in Nigeria reached a peak of 3.7 million tonnes in 2017. Despite this improvement, comparatively, Nigeria's rice statistics suggest there is an enormous potential to raise productivity and increase production (Nnadi, 2026).

To boost food security, Nigeria has tried curbing imports and is now trying to encourage more rice production at home (ThriveAgric, 2020). But there's still a lot more work that needs to be done, especially in the area of rice threshing which comes in during rice harvesting; this process is currently handled manually by most farmers and it is a very tedious process and this normally result into a lot of losses for the farmers. Once the rice is harvested by cutting the stalks from the stem if it is not threshed immediately the seeds start dropping from the cut stalks and cannot be picked again because they are scattered. The inability of most farmers to buy a rice threshing machine normally give rise to losses in billions of Naira every harvesting season. Here in Nigeria 90% of rice harvesting is handled by peasant farmers manually and only 10% of rice harvesting is mechanized and is handled by mechanized farms with combined harvesters and rice threshing machines. The need for designing and producing a rice threshing machine that will be cheap and affordable by low income farmers therefore cannot be over emphasized.

This study seeks to design and produce an affordable rice threshing machine for Nigerian farmers that will be portable, and will utilize liquid fuel to be used on rice farms during harvesting of rice. Thus, increasing productivity, reducing labour cost, and harvest losses.

2. MATERIALS AND METHOD

2.1 Materials and Tools / Equipment

Production of a rice threshing machine involves various materials that are chosen for their durability, strength and ability to withstand the mechanical stresses of the threshing process. The major materials required to produce the rice thresher included; computer, AutoCAD software, power saw, welding machine, marking tools, steel sheet/ plate, angled steel for Steel frame and structure; steel plate and rods for threshing drum; mild steel for concave assembly; hardened steel rods for beaters and teeth; petrol engine for power source; mild steel sheet for grain outlet; belts and pulleys; perforated metal mesh (sieve); fasteners and fittings; safety guards and covers; paint and coating.

2.2 Method

2.2.1 Design Philosophy

There are mainly four kinds of grain threshing principles. The principles are impact, rubbing, pre-cut combing and grinding. Teeth such as spike teeth and bow teeth fixed to the drum by welding are the key threshing components of impact threshing. The thresher developed in this endeavor has peg-teeth welded to cylindrical drum and concave screen arrangement that generate impact force, in contact to thresh the material under process. Separation of rice grains from the panicle and straw occurs as a result of rubbing, impact and stripping action of the drum in the threshing chamber.

2.2.2 DESIGN CONSIDERATIONS

2.2.2.1 General Thresher Consideration

In designing the machine, some of the following factors were considered:

a. Selection of materials: It is essential that a designer should have a thorough knowledge of the properties of materials and their behavior under working conditions. Some of the characteristics of materials are; strength, durability, flexibility, weight, heat and corrosion resistance, electrical conductivity.

b. Form and Size of the parts: This is based on judgment. The smallest practicable cross-section may be used, but it may be checked that the stresses induced in the designed cross-section are reasonably safe. In order to design any machine part for form and size, it is necessary to know the forces which the parts must sustain. Likewise, to anticipate any suddenly applied or impact load which may cause failure.

c. Frictional resistance and lubrication: There is always a loss of power due to frictional resistance and it should be noted that the friction of starting is higher than that of running friction. It is essential that attention must be given to the lubrication of moving parts in contact with one another.

d. Ease of Operation: This is a critical feature to ensure that the machine can be operated by a variety of operators, mainly since it will be used by people who live in remote areas and have no prior experience with the equipment.

e. Maintainability: The maintainability of the machine is an important issue to consider during the design phase. It's vital to design a machine that's easy to repair and restore if it breaks down.

f. Safety: This is an important factor to consider during the design and fabrication stages. This is to ensure that the safety and lives of operators who are close to the equipment are not threatened in any manner while it is in use.

g. Reliability: In terms of servicing, the machine should be of good quality. The threshing machine should be dependable and sturdy because it will be subjected to a variety of forces and conditions.

h. Availability of Material: This is to enhance the replacement of damage parts.

2.2.2.2 Rice Thresher Consideration

In the case of designing the rice thresher, the following factors were considered:

i. Physical properties of crop - size, moisture content, angle of repose, bulk density, grain/straw ratio

ii. Concave length

iii. Crop feed rate

iv. Threshing speed

v. Conclave clearance

vi. Cylinder capacity

vii. Power requirement

viii. Materials of construction

2.2.3 Machine Description

The operation of a Rice Threshing Machine consists of several stages, from feeding the harvested rice to separating the grains from the straw and collecting the clean rice. The stages include:

1) Feeding the machine: Firstly, the harvested rice plants, with grains attached, are fed into the machine. This can be done manually or using a feeding conveyor or hopper.

The feeding conveyor ensures the rice enters the threshing drum evenly and continuously.

2) Threshing: Once the rice enters the machine, it encounters the threshing drum. The drum is equipped with beaters or spikes that rotate at high speed. As the rice plants pass through the drum, the mechanical action of the beaters or spikes separates the grains from the panicles. The concave (or semi-circular gate) beneath the drum helps in this separation process, providing resistance and allowing the grains to fall through while retaining larger plant material. The operator can adjust various settings on the machine to optimize threshing efficiency, such as adjusting the drum speed, concave clearance, airflow intensity and sieve size to accommodate different rice varieties and moisture levels.

3) Separation: The mixture of grains, straw and chaff falls onto the vibrating sieve. The sieve allows the smaller grains to pass through while larger pieces of straw and chaff are retained and removed. The blower or fan are used to create airflow that helps separate lighter chaff and straw from heavier grains. The air stream blows away the lighter materials which are collected separately.

4) Cleaning: The separated grains pass through additional sieves to remove more remaining impurities like small straws, dust and broken grains. Some machine has aspirators that control airflow to further clean the grains by blowing remaining light particles. The cleaned grains are collected in a bag while the collected straw and chaff are expelled from a separate outlet and gathered for disposal or animal feed.

The threshing machine was equipped with Safety Guards and covers to prevent accidents with moving parts. Emergency stop buttons was also provided to quickly stop the machine in case of any issues. Likewise a Power Source (such as an internal combustion engine using gasoline or diesel) was to be used to power the machine.

By efficiently following this description, a rice threshing machine will significantly reduce labour cost and post-harvest loss while increasing productivity and improving overall efficiency of food processing in the Nigerian Industry.

2.2.4 Design Calculation

Design calculations are necessary in the development of the threshing machine to ensure that each component operates efficiently and safely under the expected working conditions. These calculations help determine the required power, rotational speeds, belt drive relationships, forces acting on moving parts, feed capacity, and hopper volume. Proper engineering design ensures that the machine performs efficiently without mechanical failure, excessive energy consumption, or operational instability.

2.2.4.1 Power

The power required to operate the threshing unit is determined from the relationship between torque and rotational speed of the shaft. Power represents the rate at which work is done by the motor to drive the threshing mechanism. The torque is derived using Equation 2.1.

$$T = \frac{P \times 9550}{N} \qquad \text{Equation 2.1}$$

Where T is Torque (N.m), P is power (kW) and N is rotational speed (rpm)

Equation 2.1 uses the power to determine transmission through the threshing shaft. Adequate power ensures that the drum rotates at the required speed to effectively detach grains from the crop material while preventing mechanical overloading of the machine.

2.2.4.2 Velocity ratio of belt drive

The velocity ratio of the belt drive determines the relationship between the rotational speed of the driving pulley and the driven pulley. This is mathematically expressed in Equation 2.2.

$$vr = \frac{N_2}{N_1} = \frac{d_1}{d_2} = \frac{T_1}{T_2} \qquad \text{Equation 2.2}$$

Where $N_1 = speed\ in\ thresher, N_2 = speed\ in\ motor, d_1 = diameter\ at\ thresher$

$d_2 = diameter\ at\ motor, T_2 = Torque\ at\ motor, T_1 = Torque\ at\ thresher$

This relationship ensures that the desired speed of the threshing drum and blower shafts is obtained from the motor output. Proper velocity ratio selection improves power transmission efficiency and minimizes belt slippage.

2.2.4.3 Threshing Velocity

Threshing velocity refers to the linear speed of the threshing drum or beaters during operation. It determines how effectively the grains are separated from the crop material. This is mathematically expressed in Equation 2.3.

$$V = \frac{\pi DN}{60} \qquad \text{Equation 2.3}$$

Where $D = drum\ diameter, N = rotational\ speed\ of\ the\ threshing\ unit$

A suitable threshing velocity is necessary to achieve efficient grain separation without causing excessive grain breakage or mechanical damage.

2.2.4.4 Rotational Speed and Angular Velocity (ω)

The rotational speed (N) of the threshing unit, neutral joint, and blower shafts is determined by the speed ratio of the pulleys. The rotational speed is then converted to angular velocity for use in dynamic force calculations. The angular velocity (ω) is then converted from revolutions per minute (rpm) to radians per second (rad/s) using Equation 2.4.

$$\omega = \frac{2\pi N}{60} \qquad \text{Equation 2.4}$$

Angular velocity is important in calculating centrifugal forces and other dynamic parameters acting on rotating components of the machine.

2.2.4.5 Tangential Force (F_{tan}) on the Threshing Shaft

The tangential force acting on the threshing shaft is responsible for transmitting torque from the motor to the threshing drum. It can be expressed mathematically using Equation 2.5.

$$F_{tan} = \frac{T_1}{r_{shaft}} \qquad \text{Equation 2.5}$$

This force is used in determining the strength and diameter of the shaft to ensure that it can withstand operational stresses without failure.

2.2.4.6 Centrifugal Force (F_c) of a Single Thresher Beater Rod

The centrifugal force is essential for the threshing action, calculated at the rotational speed of the threshing unit. Centrifugal force is generated when the beater rods rotate with the threshing drum. This force contributes to the impact and rubbing action required to detach grains from the crop heads. This is mathematically expressed in Equation 2.6.

$$F_c = m \times r \times \omega^2 \qquad \text{Equation 2.6}$$

F_c is the centrifugal force, m is the mass of the shaft and ῳ is the angular speed. The calculation ensures that the beater rods and drum structure are designed to withstand the forces generated during high-speed rotation.

2.2.4.7 Feed rate

Feed rate represents the quantity of crop material that can be processed by the threshing machine per unit time. It is estimated based on the available motor power and the specific energy required for threshing. A more realistic engineering estimate for the machine's maximum feed rate can be calculated using the motor's power and an assumed Specific Energy Consumption (SEC) for threshing. This is mathematically expressed in Equation 2.7 and 2.8.

$$Feed\ rate = \frac{Threshing\ Power}{Specific\ Energy\ Consumption\ (SEC)} \qquad \text{Equation 2.7}$$

Permissible feed rate (q_p)

$$q_p = \frac{q}{S_L \times M} \qquad \text{Equation 2.8}$$

Where, $q = feed\ rate, M = number\ of\ (rows\ of) beaters\ and\ S_L = Screen\ length$

The permissible feed rate ensures that the machine operates efficiently without overloading the threshing unit or reducing threshing performance.

