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Design and Development of Petrol Engine Powered Rice Harvester

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Abstract
Towards finding a solution to the re-current problem of rice harvesting in Northern Nigeria, bearing in mind that small scale farmers use manual method by sickles and knife, which is time consuming, drudgery and very tedious, while the use of mechanical means involves the importation of harvesters from foreign countries at high cost. Therefore, the need to develop and fabricate rice harvesters locally becomes very necessary, hence, the aim of this work was to design and fabricate a rice harvester to improve on rice harvesting, reduce drudgery, save time and losses. Consequently, the results show the designed in isometric and autographic projection, fabricated machine, and the simulation of the solid work and the ANOVA result on cutting efficiency. The rice harvester was developed and fabricated in the workshop of the Department of Agricultural and Bio-resources Engineering, Ahmadu Bello University, Zaria, Nigeria. It is recommended that the developed machine be adopted because it is lightweight, inexpensive, easy to assemble and disassemble, easy to operate and, affordable for the small-scale farmers.

Keywords: *Design, Development, Petrol Engine, Rice harvester*

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1. Introduction

Rice harvesting depends on its physiological maturity, and is susceptible to shattering if delayed and result to losses (Imrul *et al*., 2017). Harvesting of rice is an operation that is achieved through manual or mechanical methods (Olukunle, 2010). In Nigeria it is done predominately through manual method by hand picking or using knife or sickle. This method involves intensive labour requirement, which is a major constraint to rice production in Nigeria. Hence, a mechanical way of harvesting is needed to confront the challenges facing rice harvesting. The mechanical method of harvesting unlike manual method can handle more land in lesser time with less drudgery (Agidi, 2015). Records of rice harvesters show that a good amount of work has been done in the developed countries. For example, a combined harvester, which incorporates reaping, threshing, cleaning and bagging, can handled tons of crop in a single day (Olukunle, 2010). But land fragmentation, spare parts facilities for repairing it, poor technical known how of operation / maintenance and it cost are among its disadvantages as most small-scale Nigerian farmers cannot afford the price (Imrul *et al*., 2017).

Other mechanical harvesters had been developed to tackle these disadvantages such as mechanical reapers and binders. However, these machines have their shortcomings too, namely the difficulties of applying reapers in field conditions, much labour for gathering and transferring the panicles along with the straws (Nguyen, 2006). The mechanical, engineering and physical properties of the grain crops relative to the design process of such machines to eliminate losses due to handling are also a disadvantage for both reapers and binders at field performance (Ajav and Fakayode, 2013). Similarly, the choice of foreign machineries is not quite appropriate due to factors like size of the farm. Considering the small-scale farmers in Nigeria, the need to further develop the harvester that is affordable and can be available to them becomes compulsory. The aim of this study is to develop a rice harvester using local available materials.

2. Materials and methods

2.1 Materials selection

The selection of materials was done base on the affordability, qualities and standard. The materials were sourced locally and selected based on their coast, availability, strength in relation to the forces acting on them on the machine. Materials such as galvanized angle pipe, cast iron, mild steel flat bars, flat bar and panel saw, rivets, bolts and nuts were selected based on their strength, toughness, brittleness, high relative density, malleability and ductility.

2.2 Machine design

Steps in the design process included conceptual stage, embodiment stage and detail stage (Godfrey, 2013). As in seen in Fig. 1 and 2, the design was made in third angle projection showing both the isometric and orthorgraphic projection which consist of bevel gears, gear box, cutting blade, front and real wheels, front wheel chain drive, blade crack link, cutting blade cranck link, double groove belt, prime mower, frame and handle

