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Modification of a Hand-Guided Motorized Two-Row Cowpea Planter (*Vigna unguiculata* (L) Walp)

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Modification, Cowpea Planter, Seed Metering Mechanism, Power Transmission, Gear Reduction, Performance Evaluation

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ABSTRACT

Cowpea (Vigna unguiculata (L) Walp) is an essential leguminous crop widely cultivated in sub-Saharan Africa for its nutritional and economic benefits. However, traditional planting methods are labor-intensive, inefficient, and contribute to low productivity. This study aimed to modify and evaluate the performance of an existing hand-guided motorized two-row cowpea planter to enhance planting efficiency and seed placement accuracy. Key modifications included improvements in the power transmission system using a gear reduction mechanism (1:20 ratio) to regulate planting speed, optimization of the seed metering mechanism for uniform seed distribution, and structural enhancements for better operational efficiency. The modification on the planter was done using locally available materials to ensure cost-effectiveness, durability, and ease of maintenance. It was observed that the operation speed of the machine affects all the parameters, which include: theoretical and effective field capacity (ha/h), field efficiency (%), fuel consumption (l/ha) and percentage field germination (%) evaluated during the performance evaluation of the machine. As operation speed increased from 0.192 to 0.228 km/h, theoretical field capacity (ha/h), effective field capacity and fuel consumption (l/ha) increased from 0.1922 – 0.2278 ha/h; 0.1389 - 0.1818 ha/h and 6.55 – 7.50 l/ha, respectively. the highest field efficiency was obtained at an operation speed of 0.214km/h, while percentage seed germination ranged from 84.62 – 92.31 % and the total area covered during the operation was 0.0267 ha. The results were higher compared to those obtained by the existing cowpea planter, where the minimum effective field capacity and field efficiency were 0.044ha/h and 69.8 %, respectively and the maximum effective field capacity and field efficiency were 0.057ha/h and 71.1 %. Therefore, the modified cowpea planter improved seed placement, reduced labour and drudgery and enhanced machine functionality. The study recommends extensive field testing under various soil conditions and the potential integration of additional features such as fertilizer application and adjustable row spacing to increase versatility and adoption among smallholder farmers.

INTRODUCTION

Cowpea (*Vigna unguiculata* (L) Walp) is a grain legume, a major staple food crop for household nutrition in sub-Saharan Africa, especially in the dry savanna regions of West Africa. It plays an important role in human nutrition, food security, and income generation for both farmers and food vendors in the region. Cowpea belongs to the family Fabaceae and sub-family Faboideae (Guimarães *et al.,* 2023). Commonly used names of cowpea include southern pea, black eye pea, crowder pea, labia, niece, coupe, or frijole (Horn and Shimelis, 2020). Some other important local names for cowpea around the world include “niebe,” “wake,” and “ewa” “caupi” in Senegal, Hausa, Yoruba and Brazil, respectively (Ogunnigbo *et al.,* 2018). Cowpea is regarded as a cheap source of protein to poor resource farmers whose diet largely depends on starchy foods such as millet, sorghum, maize, and cassava, making it a potential crop to contribute to the alleviation of malnutrition (Purewal *et al.,* 2023).

According to Kofi (2021), about 6,991,174 tonnes of dry cowpea grains are produced annually worldwide on about 12,316,878 ha. Alabi (2024) also reported that Nigeria is a significant cowpea grower, contributing roughly 61% of Africa's total seed production, with 3.6 million metric tonnes produced in 2016. As a result, Nigeria has continued to be the world's top producer of cowpeas despite a roughly 58.5% decrease in production between 2012 and 2016, which was mostly caused by an insurgency that drove many farmers from their fields in the country's northeast. Due to the crop's economic significance to households, Nigeria is also the world's biggest consumer of cowpeas. However, due to the inability of the country to match its population growth rate with a commensurate increase in production, a persistent gap has been reported between the country’s supply and demand for cowpea.

Over the years, manual, hand push and animal-driven methods of planting have been employed, particularly in developing countries. Farmers in rural areas use crude implements such as a machete or sticks to sow these seeds; often, more than the required number of seeds are dropped in a hole and covered. This results in an increase in production cost because extra man-hours will be required for the thinning operation as excessive seeds are inevitably sown per hole in addition to the drudgery involved and the boring nature of the work (Nag *et al.,* 2020). Hence, there is a need to develop such a machine that will help the farmer reduce his efforts while planting.

Machine parts failure is attributed to the importation of planters from other countries, whose technology adaptation differs from the topography of the Nigerian farm. Traditional methods of planting are time-consuming, uniformity of seed placement and planting depth is inadequate and health issues that can occur due to the high laborious work done. The cowpea planter developed at Ladoke Akintola University, Ogbomoso required some modification in the area of motion transmission such as chain and sprocket, metering mechanisms which involved change of gears and seed plate, these are necessary because the position of chain and sprocket in the existing planter was not aligned and the distance from the driver to the metering device is wider. Therefore, the study aimed to modify and evaluate the performance of the existing two-row cowpea planter.