2.2.4.8 Volume of Hopper (Vol)

The hopper serves as the feeding compartment of the threshing machine. The "capacity of the hopper" is calculated as its volume. The hopper is described as "Trapezium shaped" with four dimensions, suggesting it is a trapezoidal prism (a trough) or a pyramidal frustum.

$$Vol = \left(\frac{W_{top} + W_{bottom}}{2}\right) \times H \times L \quad \text{Equation 2.9}$$

Where, $W_{top} = width\ at\ the\ outer\ opening, W_{bottom} = width\ at\ drum\ opening,$ $H = hopper\ height\ and\ L = Hopper\ Length$

A properly designed hopper ensures continuous feeding of crop materials into the threshing unit and reduces interruptions during operation.

2.2.5 Materials Selection for Fabrication

Materials used for the fabrication of the Thresher are shown in Table 2.1. Most of the materials were purchased while few were fabricated. However, the fabrication was carried out at Etima Engineering workshop at Ikot Ekpene Road using various tools and equipment such as welding machines, spanners, screws etc.

Table 2.1: Materials for construction.

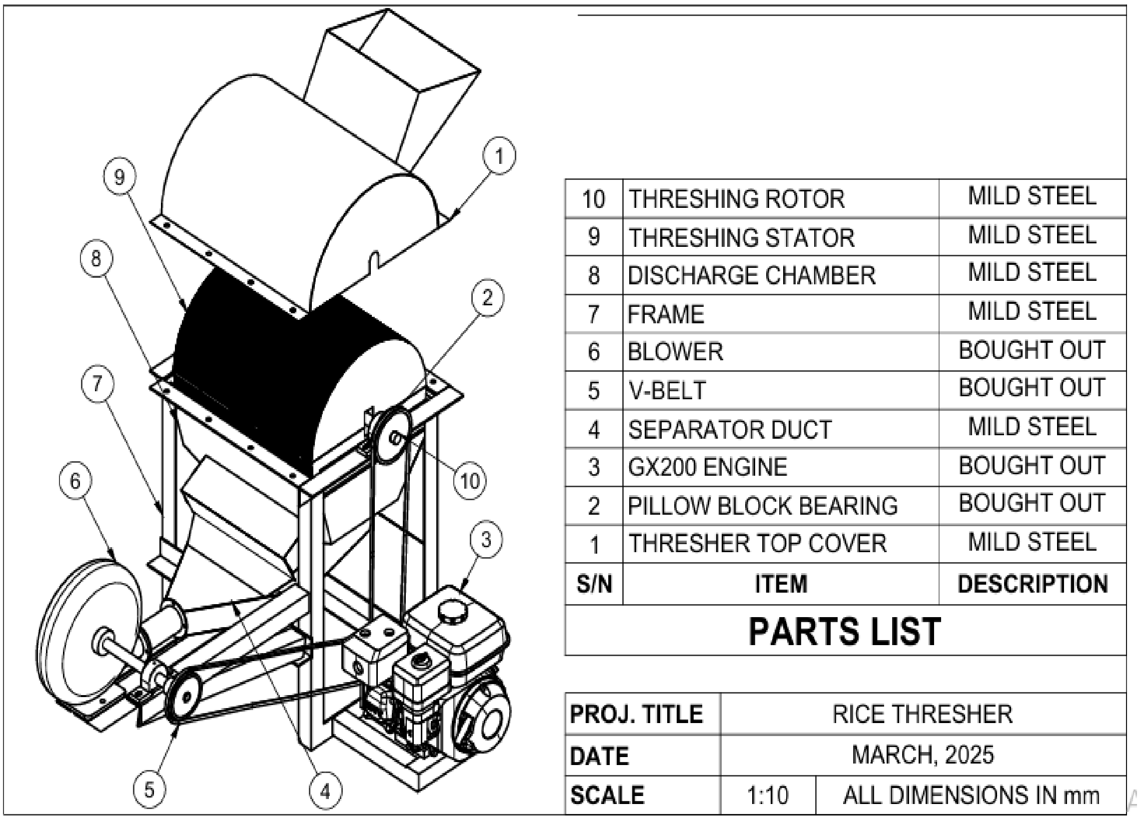
S/N	Parts	Materials
1	Threshing cylinder	mild steel
2	Thresher top cover	mild steel
3	Hopper	mild steel
4	Threshing rotor	mild steel
5	Threshing stator	mild steel
6	Discharge chamber	mild steel
7	Frame	mild steel
8	Separator duct	mild steel
9	Blower	Standard component
10	V-belt	Standard component
11	GX200 engine	Standard component
12	Pillow block bearing	Standard component

2.2.6 Production of the Rice Threshing Machine Detail parts

The various detailed parts of the threshing machine as indicated in Table 2.1 were produced using various tools like power disc, marking tools, punchers, chisels, bending machines, power files, power saw, welding machines, drills, and others. The standard parts were selected as indicated by design calculations.

2.2.7 Assembly of the Detail Parts and Standard Parts into Rice Threshing Machine

The assembly of the detailed parts of the rice thresher was accomplished by the use of jigs and fixtures. The parts were assembled together using bolts and nuts, and were dismantling for maintenance was not necessary the parts were welded together using electric arc welding. The completed assembled rice threshing machine is shown in Figures 2.1 -2.3.



S/N	ITEM	DESCRIPTION
10	THRESHING ROTOR	MILD STEEL
9	THRESHING STATOR	MILD STEEL
8	DISCHARGE CHAMBER	MILD STEEL
7	FRAME	MILD STEEL
6	BLOWER	BOUGHT OUT
5	V-BELT	BOUGHT OUT
4	SEPARATOR DUCT	MILD STEEL
3	GX200 ENGINE	BOUGHT OUT
2	PILLOW BLOCK BEARING	BOUGHT OUT
1	THRESHER TOP COVER	MILD STEEL

PARTS LIST

PROJ. TITLE	RICE THRESHER	
DATE	MARCH, 2025	
SCALE	1:10	ALL DIMENSIONS IN mm

Figure 2.1: Exploded View of rice thresher

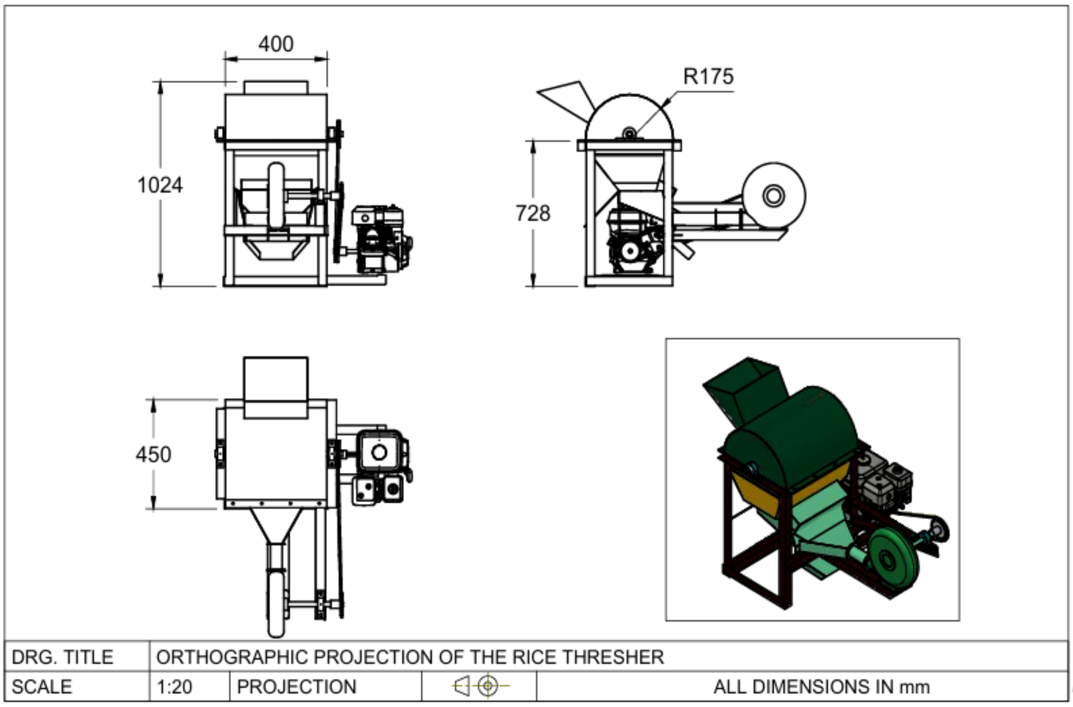


Figure 2.2: Isometric view of rice thresher

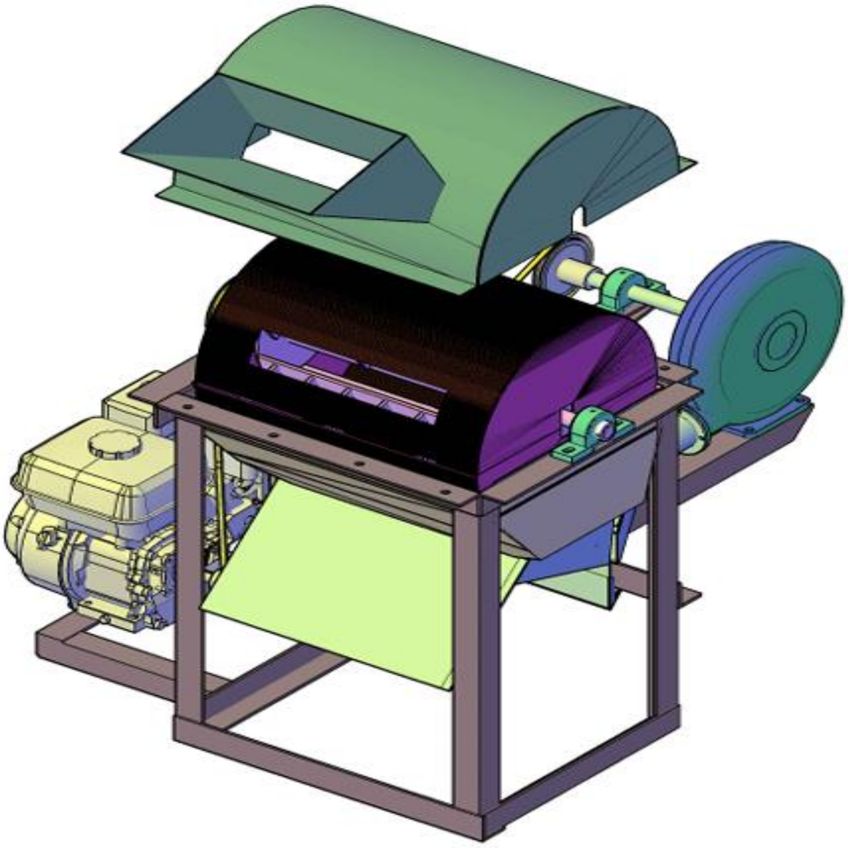


Figure 2.3: 3D view of rice thresher

2.2.8 Cost of Fabrication of the Rice Thresher

The cost of fabrication of the rice thresher is presented in Table 2.2.