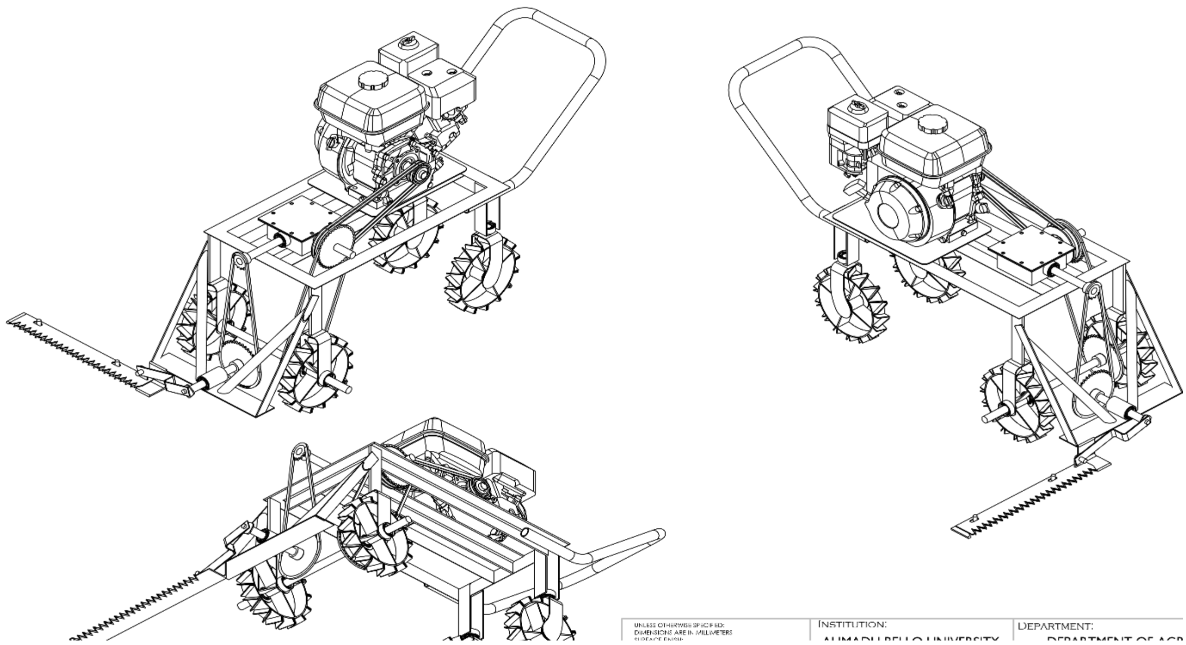

Fig. 1: Isometric drawing of the rice harvester

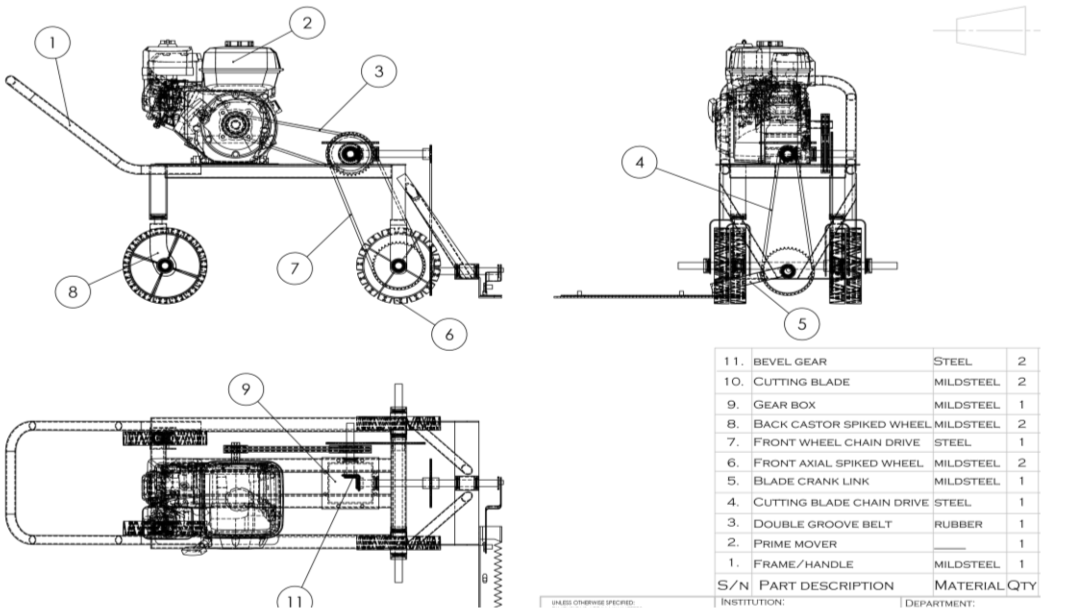

Fig. 2: Autographic projection of the rice harvester

2.3 Design considerations

The design considerations employed were as itemized below:

i. **Power source**

Considering that it might be very tedious for an operator to handle a completely mechanical machine, a petrol engine was employed in this machine to aid ease of handling the machine and also give a steadier cutting operation.

ii. **Cutting capacity**

The cutting blade and associated mechanisms such as the chain and gear drives were selected appropriately considering their compactness and their regular fixed velocity ratio output in order to make the cutting action more effective as designed for. Thus, aside from the linear blades preferred over the circular type, the length of the cutting blades was estimated to about 0.5m to aid cutting of more than 10 packed stems of rice stalks across parallel rows.

iii. **Traction/rigidity**

In order for the machine to be more stable while deployed to service within the farmland, the wheels were made to have teeth; even though the front wheels are axially linear, the back wheels were made to allow for swerving where there be the need for manoeuvres. The placement of the component parts on the device were effectively done to reduce excessive eccentricity of load on the framework (this will in-turn reduce instability and increase rigidity).

iv. **Ease of fabrication/maintenance**

Considering the ease of fabrication and maintenance, the CAD design was made to be very simple. In addendum, locally sourced materials were employed in constructing the device such that it would allow for easy maintenance.

2.4 Design assumptions

i. Translational motion was limited to 20mm.
ii. A maximum translational cutting blade speed of 300mm/s was assumed.
iii. Minimum efficiencies of belt drive, chain drive and straight bevel gears were 95%, 98% and 97%, respectively (Grainger, 2019)
iv. A toothed wheel was adopted with external diameter of 280mm

2.5 Design theory and calculations

i. **Cutting force**

The magnitude of cutting force which is also called shearing force was depended upon the area that was cut and mechanical properties of stock material. The force required to shear the blank or slug was calculated using Equation (1) (Singh, 2020)

$$F_{sh} = lt\tau_{max} \tag{1}$$

where, F_{sh} is the shearing force (N), l is the length of cut / perimeter of the stalks of rice (mm), t is the thickness of stalks material (mm), τ_{max} is the ultimate shear strength of rice stalk (N/mm^2)

ii. **Cutting power required by the blade**

Considering that the blades which slides across each other in a translational manner, the cutting power was calculated using Equation (2) (Khurmi and Gupta, 2005)

$$P_{sh} = F_{sh}v_{sh} \tag{2}$$

where P_{sh} is the shearing power required (W). v_{sh} is the adopted shearing velocity (m/s)

iii. **Speed of the lower base shaft**

The eccentricity required for converting rotational motion to translational motion was obtained by Equation (3) (Khurmi and Gupta, 2005) as

$$e = \frac{d_{cb}}{2} \tag{3}$$

where, e is the eccentricity required on the base shaft (mm.),d_{cb} is the maximum instantaneous translational displacement of the cutting blade (mm).

Also, the rotational velocity of the base shaft was obtained as:

$$N_{bs} = \frac{60v_{sh}}{\pi d_{cb}} \tag{4}$$

where N_{bs} is the angular speed of the base shaft (rpm), v_{sh} is the adopted shearing velocity (m/s), and d_{cb} is the maximum instantaneous translational displacement of the cutting blade (mm).

iv. **Selecting the petrol engine**

The petrol engine for the machine was selected based on power requirement of the machine for its operation as well as its motion and transmission systems efficiency using Equation (6) (Khurmi and Gupta, 2005).

$$P_{pm} = P_D\eta_b\eta_{ch}\eta_{bg}\eta_{ch} \tag{6}$$

where P_{pm} is the power requirement of the petrol engine prime mover (W),P_D is the design power requirement for cutting the rice stalks (W),η_b is the efficiency of the belt drive (%), η_{ch} is the efficiency of the chain drive (%), η_{bg} is the efficiency of the bevel drive (%).