MATERIALS AND METHODS

Design Considerations

In the design of hand guided two row motorized cowpea planter machines, factors such as physical properties of cowpea (length, width, thickness, moisture content, angle of repose, geometry mean, surface area, bulk density and Sphericity), selection of materials (based on availability, affordability and durability) and power requirement of the machine were considered in obtaining a good design for the machine components that result in optimum planting operation of the machine.

Material Selection

The factors considered in the selection of materials for the construction of the machine include: Availability of the materials, Cost of the material, Suitability of the materials for the working condition, ability to resist deformation under stress and externally force applied to the material without breaking.

Working Mechanism of the Machine

Power is transmitted through pulleys and belts from the 6.6 hp petrol engine to the reduction gear, which assists in increasing the torque needed for the operation of the planter. The power from the reduction gear is then transmitted to the rotational shaft. The metering device was modified to meter the amount of seed required per drop at 53 cm intra-row plant spacing. It takes its operational power from the rotational shaft through a chain and sprocket arrangement. The orientation of the power from the rotational shaft is then changed from horizontal to vertical through the arrangement of the Bevel gears inside the metering device, which then rotate the metering plate, which meters the required quantity of seed per hole during operation. The metering plate was fabricated from Teflon material. As the machine is in operation through the guiding of the operator, the furrow opener opens the soil while the delivery chute delivers the amount of seed metered by the metering device through the metering plate and the pressing wheel presses and covers the seed with the soil. The gear reduction of 1:22 was introduced to reduce the speed produced from the prime mover to the ground wheel, which makes the operation of the machine a walking type. Figure 1 shows the Isometric diagram of the modified hand-guided two-row motorized cowpea planter.

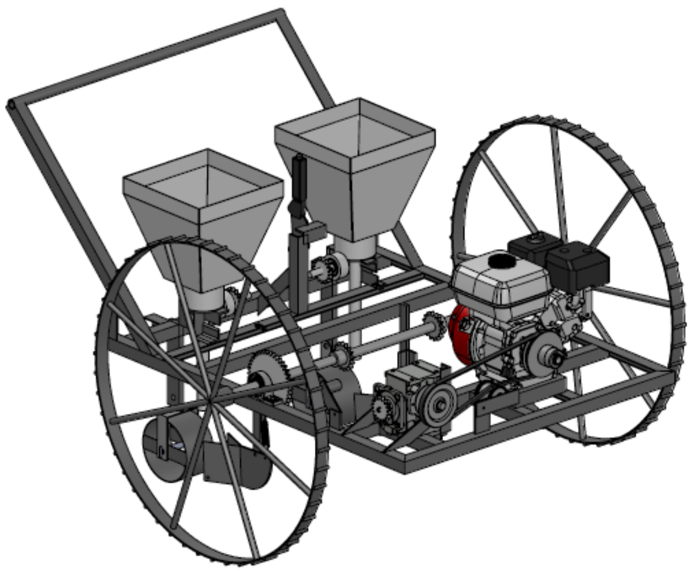


Figure 1: Isometric View of a Modified Hand-Guided Two-Row Motorized Cowpea Planter

Design of Power Transmission Unit

The belt pulley design and shaft design are the two major design on this machine. V-belt was selected to transmit the maximum power from the prime mover mounted on the frame. It can be easily installed and removed. It is also suitable for small center distance arrangement (Hall *et al.,* 1989).

Pulley analysis

The power required to drive the machine was calculated using the compound belt arrangement formula shown in Equation 1 (Hall *et al.,* 1989).

$$\frac{N_1}{N_2} = \frac{D_1}{D_2} \quad (1)$$

Where;

N_1 = Speed of the driver, rpm, N_2 = Speed of the driven, rpm, D_1 = Diameter of the driver, mm
D_2 = Diameter of the driven, mm

To calculate the recommended pulley diameter (d), the following assumptions were made:
Factor of safety = 1.5
Prime mover power rating of 7.5 hp = 5595 W = 5.59 kW
Using standard belt type and corresponding sizes, it's
Top width, b = 17 mm
Thickness, t = 11 mm
Groove angle of the pulley = 40°
The speed of the prime = 1800 rpm
Diameter of pulley on the prime mover, d_1 = 100 mm
Therefore, the torque of the electric motor was obtained using Equation 2

$$Torque = \frac{\text{Motor power } \times 100}{2\pi N} \quad (2)$$

$$= \frac{5595 \times 100}{2\pi \times 1800} = 49.47 \text{ Nm}$$

Using a compound belt arrangement, the diameter of the pulley on the wheel (d_2) = 190mm

$$\frac{N_1}{N_2} = \frac{D^2}{D^1} \quad (3)$$

$$N_2 = \frac{N_1 D_1}{D_2}$$

$N^2 = \frac{1800 \times 0.1}{0.19}$ $\quad N_2$ = 947.37 rpm

Since P_2 and P_3 are keyed together, $N_2 = N_3$
D_3 and D_4 were 60 mm respectively, therefore;
To get the speed of the rolling metering device =

$$\frac{N_2}{N_1} \times \frac{N_4}{N_3} = \frac{d_1 d_3}{d_2 d_4}$$

$$\frac{N_4}{N_1} = \frac{d_1 d_3}{d_2 d_4}$$

$N_4 = \frac{1800 \times 0.1 \times 0.06}{0.19 \times 0.06}$ $\quad N_4$ = 947.37 rpm