Table 2.2: Bill of Engineering Materials.

Components	Price
Threshing cylinder	32000
Thresher top cover	12500
Hopper	10600
Threshing rotor	25400
Threshing stator	22000
Discharge chamber	12000
Frame	49000
Separator duct	24000
Blower	18500
V-belt	45000
GX200 engine	146000
Pillow block bearing	53000
Total	450000

Summary of the cost of production of the Rice thresher is ₦450,000 ($331.6) and the cost for performance evaluation is ₦ 100,000 ($73.69).

2.2.9 Thresher Performance Evaluation

2.2.9.1 Efficiencies of the rice thresher

i. Stripping efficiency (SE)

The stripping efficiency is calculated using equation 2.10

$SE = \frac{W_{sg}}{W_{tgs}} \times 100$ Equation 2.10

Where, $W_{sg} = weight\ of\ stripped\ grain\ (g)$,

$W_{tgs} = Total\ weight\ of\ grain\ on\ stalks\ (g)$

ii. Threshing efficiency

This is the ratio of grain threshed during initial threshing to the total expressed as a percent. This is calculated using equation 2.11

$TE = \frac{W_{tg}}{W_{tgs}} \times 100$ Equation 2.11

Where, $W_{tg} = weight\ of\ threshed\ grain\ (g)$,

$W_{tgs} = Total\ weight\ of\ grain\ on\ stalks\ (g)$

iii. Cleaning efficiency

Cleaning efficiency is calculated using equation 2.12

$CE = \frac{W_{co}}{W_t} \times 100$ Equation 2.12

Where, $W_{co} = weight\ of\ chaff\ collected\ at\ the\ chaff\ outlet\ (g)$,

$W_C = Total\ weight\ of\ chaff$

iv. Separation efficiency

Separation efficiency is calculated using equation 2.13

$S_pE = \frac{W_{s1}+W_{s2}}{W_{tgs}} \times 100$ Equation 2.13

Where, $W_{s1} = weight\ of\ \ grain\ from\ outlet\ (g)$,

$W_{s2} = weight\ of\ \ grain\ from\ straw\ \ outlet\ (g)$

$W_{tgs} = Total\ weight\ of\ grain\ on\ stalks\ (g)$

2.2.9.2 Grain Losses

a) Drum loss (D_l)

This is calculated using Equation 2.14

$$D_l = \frac{W_{us}+W_{ut}}{W_{tgs}} \times 100 \qquad \text{Equation 2.14}$$

Where, $W_{usg} = weight$ of unstripped grain,

$W_{utg} = weight\ of\ unthreshed\ grain,$

$W_{tgs} = Total\ weight\ of\ grain\ on\ stalks\ (g)$

b) Cleaning loss (C_l)

This can be determined using Equation 2.15

$$C_l = \frac{W_{go}}{W_{gi}} \times 100 \qquad \text{Equation 2.15}$$

Where, $W_{go} = weight\ of grain\ at\ the\ chaff\ outlet\ (g),$

$W_{gi} = Total\ weight\ of\ grain\ at\ input\ (g)$

c) Separation loss (S_l)

This is calculated using equation 2.16

$$S_l = \frac{W_{ug}}{W_{tgs}} \times 100 \qquad \text{Equation 2.16}$$

Where, $W_{ug} = weight\ of\ unseperated\ \ grain\ (g),$

$W_{tgs} = Total\ weight\ of\ grain\ \ (g)$

d) Total grain loss (T_l)

This is calculated using equation 2.17

$$T_l = \frac{D_l+S_l+C_l}{W_{tgs}} \times 100 \qquad \text{Equation 2.17}$$

Where, $D_l = Drum\ loss, D_l = Seperation\ loss, C_l = Cleaning\ loss,$

$W_{tgs} = Total\ weight\ of\ grain\ \ (g)$

2.2.9.3 Threshing through put capacity

Rice plant of Known masses was separately fed into the rice thresher to thresh completely and thresh at various times at constant speed. The threshed rice was weighed and the residue was weighted. The time taken to thresh the rice was recorded and the through put was calculated using Equation 2.18

$$T_{pc} = \frac{W_{tg}}{t} \qquad \text{Equation 2.18}$$

Where $T_{pc} = throughput, W_{tg} = weight\ of\ threshed\ grain\ (g)\ and\ t = time\ of\ threshing$ (s)

2.2.9.4 Threshing efficiency with varying masses and constant time

Rice plant of 7 different masses (200g, 300g, 400g, 500g, 600g, 700g and 800g) were separately fed into the rice thresher at constant time of 5 min and constant speed. The threshed rice was weighed and the residue was weighted. The threshing efficiency was calculated in response to time using Equation 2.11.

2.2.9.5 Design of Experiment and Analysis of Data

The machine was evaluated under different conditions of rice moisture content level of 12, 15 and 18 % wb which was attained by adding a calculated amount of quantity water determined from Equation 2.14 (Mohsenin, 1980) and Time of 120, 240 and 360 sec which was attained using a stop watch. The experiment uses face centered - composite design with three (3) moisture content and three (3) threshing time resulting in a total of 9 runs as shown in Table 2.1.

Table 2.1: Experimental Design Runs

StdOrder	RunOrder	Moisture Content	Threshing Time
3	1	12	360
8	2	18	240
6	3	15	360
5	4	15	240
4	5	15	120
9	6	18	360
7	7	18	120
2	8	12	240
1	9	12	120

The data was processed in Microsoft Excel 2010 and analyzed using analysis of variance (ANOVA) with a tolerance rate (α) of 0.05. Regression analysis was used to model the dependent variable as function of independent variable and the optimum operational conditions were determined using response surface methodology (RSM) on Minitab 20. The numerical optimization of the rice thresher was carried out by super-positioning of the different responses (Threshing Efficiency, Cleaning Efficiency, Separation Efficiency, Cleaning Loss, Separation Loss, Total grain Loss and Throughput)

2.2.10 Statistical Analysis

All experimental data were expressed as means of triplicate values. The mean and standard deviation of all values were carried out using Microsoft Excel (2010) and SPSS. The statistical measures for assessing the influence of processing parameters on the machine efficiency and the quality of the fitted models includes the following: Coefficient of correlation (r or R), coefficient of determination (r), mean bias error (MBE), Reduced chi square (R^2), root mean square error (RMSE), modelling efficiency (EF), Mean square error (MSE), Sum square error (SSE), mean percent error (MPE) (Onwude *et al.,* 2016; Aviara and Igbeka, 2016).

3. RESULTS AND DISCUSSION

3.1 Result

The results obtained are presented in this section

3.1.1 Design and production of rice thresher

3.1.1.1 Machine Description, Parameters and Values

The overall description and dimensions of the machine is presented in Table 3.1.

Table 3.1: Machine component and their description

S/N	Component	Descriptions
1	Frame	450mm by 450mm by 733mm
2	Hopper	Trapezium shaped hopper with dimension of 120mm by 250mm by 310mm by 50mm
3	Drum	Cylindrical shaped with dimensions of D390mm by 390mm
4	Screen	Cylindrical shaped with dimensions of D300 mm by 345 mm with 1mm hole spacing.

5	Shaft	Cylindrical shaped with dimensions of D900 mm by 390 mm with angular beaters made of 4mm rod made up of 9 rows and 7 columns.
6	Belt	An A42, A44 and A66 belt are used to connect the electric motor to threshing unit, threshing unit to neutral joint and neutral point to blower. Each belt had a thickness of 8mm and width of 13mm.
7	Pulley	Pulleys of different dimensions were used at different intervals. The pulley at the elect motor was 7.7mm, threshing unit was 15.7mm, neutral point was 10.5mm and blower was 4.3mm. the distance between each pulley were; 680mm from electric motor to threshing unit, 390mm from threshing unit to neutral joint and 460mm from neutral point to blower.
8	Electric motor	GX200 engine was used with an electric power of 5.5hp and speed of 3600rpm.

The assembled rice threshing machine can be seen in Figures 2.1-2.3.

Data gotten using model equations are presented in Table 3.2

Table 3.2: Machine parameters and values

PARAMETER	**Values**	**Unit**
Volume of hopper	0.00287	m^3
Gate	75	M
permissible feed rate	0.5726	kg/s
feed rate	1.778	kg/s
threshing velocity	35.95	m/s
Tangential Force	49.31	N
centripetal force	32.86	N
Torque at electric motor	10.89	Nm
Torque at threshing unit	22.19	Nm
Power	4.101	kW
speed in thresher unit	1765.61	Rpm
speed moving to joint	2640	Rpm
Speed at fan	6446.51	Rpm

length of belt 1	1396.78	Mm
length of belt 2	821.18	Mm
length of belt 3	943.27	Mm
angular velocity at electric motor	376.99	rad/s
angular velocity at threshing unit	184.9	rad/s
angular velocity at neutral point	276.51	rad/s
angular velocity at blower	675.87	rad/s

3.1.2 Performance evaluation

The efficiencies of the machine and losses occurred during performance evaluation is analyzed in this section.

3.1.2.1 Machine Efficiencies

The machine efficiency such as cleaning, threshing, stripping and separation efficiency for five (5) experimental runs are presented in Table 3.3 with respect to their mean and standard deviation.

Table 3.3: Efficiency of rice threshing

PARAMETERS	**1**	**2**	**3**	**4**	**5**	**Mean ± Sd**
Stripping Efficiency (%)	3.12	2.9452	3.44	3.5862	3.0562	3.23 ± 0.2713
Threshing Efficiency	78	79.6	80	83.4	82.6	80.72 ± 2.2298
Cleaning Efficiency	82	83.4	87.3	87.9	88	85.72 ± 2.8137
Separation Efficiency	78.44	80.008	80.4	83.732	82.948	81.11 ± 2.1852

3.1.2.2 Machine Losses

The Losses incurred during experimental runs such as drum loss, cleaning loss, separation loss are presented in Table 3.4.

Table 3.4: machine losses incurred during experimental runs.

PARAMETERS	1	2	3	4	5	Mean ± Sd
Drum Loss (%)	22	20.4	20	16.6	17.4	19.28 ± 2.2298
Cleaning Loss	4.34	4.388	4.4	4.502	4.478	4.42 ± 0.0669
Separation Loss	6.002	6.0964	6.12	6.3206	6.2734	6.16 ± 0.1316
Total grain Loss	11.97852	11.03014	10.17333	9.140867	9.707379	10.41 ± 1.1186

^Based on general processed weight.

3.1.2.3 Threshing efficiency with varying masses and constant time

The result of the threshing efficiency per 2min time is presented in Table 3.5 and its graphically represented in Figure 3.4.

Table 3.5: threshing efficiency with varying masses at 2min time.