v. **Rotational speed of the gearbox input shaft**

The input shaft of the gearbox gets its rotational torque from the prime mover through a belt drive, calculated using Equation (7) (Khurmi and Gupta, 2005).

$$N_{is} = \frac{d_{pm} \times N_{pm}}{d_{is}} \quad (7)$$

where N_{is} is the rotational speed of the gearbox input shaft (rpm),d_{is} is the diameter of the pulley on the gearbox input shaft (mm), N_{pm} is the rotational speed of the prime mover output shaft (rpm), and d_{pm} is the diameter of the pulley on the prime mover output input shaft (mm).

vi. **Length of belt**

Length of belt was obtained using the relation given in Equation (8) (Khurmi and Gupta, 2005)

$$l_b = \frac{\pi}{2}\left(d_{is} + d_{pm}\right) + 2x + \frac{\left(d_{is} - d_{pm}\right)^2}{4x} \quad (8)$$

where l_b is the length of the belt (mm), d_{is} is the diameter of the pulley on the gearbox input shaft (mm), d_{pm} is the diameter of the pulley on the prime mover output input shaft (mm), and x is the center distance between the prime mover output shaft and gearbox input shaft (mm)

vii. **Selection of chain drive for the gearbox output shaft and the base shaft**

The chain drive transmitting power was obtained as described by Equation (9) (Khurmi and Gupta, 2005).

$$V.R = \frac{N_{is}}{N_{bs}} = \frac{T_{bs}}{T_{is}} \quad (9)$$

where $V.R$ is the velocity ratio, N_{is} is the rotational speed of the gearbox input shaft (rpm), N_{bs} is the rotational speed of the base shaft (rpm), T_{is} is the number of teeth on the gear-box input shaft, and T_{bs} is the number of teeth on the base shaft.

viii. **Shaft diameter**

The minimum shaft diameter was obtained by designing it against bending and twisting forces using the ASME shaft design code given by Equation (10) (Khurmi and Gupta, 2005).

$$d_{sw} = \sqrt[3]{\frac{16}{\pi\tau}\sqrt{(K_m M)^2 + (K_t T)^2}} \quad (10)$$

where d_{sw} is the safe diameter for the wheel axial shaft (mm),M is the maximum bending moment upon the shaft (Nm),K_m is the combined shock and fatigue factor for bending (1.75), K_t is the combined shock and fatigue factor for Torsion (1.50),T is the maximum torque transmitted by the shaft (Nm), and τ is the maximum allowable shear stress on the shaft material (N/m^2).

2.6 Materials and cost

The cost of materials used for the construction of the rice harvester is presented in Table 1.

Table 1: Cost of materials used for the construction of the rice harvester.

Description	Quantities	Unit Cost	Total Cost
30mm 30mmanngle iron	3	2,750	8,250
2mm sheet metal	2	2,950	5,900
18mm diameter rod	1	2,100	2,100
Cutting blades	2	7,500	15,000
30mm diameter shaft	3	2,500	7500
G 12 electrodes	2pks	2,000	4,000
B 72,67, v- belts	2	950	1,900
Gross paint	I tin	2500	2500
Bearings	6	550	3,300
Bevel gears	2	1300	2,600
Chain and sprocket	2	1150	3100
5HP Prime Mover	1	22000	22000
TOTAL			78,150

2.7 Development and fabrication process

Three basic components that includes cutting unit, power source and power transmission system were considered. The cutter bar, ground wheel, shaft, frame, and other necessary parts of the rice harvester were made of MS angles iron, MS rod, MS flat bar and square bar. The frame was made capable of bearing the weight of the prime mover and cutting unit. The overall length and width of the harvester was 1664 mm and 400 mm, respectively. The weight of the harvester was calculated or determined to reduce the total weight of the machine and drudgery on the operator. Where permanent fixture was necessary, the parts were properly welded. Some parts were firmly tightened with bolts and nuts where adjustments were regularly required. Two numbers of galvanized pipes were bent to carry the wheel shaft.