	WEIGHT OF THRESHED GRAIN (g)			WEIGHT OF RESIDUE (g)			Threshing efficiency (%)		
WEIGHT OF GRAIN	A	B	C	A	B	C	A	B	C
200	170.4	169.2	170.2	29.6	30.8	29.8	85.2	84.6	85.1
300	229.2	227.7	229.8	70.8	72.3	70.2	76.4	75.9	76.6
400	276.8	277.2	274.0	123.2	122.8	126.0	69.2	69.3	68.5
500	321.5	319.5	321.5	178.5	180.5	178.5	64.3	63.9	64.3
600	376.2	372.0	375.6	223.8	228.0	224.4	62.7	62	62.6
700	413.7	414.4	415.8	286.3	285.6	284.2	59.1	59.2	59.4
800	434.4	431.2	439.2	365.6	368.8	360.8	54.3	53.9	54.9

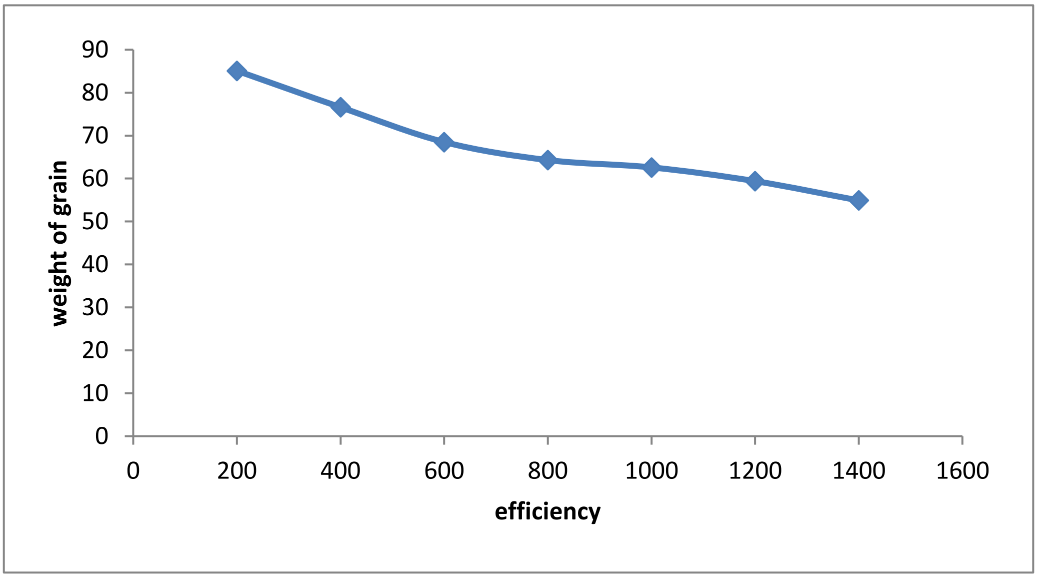


Figure 3.4: Graph of weight of grain versus efficiency at 2min

3.1.4 Design of Experiment and Analysis of Data

Response surface methodology (RSM) was mathematical and statistically employed to explore the relationships between Moisture content and threshing time as a factor in response to the threshing efficiency %, cleaning efficiency %, separation efficiency %, cleaning loss %, separation loss %, total grain loss % and throughput g/sec. The results are presented this section. The significance of each factor and their interactions were assessed using Analysis of Variance (ANOVA), while model adequacy was evaluated using regression statistics such as R^2 values.

3.1.4.1 Effect of factors on Threshing Efficiency

The influence of moisture content and threshing time on the threshing efficiency is analyzed using ANOVA and presented in Table 3.6 and 3.7. The regression equation is given in Equation 3.1, the response surface is presented in Figure 3.4 while the contour plot is presented in Figure 3.5.

Table 3.6: Analysis of Variance for Threshing Efficiency

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	230.237	46.047	17.08	0.021
Linear	2	192.158	96.079	35.64	0.008
Moisture Content	1	0.267	0.267	0.10	0.774
Threshing Time	1	191.891	191.891	71.18	0.003
Square	2	37.407	18.703	6.94	0.075
Moisture Content*Moisture Content	1	24.364	24.364	9.04	0.057
Threshing Time*Threshing Time	1	13.042	13.042	4.84	0.115
2-Way Interaction	1	0.672	0.672	0.25	0.652
Moisture Content*Threshing Time	1	0.672	0.672	0.25	0.652
Error	3	8.087	2.696		
Total	8	238.324			

Table 3.7: Model Summary Threshing Efficiency

S	R-sq	R-sq(adj)	R-sq(pred)
1.64187	96.61%	90.95%	64.11%

$$Threshing\ Efficiency = -10.7 + 11.29\ Moisture\ Content + 0.1152\ Threshing\ Time - 0.388\ Moisture\ Content * Moisture\ Content - 0.000177\ Threshing\ Time * Threshing\ Time + 0.00114\ Moisture\ Content * Threshing\ Time$$

Equation 3.1

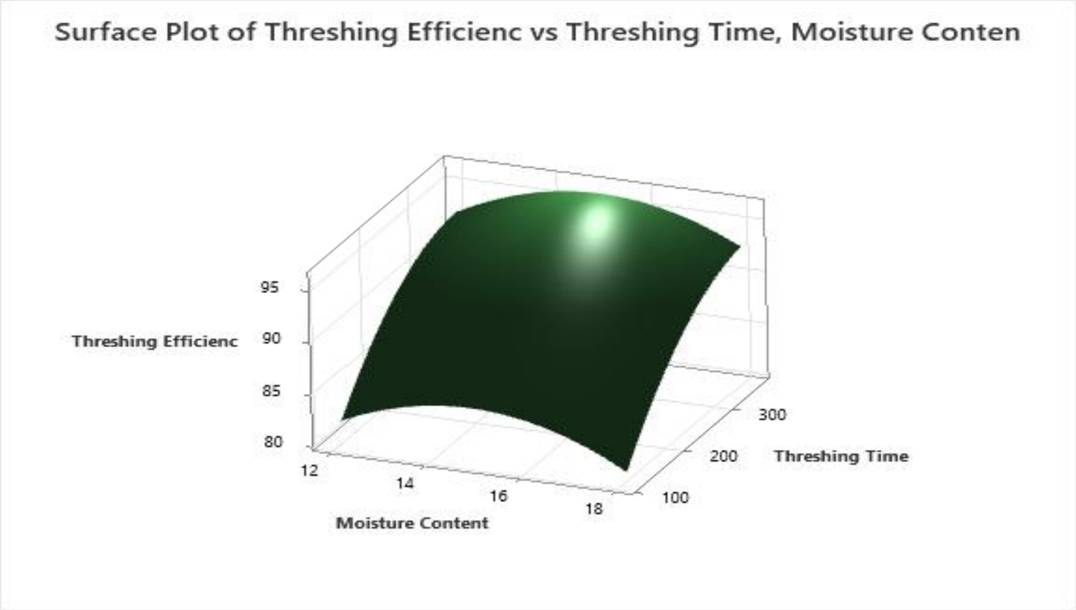


Figure 3.5: Surface plot of threshing Efficiency

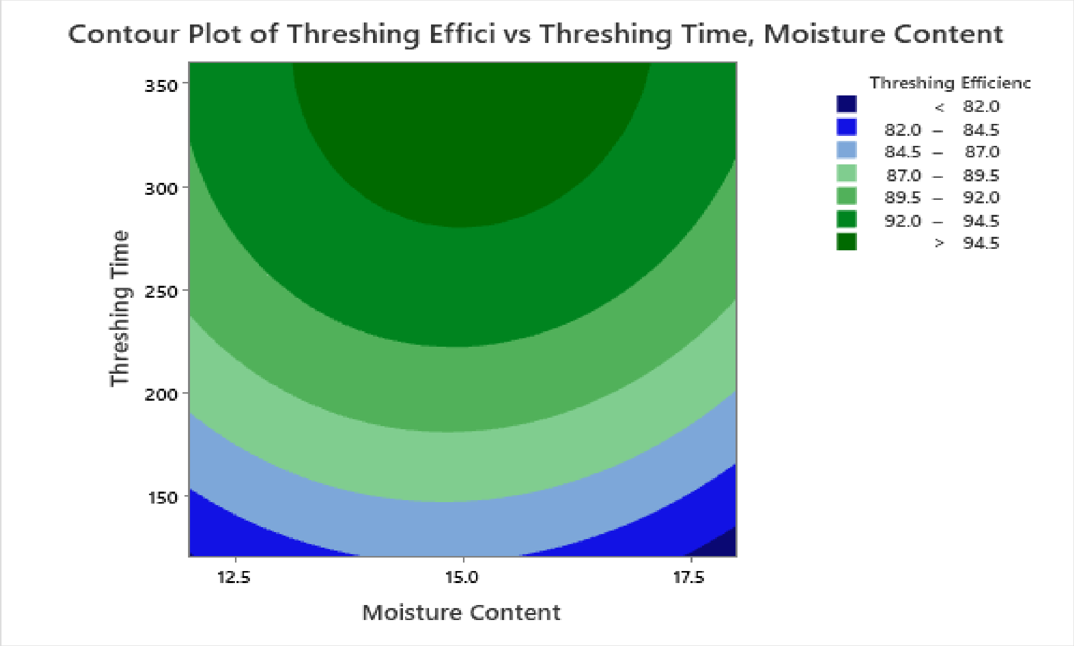


Figure 3.6: Contour plot of threshing Efficiency

3.1.4.2 Effect of factors on Cleaning Efficiency

The ANOVA of the influence of moisture content and threshing time on the cleaning efficiency, the regression equation, the surface response and the contour plot are presented in Table 3.8 and 3.9, Equation 3.2, Figure 3.7 and Figure 3.8 respectively.

Table 3.8: Analysis of Variance for Cleaning Efficiency

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Model	5	12.2667	2.4533	0.16	0.961
Linear	2	8.3367	4.1683	0.28	0.776
Moisture Content	1	5.8017	5.8017	0.38	0.579
Threshing Time	1	2.5350	2.5350	0.17	0.709
Square	2	3.7700	1.8850	0.12	0.887
Moisture Content*Moisture Content	1	1.1250	1.1250	0.07	0.803
Threshing Time*Threshing Time	1	2.6450	2.6450	0.18	0.704
2-Way Interaction	1	0.1600	0.1600	0.01	0.925
Moisture Content*Threshing Time	1	0.1600	0.1600	0.01	0.925
Error	3	45.2933	15.0978		
Total	8	57.5600			

Table 3.9: Model Summary Cleaning Efficiency

S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**
3.88559	21.31%	0.00%	0.00%

$$Cleaning\ Efficiency = 55.2 + 2.96\ Moisture\ Content + 0.052\ Threshing\ Time - 0.083\ Moisture\ Content * Moisture\ Content - 0.000080\ Threshing\ Time * Threshing\ Time - 0.00056\ Moisture\ Content * Threshing\ Time \quad \text{Equation 3.2}$$

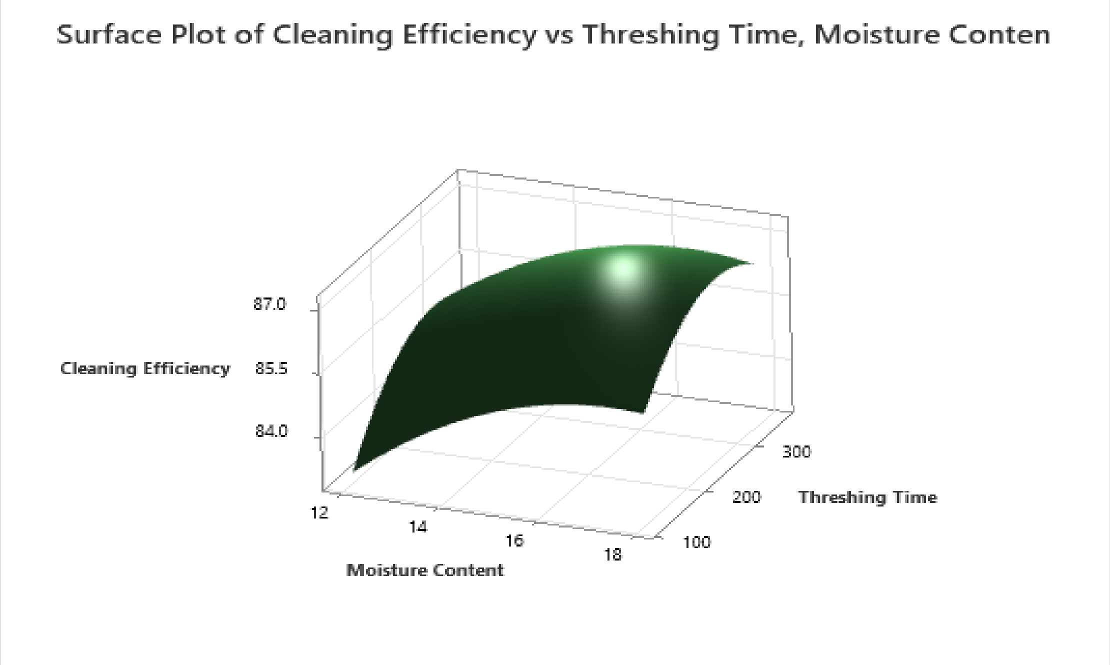


Figure 3.7: Surface plot of Cleaning Efficiency

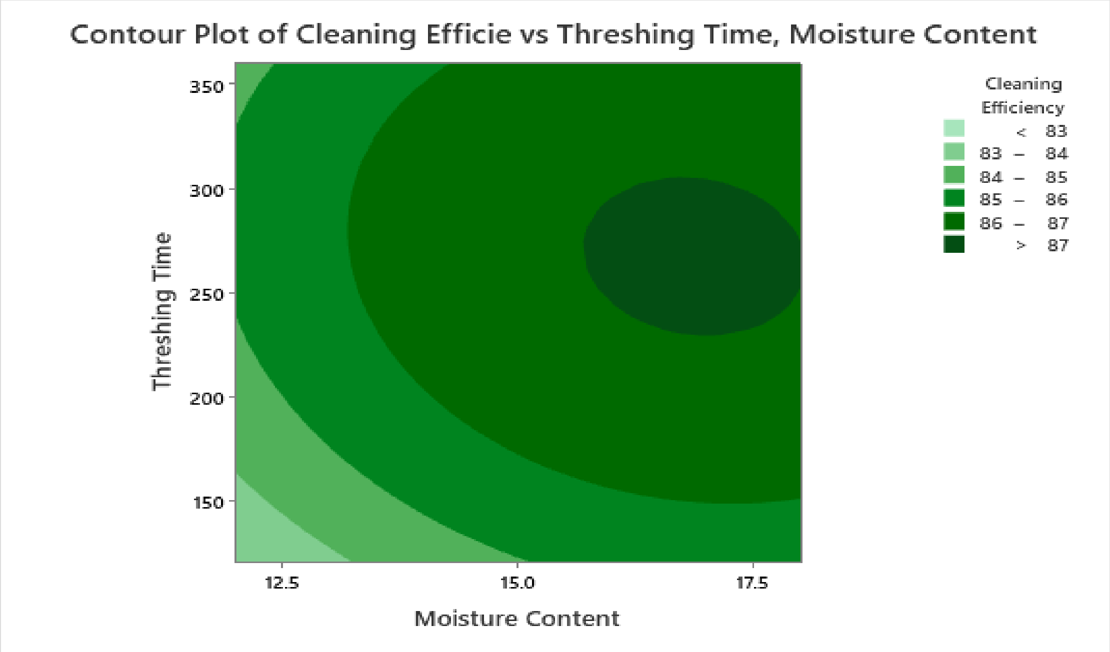


Figure 3.8: Contour plot of Cleaning Efficiency
Source: Researcher (2026)

3.1.4.3 Effect of factors on Separation Efficiency

The influence of moisture content and threshing time on the Separation efficiency is analyzed using ANOVA, regression equation, response plot and contour plot as presented in Table 3.10, Equation 3.3, Figure 3.9 and Figure 3.10. The summary of ANOVA is presented in Table 3.11.

Table 3.10: Analysis of Variance for Separation Efficiency

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	5765.3	1153.07	0.69	0.665
Linear	2	2247.8	1123.90	0.67	0.573
Moisture Content	1	2062.1	2062.07	1.24	0.347
Threshing Time	1	185.7	185.73	0.11	0.760
Square	2	3516.9	1758.44	1.06	0.450
Moisture Content*Moisture Content	1	444.5	444.48	0.27	0.641
Threshing Time*Threshing Time	1	3072.4	3072.40	1.84	0.268
2-Way Interaction	1	0.7	0.67	0.00	0.985
Moisture Content*Threshing Time	1	0.7	0.67	0.00	0.985
Error	3	4997.5	1665.83		
Total	8	10762.8			

Table 3.11: Model Summary Separation Efficiency

S	R-sq	R-sq(adj)	R-sq(pred)
40.8146	53.57%	0.00%	0.00%

$$Separation\ Efficiency = 419 - 56.1\ Moisture\ Content + 1.34\ Threshing\ Time + 1.66\ Moisture\ Content * Moisture\ Content - 0.00272\ Threshing\ Time * Threshing\ Time + 0.0011\ Moisture\ Content * Threshing\ Time \qquad \text{Equation 3.3}$$

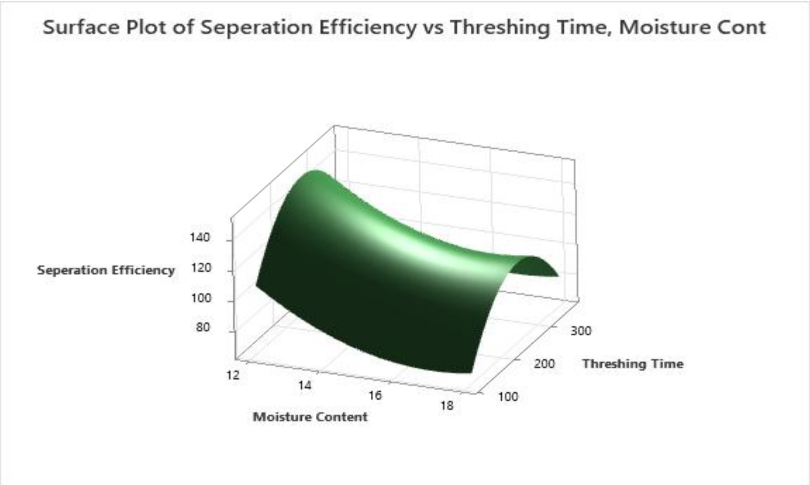


Figure 3.9: Surface plot of Separation Efficiency

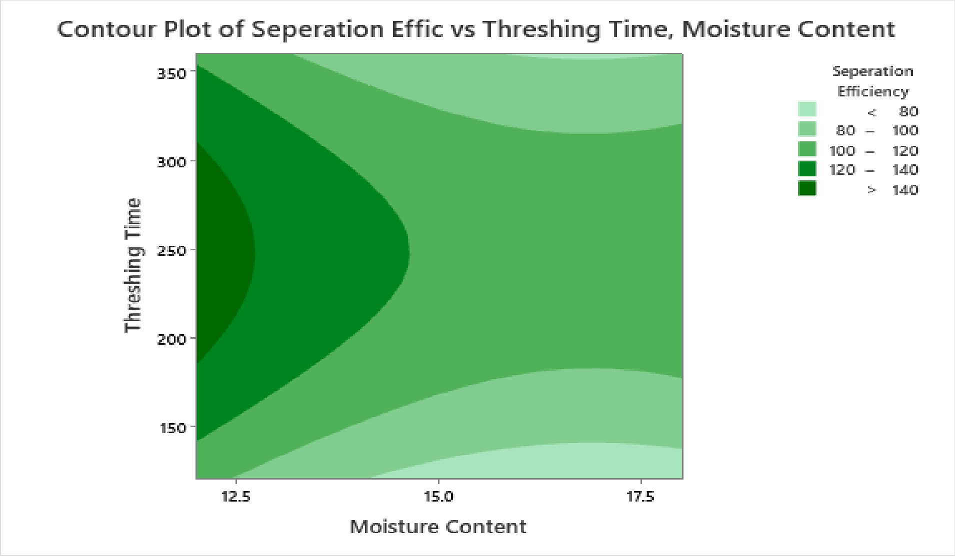


Figure 3.10: Contour plot of Separation Efficiency

3.1.4.4 Effect of factors on Cleaning loss

The cleaning loss incurred during threshing was analyzed using ANOVA, regression analysis, contour plot and surface plot as presented in Table 3.12, Equation 3.4, Figure 3.11 and Figure 3.12 respectively. Table 3.13 presents a model summary of the R square values.