2.8 Performance indicator

i. Cutting efficiency

$$CE = \left\{\frac{W_1}{W_2}\right\} 100 \ (\%) \qquad (11)$$

where CE= Cutting efficiency, %, W_1 = No. of plants before cutting; W_2 = No. of plants left after cutting

3. Results and discussion

3.1 Machine description

The Rice harvester as seen in Fig. 3 to 6 comprise various working sections; ranging from power source, power transmission components, cutting components amongst others. The machine has its power source from a petrol engine, parts attached directly to this power source were belt and chain drive; double-groove belt drive connecting to the gear box input shaft and a chain drive connecting the gearbox input shaft to the front axial spiked wheels. Within the central gear box were two equal bevel gears for input and output torque concurrently. Thus, the output shaft was connected to a lower parallel shaft; this shaft has been the actuation source for the cutting blade through a connecting crank link. The connecting clank link was connected in such an eccentric manner to the lower parallel shaft such that a constant translational motion was obtained between the lower and upper cutting blade.

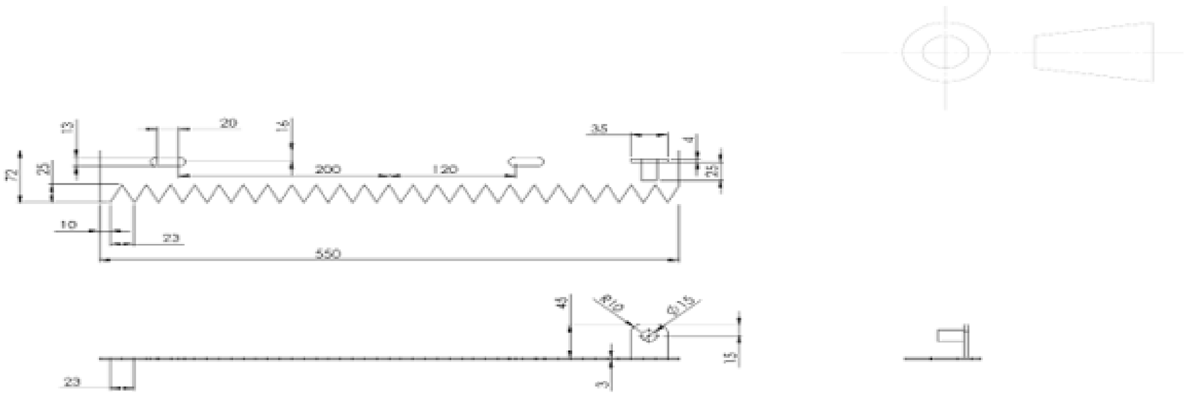

Fig. 3: Cutter bar

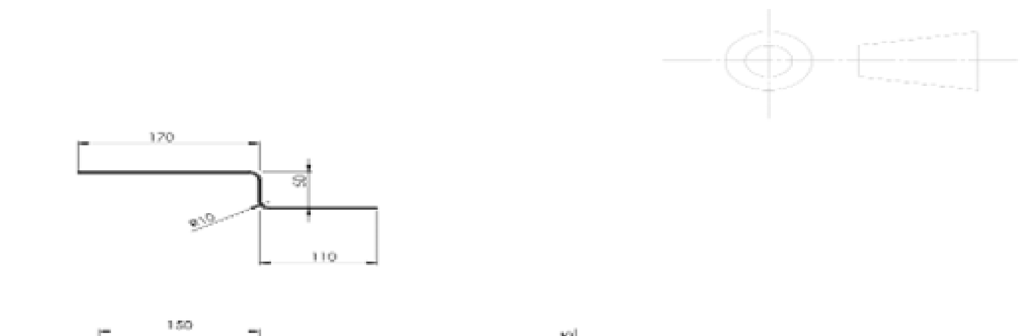

Fig. 4: Cutter bar crank

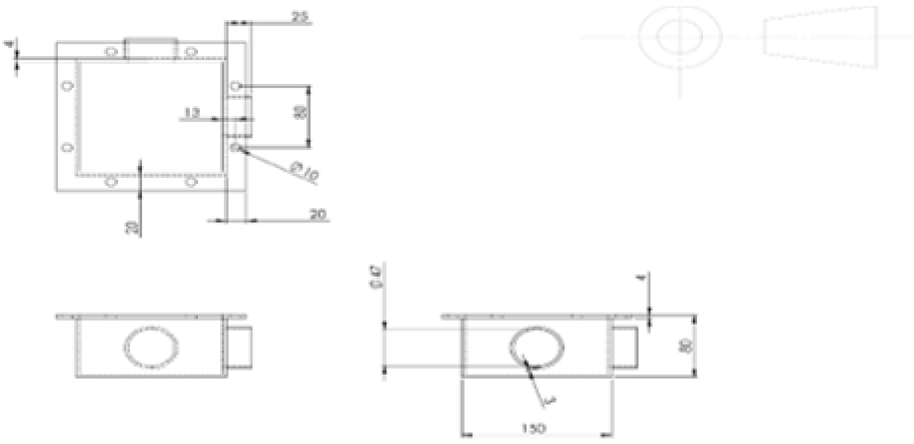

Fig. 5: Working drawing of the gear box

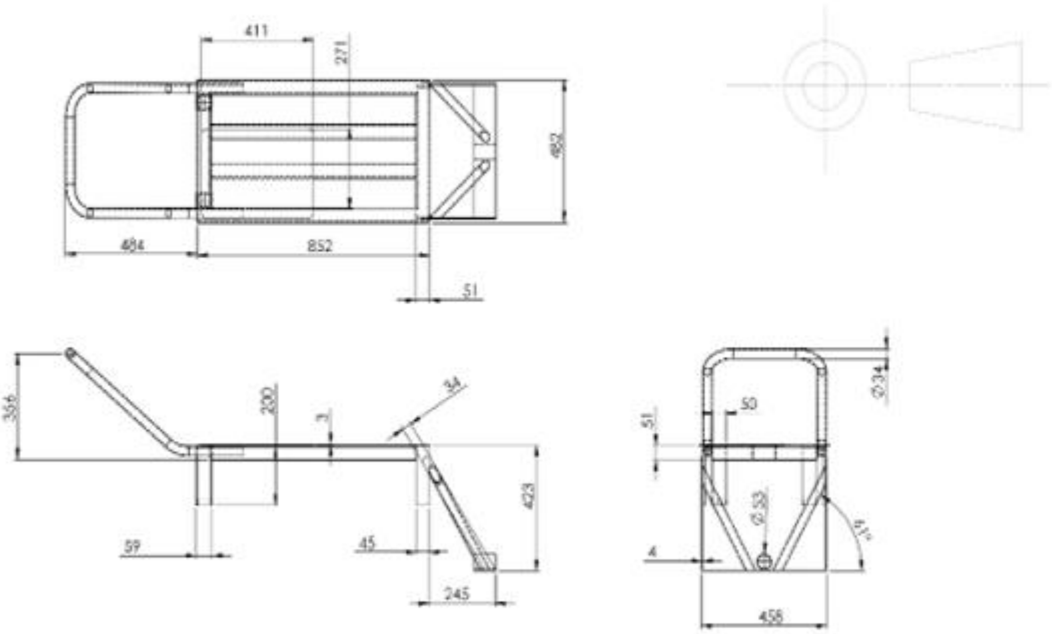

Fig. 6: Working drawing of the frame

3.2 Working principle of the machine

The cutting action of the machine seen in Fig. 7 was based on translational motion of two sharp adjacent blades placed by the frontal side of the machine. One prime mover (i.e. a petrol engine) was used in powering both the cutting blades as well as the motion of the device. Even though the source of linear motion is from the front traction wheels, there were two swivel/castor wheels behind that would assist the operator in navigating/manoeuvring the device within the farm land while harvesting the rice stalks.