Table 3.12: Analysis of Variance for Cleaning Loss

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	0.263445	0.052689	15.46	0.024
Linear	2	0.219368	0.109684	32.19	0.009
Moisture Content	1	0.000068	0.000068	0.02	0.897
Threshing Time	1	0.219300	0.219300	64.36	0.004
Square	2	0.042457	0.021228	6.23	0.085
Moisture Content*Moisture Content	1	0.027842	0.027842	8.17	0.065
Threshing Time*Threshing Time	1	0.014614	0.014614	4.29	0.130
2-Way Interaction	1	0.001620	0.001620	0.48	0.540
Moisture Content*Threshing Time	1	0.001620	0.001620	0.48	0.540
Error	3	0.010222	0.003407		
Total	8	0.273667			

Table 3.13: Model Summary Threshing Efficiency

S	R-sq	R-sq(adj)	R-sq(pred)
0.0583716	96.26%	90.04%	63.12%

Source: Researcher (2026)

$$\mathit{Cleaning\ Loss} = 1.23 + 0.381\,\mathit{Moisture\ Content} + 0.00360\,\mathit{Threshing\ Time} - 0.01311\,\mathit{Moisture\ Content} * \mathit{Moisture\ Content} - 0.000006\,\mathit{Threshing\ Time} * \mathit{Threshing\ Time} + 0.000056\,\mathit{Moisture\ Content} * \mathit{Threshing\ Time} \qquad \text{Equation 4.4}$$

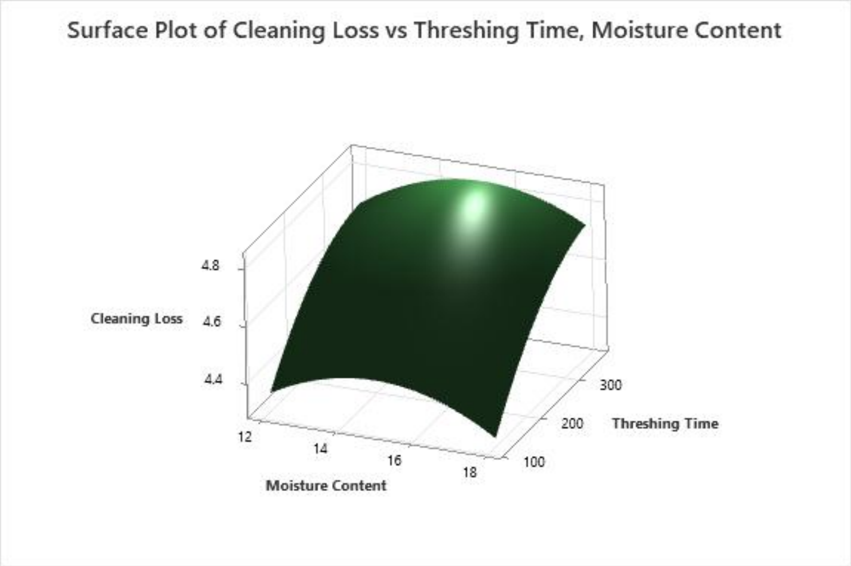


Figure 3.11: Surface plot of Cleaning Loss

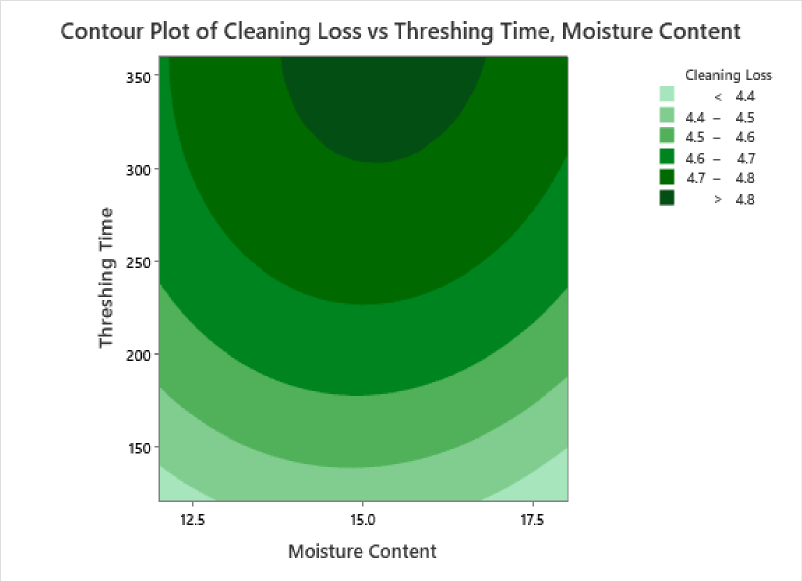


Figure 3.12: Contour plot of Cleaning Loss

3.1.3.1 Effect of factors on Separation Loss

The influence of moisture content and threshing time on the Separation loss is analyzed using ANOVA and its presented in Table 3.14 and 3.15. The regression equation is given in Equation 3.5. The response surface is presented in Figure 3.13 while the contour plot is presented in Figure 3.14.

Table 3.14: Analysis of Variance for Separation Loss

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	0.875234	0.175047	16.62	0.021
Linear	2	0.729851	0.364926	34.64	0.008
Moisture Content	1	0.000192	0.000192	0.02	0.901
Threshing Time	1	0.729659	0.729659	69.27	0.004
Square	2	0.141862	0.070931	6.73	0.078
Moisture Content*Moisture Content	1	0.092642	0.092642	8.79	0.059
Threshing Time*Threshing Time	1	0.049221	0.049221	4.67	0.119
2-Way Interaction	1	0.003520	0.003520	0.33	0.604
Moisture Content*Threshing Time	1	0.003520	0.003520	0.33	0.604
Error	3	0.031602	0.010534		
Total	8	0.906835			

Table 3.15: Model Summary Separation Loss

S	R-sq	R-sq(adj)	R-sq(pred)
0.102635	96.52%	90.71%	64.14%

$$Separation\ Loss = 0.46 + 0.696\ Moisture\ Content + 0.00690\ Threshing\ Time - 0.02391\ Moisture\ Content * Moisture\ Content - 0.000011\ Threshing\ Time * Threshing\ Time + 0.000082\ Moisture\ Content * Threshing\ Time \qquad \text{Equation 3.5}$$

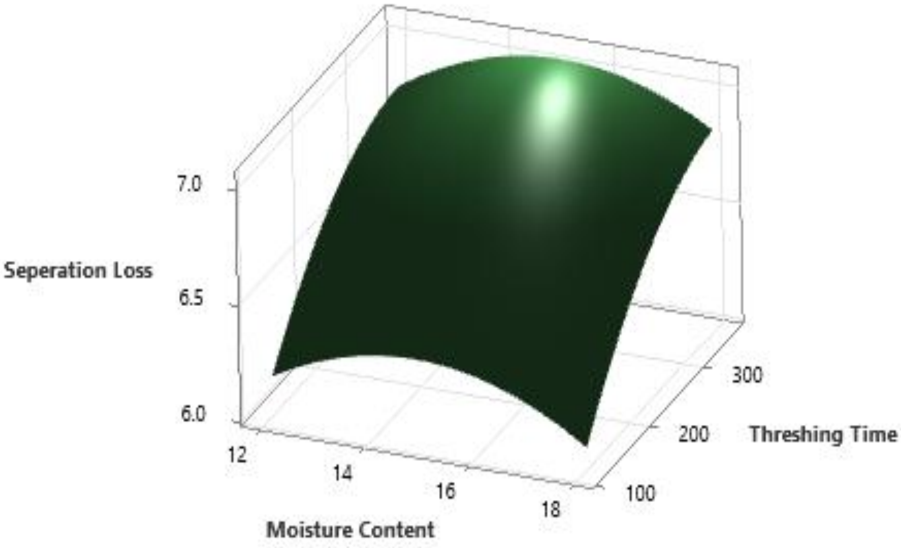


Figure 3.13: Surface plot of Separation Loss

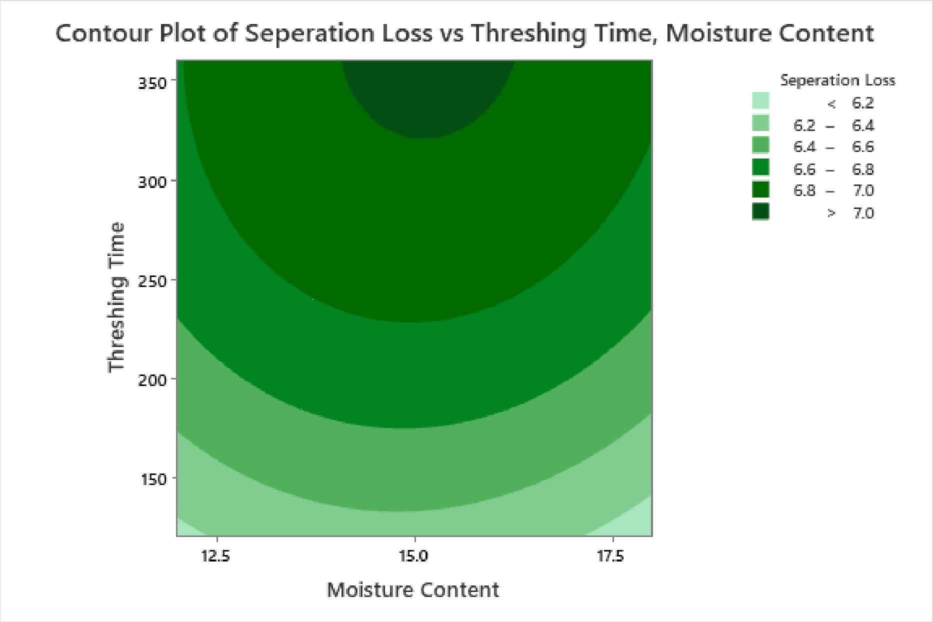


Figure 3.14: Contour plot of Separation Loss

3.1.3.2 Effect of factors on Total Grain Loss

The total grain loss incurred during threshing as influenced by moisture content and threshing time was analyzed using ANOVA, regression analysis, contour plot and surface plot as presented in Table 3.16, Equation 3.6, Figure 3.15 and Figure 3.16 respectively. Table 3.17 presents a model summary of the R square values.

Table 3.16: Analysis of Variance for Total Grain Loss

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	0.003009	0.000602	19.07	0.018
Linear	2	0.002514	0.001257	39.83	0.007
Moisture Content	1	0.000084	0.000084	2.65	0.202
Threshing Time	1	0.002431	0.002431	77.01	0.003
Square	2	0.000495	0.000247	7.84	0.064
Moisture Content*Moisture Content	1	0.000307	0.000307	9.74	0.052
Threshing Time*Threshing Time	1	0.000187	0.000187	5.94	0.093
2-Way Interaction	1	0.000000	0.000000	0.01	0.941
Moisture Content*Threshing Time	1	0.000000	0.000000	0.01	0.941
Error	3	0.000095	0.000032		
Total	8	0.003104			

Table 3.17: Model Summary Threshing Efficiency

S	R-sq	R-sq(adj)	R-sq(pred)
0.0056181	96.95%	91.87%	63.18%

$$Total\ grain\ Loss = 0.445 - 0.0399\ Moisture\ Content - 0.000481\ Threshing\ Time + 0.001377\ Moisture\ Content * Moisture\ Content + 0.000001\ Threshing\ Time * Threshing\ Time - 0.000001\ Moisture\ Content * Threshing\ Time \quad \text{Equation 3.6}$$