Assembly drawing of the rice harvester adequately describes the linkages between various parts of the machine. Once the petrol engine is put on, the double grooved belt drive connected from the engine transmits rotational torque to the input shaft of the gear box; considering the selected sizes of the pulleys, the speed was reduced. On this input shaft thus, a selected chain drive is then used in reducing the rotational speed from the gearbox input shaft to the shaft of the front traction wheels. Within the gearbox, equal and perpendicular bevel gears/shafts are then connected to such extent that the output shaft gives same rotational speed and torque as the input shaft. Thus, a speed reduction chain drive is then used in transmitting rotational torque to the lower base parallel shaft (on this shaft, the speed was reduced further). Thus, the cutting blade gets its translation motion from this lower rotating shaft through a connecting crank link. The machine also has a handle behind that helps the user get full hold of it while being used on the farmland. This is different from the reports presented by other researchers (Imrul *et al.*, 2017; Wagiman *et al.*, 2019; Ashaful *et al.*, 2018).

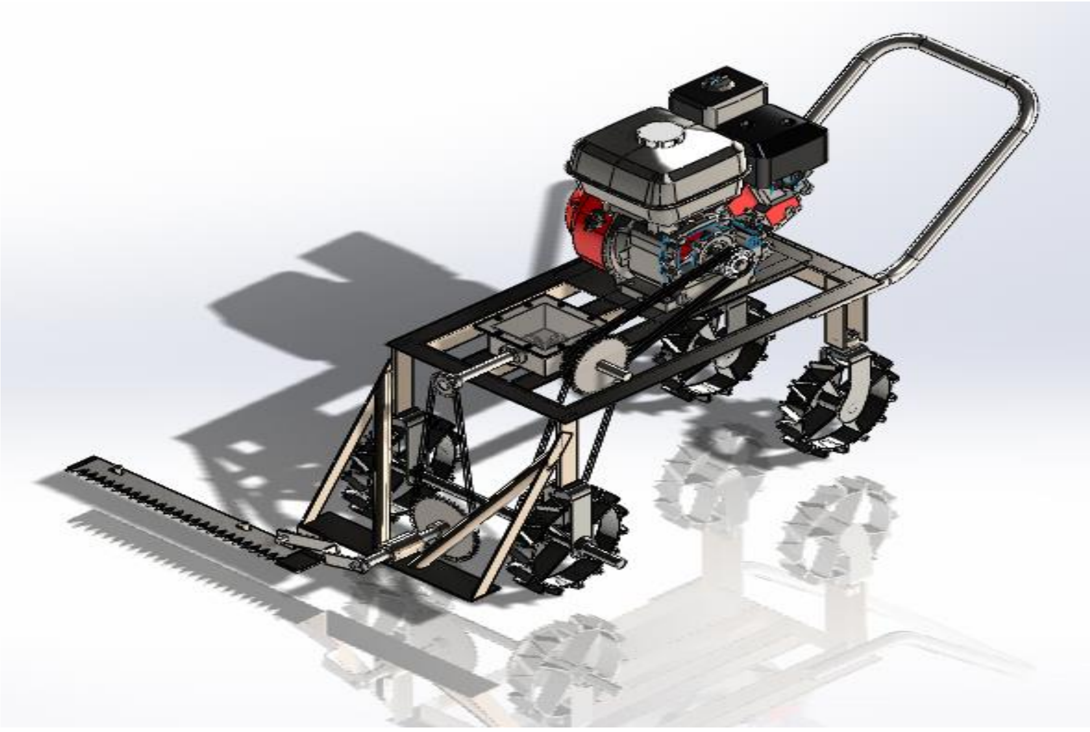

Fig. 7: Developed rice harvester

3.3 Simulation of the solid work

The simulation of the solid model by finite element mesh analytical method was done for the frame on the stress at maximum of 2.62N/m^3 and the minimum of 0.3N/m^3. While the strain was calculated to be at maximum of 0.0055 and minimum of 0.001. The displacement on the frame was noted to be 16.17mm at maximum while at minimum it was noted to be 0.01mm. Other calculated properties were the yield strength (6.204N/m^2), tensile strength (7.238N/m^2) and elastic modulus (2.1N/m^2). This is similar to the report of Abdulkarim *et al*. (2017).