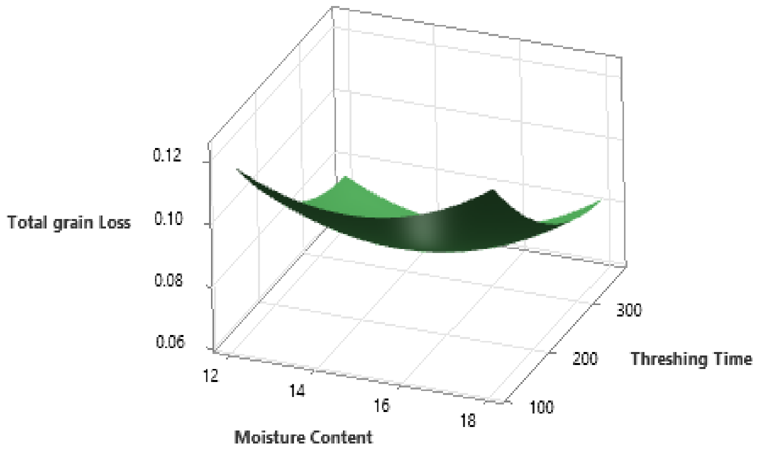


Figure 3.15: Surface plot of Total Grain Loss

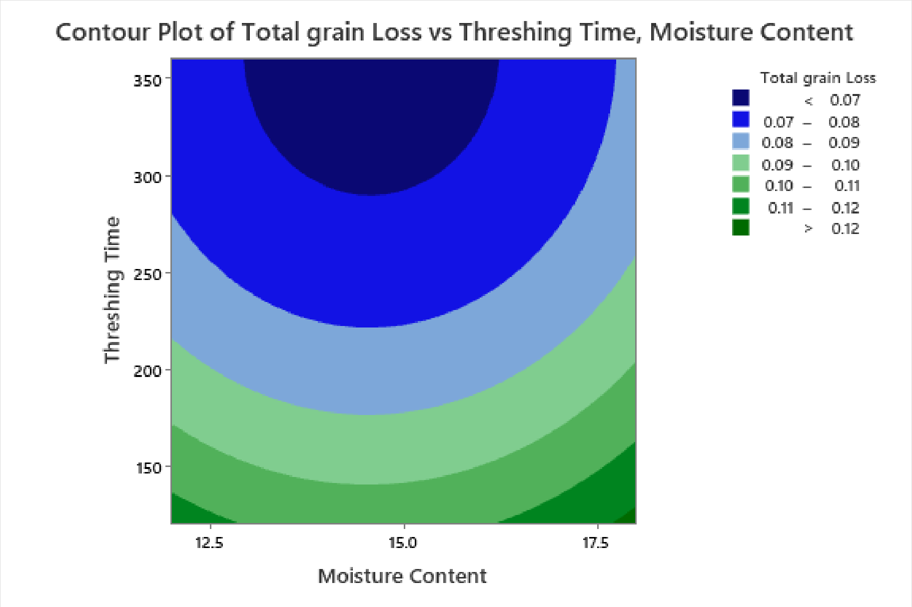


Figure 3.16: Contour plot of Total Grain Loss

3.1.3.3 Effect of factors on Throughput

The throughput capacity of the rice thresher was significantly affected by the threshing time as observed in the ANOVA. The summary of the ANOVA and the ANOVA was represented in Table 3.19 and 3.18 respectively

Table 3.18: Analysis of Variance for Throughput Capacity

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	1.17093	0.23419	770.35	0.000
Linear	2	1.09592	0.54796	1802.51	0.000
Moisture Content	1	0.00033	0.00033	1.08	0.375
Threshing Time	1	1.09559	1.09559	3603.93	0.000
Square	2	0.07445	0.03723	122.45	0.001
Moisture Content*Moisture Content	1	0.00274	0.00274	9.02	0.057
Threshing Time*Threshing Time	1	0.07171	0.07171	235.88	0.001
2-Way Interaction	1	0.00056	0.00056	1.83	0.269
Moisture Content*Threshing Time	1	0.00056	0.00056	1.83	0.269
Error	3	0.00091	0.00030		
Total	8	1.17184			

Table 3.19: Model Summary Throughput Capacity

S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**
0.0174355	99.92%	99.79%	99.05%

The regression equation stating the behavioral characteristics of the process variable on throughput capacity is represented in Equation 3.7.

$$\begin{aligned} Throughput = {} & 1.624 + 0.1131\, Moisture\ Content \\ & - 0.010365\, Threshing\ Time \\ & - 0.00412\, Moisture\ Content * Moisture\ Content \\ & + 0.000013\, Threshing\ Time * Threshing\ Time \\ & + 0.000033\, Moisture\ Content * Threshing\ Time \end{aligned}$$

Equation 3.7

Figure 3.17 and 3.18 represents the surface and contour plot o the influence of moisture content and threshing time on the throughput.

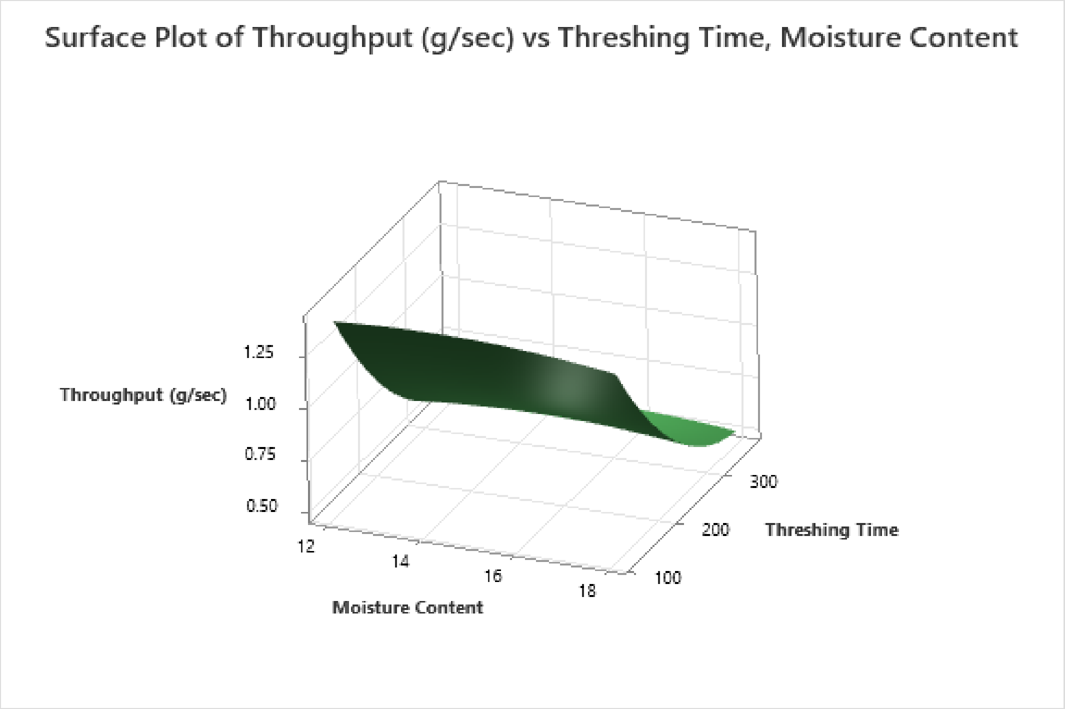


Figure 3.17: Surface plot of Throughput Capacity

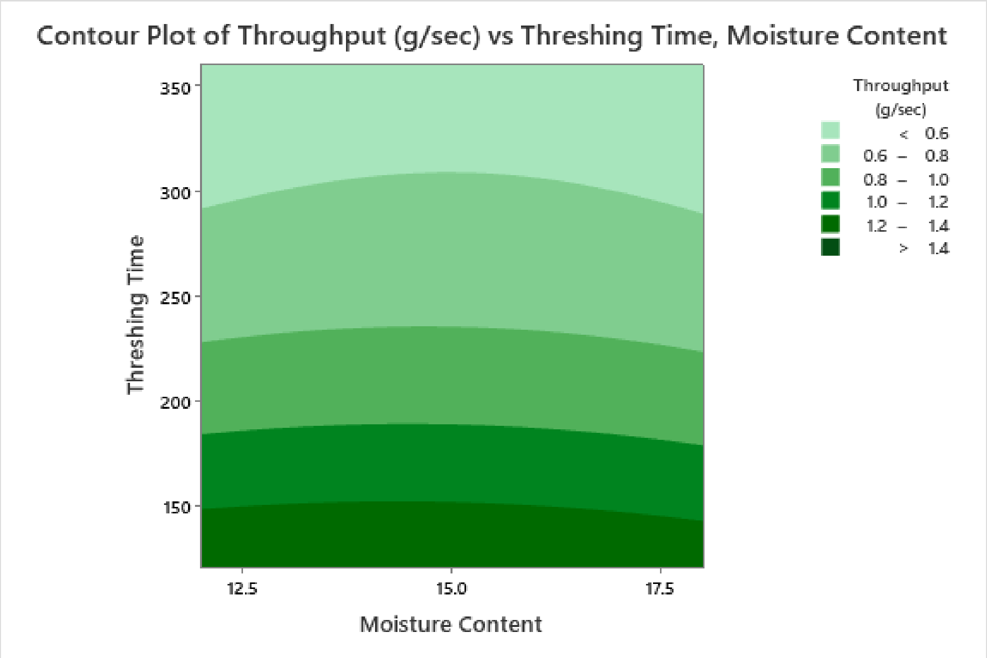


Figure 3.18: Contour plot of Throughput Capacity

3.2 Discussion

The results obtained from the design, fabrication, and performance evaluation of the rice thresher provide important insights into the effectiveness, reliability, and suitability of the machine for small- to medium-scale rice processing. This project focused on machine design parameters, operational performance, efficiency indices, and losses, while relating the findings to existing studies on rice threshers and grain processing machinery.

The overall design of the rice thresher demonstrates careful consideration of functional requirements, material availability, and operational efficiency. The frame dimensions of 450 mm by 450 mm by 733 mm provided adequate structural stability during operation. Similar frame proportions have been reported by Adewole *et al.* (2018), who emphasized that compact frames reduce vibration and enhance operational safety. The use of a trapezium-shaped hopper ensured smooth grain flow into the threshing drum. This hopper geometry aligns with the findings of Adeyeye *et al.,* (2019) Olaoye and Oyelade (2019), who reported improved feed uniformity with trapezoidal hoppers.

The cylindrical drum with a diameter of 390 mm was effective in achieving adequate threshing action. Drum dimensions play a critical role in threshing efficiency, as noted by Singh *et al.* (2017). The selected drum size provided sufficient contact between rice panicles and beaters, thereby improving grain detachment. The shaft design, incorporating angular beaters made from 4 mm rods arranged in nine rows and seven columns, enhanced the impact and rubbing action required for effective threshing. This configuration is consistent with earlier designs reported by Akande and Adebayo (2016), who highlighted the importance of beater arrangement in reducing unthreshed grain.

The screen dimensions and 1 mm hole spacing were appropriate for rice grain separation. Fine perforation sizes are known to reduce grain loss while maintaining cleaning efficiency. According to FAO (2016), screen perforation size should closely match grain dimensions to optimize separation. The belt and pulley system adopted in the machine enabled effective power transmission across the threshing unit, neutral joint, and blower. The use of A42, A44, and A66 belts ensured flexibility and minimized slippage during operation.