3.4 Testing the machine

3.4.1 Effect of height, speed and moisture on cutting efficiency (CE) in 2020 and 2021.

Table 2 shows that height, speed and moisture content show no (P ≥0.05) effect on CE in 2020 wet season. However, in 2021 wet season, the result reveals that height, speed and moisture content show effect (P ≤ 0.01). And the highest CE (69.0%, 68.8%), were recorded at the height, speed and moisture content of 20cm, 5mls and 20%.

Table 2: ANOVA result of height, speed and moisture on cutting efficiency

	2020					2021				
SOURCE	DF	SS	MS	F.Val.	Pr > F	DF	SS	MS	F.Val.	Pr > F
Rep	2	409.302	204.65	1.67^{ns}	0.1984	2	419.05	209.526	1.96^{ns}	0.1515
Height (H)	2	744.214	372.10	3.03^{ns}	0.0567	2	1632.2	816.147	7.63**	0.0012
Speed (S)	2	73.920	36.960	0.30^{ns}	0.7411	2	1088.4	544.249	5.08**	0.0096
Moist(M)	2	214.34	107.17	0.87^{ns}	0.4234	2	1105.0	552.532	5.16**	0.0090
H*S	4	91.118	22.779	0.19^{ns}	0.9448	4	327.51	81.8789	0.76^{ns}	0.5529
H*M	4	1195.6	298.91	2.44*	0.0586	4	850.39	212.598	1.99^{ns}	0.1103
S*M	4	346.34	86.585	0.71^{ns}	0.5915	4	94.388	23.5970	0.22^{ns}	0.9258

H*S*M	8	1864.6	233.07	1.90^{ns}	0.0797	8	1609.0	201.137	1.88^{ns}	0.0834
Error	52	6377.28	122.64			52	5565.6	107.032		
Total	80	11316.8				80	12692.			

ns= not significant *= Significant at ($P\leq 0.05$) **= Significant at ($P\leq 0.01$)

3.4.2 Interaction of height, speed and moisture content on cutting efficiency

Table 3 shows the highest CE (74.9%) at 25cm, 4m/s and 20% height, speed and moisture content respectively. While the lowest CE (57.9%) was realized at the height, speed and moisture (25cm, 3mls, 13%) respectively. This is similar to the report of Ogunlowo, and Olaoye (2017), who realized a higher cutting efficiency of 91.83%, at moisture content of 21.2% and engine speed of 1400rpm respectively. The values collaborated the observation made by Ojomo *et al.* (2012) and Moheb (2006).

Table 3: Interaction of height, speed and moisture on cutting efficiency

Treatment (selected)	Cutting efficiency (%)
$H_2S_3M_3$	64.0a-g
$H_3S_1M_1$	57.9b-h
$H_3S_1M_2$	62.4a-g
$H_3S_2M_2$	74.9a
$H_3S_3M_3$	74.6a
SE±	4.372

Means by same letter(s) are not different at *P=0.05* using DMRT. H_1 = 15cm H_2 = 20cm H_3 = 25cm S_1 = 3m/s S_2 = 4m/s S_3 = 5m/s M_1 = 13% M_2 = 20% M_3 = 27%

4. Conclusion

On the basis of the designed and the development of the rice harvester the following conclusion were drawn; The harvesting machine is lightweight, inexpensive, easy to assemble and disassemble, easy to operate and cost effective, hence affordable by the small scales. Also, it will provide reduction in drudgery during rice harvesting hence changing farmers' status, attracting youths and women into taking up rice production in Nigeria. While the servicing and maintenance will be easy due to availabilities of spare parts and skilled labour such as harvester mechanic. And many labourers can begin leaning and practicing repair and maintenances of the machine. The income–from sales, and maintenance services can improve the economy of Nigeria.

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