The electric motor used, with a power rating of 5.5 hp and speed of 3600 rpm, was adequate for driving the threshing and cleaning mechanisms. Similar motor specifications have been reported by Ibrahim *et al.* (2020) for small-scale rice threshers. The calculated torque at the electric motor (10.89 Nm) and threshing unit (22.19 Nm) indicated efficient power transfer. The higher torque at the threshing unit suggests effective speed reduction through pulley ratios, which is essential for minimizing grain breakage.

The calculated threshing velocity of 35.95 m/s falls within the recommended range for rice threshing. Studies by Miu and Kutzbach (2018) indicate that threshing velocities between 30 and 40 m/s provide effective grain separation without excessive damage. The angular velocities recorded at different machine components show a logical progression, with the highest angular velocity observed at the blower. This high blower speed contributed to effective cleaning by removing chaff and light impurities.

The hopper volume of 0.00287 m^3 was sufficient for batch feeding during experimental runs. Hopper capacity influences feed rate stability, as observed by Bello *et al.* (2019). The permissible feed rate of 0.5726 kg/s ensured controlled feeding, while the actual feed rate of 1.778 kg/s demonstrated the machine's ability to handle increased loading. However, higher feed rates were observed to affect threshing efficiency when threshing time is limited. The performance evaluation results revealed strong overall machine efficiency. The mean threshing efficiency of 80.72% indicates effective grain detachment from panicles. This value compares favorably with results reported by Adejumo *et al.* (2015), who recorded threshing efficiencies ranging from 75% to 85% for motorized rice threshers. The consistency across five experimental runs, as indicated by a standard deviation of 2.23, suggests reliable machine performance.

Cleaning efficiency recorded a mean value of 85.72%. This high cleaning efficiency reflects the effectiveness of the blower and screen combination. Similar cleaning efficiencies have been reported by Singh and Sharma (2016), who attributed high cleaning efficiency to appropriate airflow velocity and screen design. The separation efficiency of 81.11% further confirms the machine's capability to effectively separate grains from residues.

Stripping efficiency showed a comparatively low mean value of 3.23. This result is expected, as stripping efficiency typically measures the proportion of grains detached during initial impact. Low stripping values indicate that most grain separation occurred during threshing rather than stripping alone. This observation aligns with findings by Olaoye (2018), who noted that stripping efficiency is generally lower in drum-type threshers.

The analysis of machine losses provides additional insight into performance limitations. Drum loss recorded a mean value of 19.28%. Drum loss is often associated with unthreshed grains remaining attached to straw. This level of loss is comparable to values reported by Akande *et al.* (2017), who observed drum losses between 15% and 22% in similar machines. The reduction in drum loss across successive runs suggests improved operator familiarity and feed control.

Cleaning loss was relatively low, with a mean value of 4.42%. This indicates that minimal grains were blown away during the cleaning process. According to FAO (2016), cleaning losses below 5% are considered acceptable for small-scale threshers. Separation loss averaged 6.16%, which is within the range reported by Ibrahim *et al.* (2020). These losses may be attributed to improper airflow adjustment and grain overlap on the screen.

Total grain loss decreased progressively from 11.98% in the first run to 9.14% in the fourth run. This trend suggests that machine performance improves with consistent operation and operator adjustment. Similar trends have been reported by Bello and Adeoye (2019), who noted reduced losses after initial trial runs.

The evaluation of threshing efficiency under varying grain masses at a constant time of five minutes provides important operational insights. At a grain mass of 200 g, threshing efficiency exceeded 85%, indicating excellent performance at low feed rates. As grain mass increased to 300 g and 400 g, threshing efficiency declined to approximately 76% and 69%, respectively. This decline is attributed to increased material load, which reduced effective contact between grains and beaters (Yang, *et al.,* 2025a).

At higher grain masses of 500 g to 800 g, threshing efficiency dropped further to values below 65%. This result highlights the limitation of the machine at excessive feed rates. According to Singh *et al.* (2017), overloading threshing drums leads to reduced impact energy per grain and increased clogging. The consistent trend across replicates A, B, and C confirms the reliability of the observed pattern.

The inverse relationship between feed mass and threshing efficiency is consistent with earlier studies. Adejumo *et al.* (2015) reported similar efficiency reductions at higher feed rates. The results emphasize the importance of maintaining optimal feed rates to achieve high threshing efficiency and reduce losses.

The ANOVA results show that the model is statistically significant ($p = 0.021 < 0.05$), indicating that the selected factors adequately explain variations in threshing efficiency. The high R^2 value of 96.61% further confirms that the model explains most of the variability in the response. From the linear terms, threshing time was found to be highly significant ($p = 0.003$), while moisture content was not significant ($p = 0.774$). This implies that threshing efficiency is primarily influenced by the duration of threshing rather than the moisture level within the tested range. The square terms indicate slight curvature effects, particularly for moisture content ($p \approx 0.057$), suggesting that there may be an optimum moisture level beyond which efficiency does not improve significantly. However, the interaction between moisture content and threshing time was not significant ($p = 0.652$), indicating that both factors act independently. The surface and contour plots in Figures 4.5 and 4.6 shows that threshing efficiency increases with increasing threshing time, while moisture content has a relatively mild effect. This aligns with the mechanical principle that longer exposure to threshing action enhances grain detachment.

The ANOVA results for cleaning efficiency indicates that the model is not statistically significant ($p = 0.961$), with a very low R^2 value of 21.31% . This suggests that moisture content and threshing time do not significantly affect cleaning efficiency. Both moisture content ($p = 0.579$) and threshing time ($p = 0.709$) were not significant, and neither were their quadratic or interaction terms. This indicates that cleaning efficiency is likely controlled by other machine parameters such as airflow, sieve design, or blower efficiency rather than the variables considered in this study. The surface and contour plots show no clear trend, confirming that variations in moisture content and threshing time do not meaningfully influence cleaning efficiency (Vanitha, *et al.,* 2025).

The ANOVA results shows that the model for separation efficiency is not significant ($p = 0.665$), with a moderate R^2 value of 53.57%. Both moisture content ($p = 0.347$) and threshing time ($p = 0.760$) were statistically insignificant. The lack of significance indicates that separation efficiency is not strongly influenced by these factors within the experimental range. Instead, separation efficiency is more dependent on machine design features such as concave clearance, sieve motion, and airflow characteristics. The response surface plots show irregular patterns without a clear trend, supporting the conclusion that the selected factors do not significantly affect separation efficiency (Yang, *et al.,* 2025b).

The ANOVA results indicated that the cleaning loss model is statistically significant ($p = 0.024$) with a high R^2 value of 96.26%. This indicates that the model adequately explains variations in cleaning loss. Threshing time was found to be highly significant ($p = 0.004$), while moisture content remained insignificant ($p = 0.897$). This suggests that cleaning loss is mainly influenced by the duration of threshing. As threshing time increases, cleaning loss also increases due to excessive agitation, which may cause grains to be blown away with chaff. The quadratic terms indicate slight curvature, suggesting that excessive threshing time leads to diminishing returns. The surface plots show an increase in cleaning loss with increasing threshing time, reinforcing the need to optimize threshing duration.

The ANOVA results illustrates that the model is significant (p = 0.021) with a high R² value of 96.52% for losses incurred during separation. Similar to cleaning loss, threshing time is highly significant (p = 0.004), while moisture content is not. This shows that prolonged threshing increases separation loss, likely due to grain scattering or excessive mechanical impact. The quadratic terms suggest that separation loss increases more rapidly at higher threshing durations. The contour plots confirm that separation loss increases with threshing time, emphasizing the need for controlled operation.

During threshing, grain loss are inevitable. The ANOVA results expresses how the model is significant (p = 0.018) with a high R² value of 96.95%. Threshing time again emerges as the dominant factor (p = 0.003), while moisture content is not significant. This indicates that total grain loss is primarily influenced by threshing duration. Longer threshing times lead to increased losses due to both cleaning and separation losses. The response surface plots show a clear trend of increasing grain loss with increasing threshing time, highlighting the importance of optimizing threshing duration.

The ANOVA results shows that the model for the throughput capacity is highly significant (p = 0.000) with an exceptionally high R² value of 99.92%. This indicates an excellent model fit. Threshing time was found to be extremely significant (p = 0.000), whereas moisture content was not significant (p = 0.375). This confirms that throughput capacity is primarily determined by the rate at which the machine processes material over time. The negative quadratic effect of threshing time suggests that excessively long threshing durations reduce throughput efficiency due to slower processing rates. The surface plots show that throughput decreases as threshing time increases, indicating a trade-off between efficiency and productivity.

From the Data analysis, the results consistently show that the threshing time is the most influential factor affecting almost all performance parameters, moisture content has minimal direct statistical significance within the tested range, increasing threshing time improves threshing efficiency but also increases losses and reduces throughput (Wang, *et al*., 2024).

Thus, an optimum operating condition must be selected to balance efficiency, grain quality, and machine performance.

Overall, the results demonstrate that the developed rice thresher performs effectively within recommended operating conditions. The machine design parameters contributed positively to performance outcomes. The efficiencies obtained are comparable to those reported in published literature, confirming the validity of the design approach. While some losses were observed, they remain within acceptable limits for small-scale rice processing.

The findings suggest that the machine is suitable for rural farmers and small processing units. With minor modifications, such as adjustable feed control and improved airflow regulation, performance could be further enhanced. The study contributes to ongoing efforts to improve mechanized rice processing in developing regions like Nigeria.

4. CONCLUSION

The work ‘’Design and Production of a Rice Threshing Machine to Enhance Rice Harvesting in Nigeria’’ has been carried out with the intent of boosting rice production in Nigeria. From the detailed study carried out on the research work, the following conclusions were drawn from the work:

1. The research work designed and produced a rice threshing machine for rice threshing after rice harvest.
2. The research work evaluated the cost of producing a unit of the machine and put the cost at ₦450,000 ($331.6), while the performance evaluation cost was ₦100,000 ($73.69).
3. The study evaluated the performance of the produced rice threshing machine and measured parameters such as stripping efficiency, threshing efficiency, cleaning efficiency, total weight of chaff, separation efficiency, grain losses and threshing throughput capacity.
4. The study carried out DOE and analysis of data.
5. The research study revealed that the stripping efficiency of the rice threshing machine was 3.23, the threshing efficiency was 80.72, the cleaning efficiency was 85.72, and the separation efficiency was 81.11.
6. The research work showed that grain losses were as follows: drum losses 19.28, cleaning losses 4.42, and separation 6.16.

7. The study showed that the weight of grain produced decreased with increased efficiency.
8. The study developed model equations for cleaning efficiency, separation efficiency, cleaning losses, separation losses and total grain loss.
9. The study observed that the throughput capacity of the rice thresher was significantly affected by the threshing time. The ANOVA results show that the model for the throughput capacity is highly significant (P = 0.0000) with an exceptionally high R^2 value of 99.92%. This indicates an excellent model fit.
10. Threshing time was find to be extremely significant (P= 0.0000), whereas moisture content was not significant (P = 0.375). This confirms that throughput capacity is primarily determined by the rate at which the machine processes material over time.

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