Determination of belt length and distance between pulleys

The belt length and pulley distance were calculated using Equation 4 (Ani *et al.*, 2016)
From P_1 and P_2
Let P_1 be the pulley of the prime mover
Let P_2 be the pulley of the driven
The length of the belt for a V-belt =

$$L = \pi(r_1 + r_2) + 2C + \frac{(r_1 - r_2)^2}{C} \tag{4}$$

Where;

r_1 = Radius of the driver, mm, r_2 = Radius of the driven, mm, C = Centre distance (400) mm

Therefore,

$$L = \pi(50 + 95) + 2 \times 400 + \frac{(50 - 95)^2}{40}$$

L = π (145) + 800 + 5.06

L = 1260.6 mm

L = 1.2 m

From P_3 and P_4

C = 425 mm

$$L = \pi\,(r_1 + r_2) + 2C + \frac{(r1 - r2)^2}{C}$$

$$L = \pi(60 + 60) + 2 \times 425 + \frac{(60 - 60)^2}{425}$$

= π (120) + 850 + 0

L = 1226.9 mm

L = 1.2 m

Determination of angle of contact

The angle of contact was determined using Equation 5 (Ani *et al.,* 2016).

Between P_1 and P_2

$$Sin\alpha \ \frac{(r_1 - r_2)}{C} \tag{5}$$

$$\alpha = Sin^{-1}\frac{(50-95)}{400} = -6.5°$$

$$\theta = (180 - 2\alpha)\frac{\pi}{180} \tag{6}$$

$$\theta = \big(180 - 2(-6.5)\big)\frac{\pi}{180} \quad \theta = 3.36 \text{ rad}$$

Between P_2 and P_3

As shown in Equation 3

$$Sin\ \alpha = \frac{(r1 - r2)}{C} \tag{7}$$

$$\alpha = Sin^{-1}\frac{(60-60)}{425} = 0°$$

$$\theta = (180 - 2\alpha)\frac{\pi}{180}$$

$\theta = \frac{(180 - 2(0))\,\pi}{180}$ $\theta = 3.14$ rad

Determination of belt tension

The belt tension was determined using Equation 8 as given by (Ani *et al.*, 2016)

From P_1 and P_2

$$P = (T_1 - T_2)V \quad (8)$$

Where;

P = Power Transmitted (Watts)

T_1 = Tension on the Tight side, N

T_2 = Tension on the slack side, N

V = Velocity of the belt, m/s

$$V = \frac{\pi \times \mathrm{d} \times \mathrm{n}}{60} \quad (9)$$

$$V = \frac{\pi \times 0.1 \times 1800}{60}$$

V = 9.4 m/s

Power required for rotating the wheel was assumed to be 6.5 hp = 4849 W = 4.85 kW

$$P = (T_1 - T_2)V$$

$$4849 = (T_1 - T_2) \times 9.4$$

$$(T_1 - T_2) = \frac{(4849)}{9.4}$$

$$(T_1 - T_2) = 515.85$$

An expansion to determine T_1 and T_2, considering the angle of contact and coefficient of friction, was determined using Equation 10 as given by (Ani *et al.*, 2016).

$$2.3 log \frac{T_1}{T_2} \mu\theta \quad (10)$$

Where μ = Coefficient of friction (0.5)

θ = Angle of contact

Therefore;

$$2.3 log \frac{T_1}{T_2} 0.5 \times 3.36$$

$$2.3 log \frac{T_1}{T_2} = 1.68$$

$$\frac{\mathrm{T}_1}{\mathrm{T}^2} = e^{0.7304}$$

$$\frac{T_1}{T_2} = 2.076$$

$$T_1 = 2.076T_2$$

Recall that

$T_1 - T_2 = 515.85$

$2.076T_2 - T_2 = 515.85$

$T_1 = 515.85$

$T_2 = \frac{515.85}{1.076}$

$T_2 = 479.4\ N$

But

$T_1 = 2.076T_2$

$T_1 = 2.076 \times 479.4$

$T_1 = 995.2\ N$

Power transmitted by the belt as previously described in Equation 3

$P = (T_1 - T_2)V$

$= (995.2 - 479.4) \times 9.4$

$= 4849\ W$

$P = 4.85\ kW$

From P_3 and P_4

$P = (T_1 - T_2)V$

$V = \frac{\pi \times \mathrm{d} \times \mathrm{n}}{60}$

$V = \frac{\pi \times 0.06 \times 947.37}{60}$

$V = 2.98\ m/s$

Power required for rotating the metering device was assumed to be 6.5 hp = 4849 W = 4.85 kW

$P = (T_1 - T_2)V$

$4849 = (T_1 - T_2)\ 2.98$

$(T_1 - T_2) = \frac{(4849)}{2.98}$

$(T_1 - T_2) = 1627.18$

An expansion to determine T_1 and T_2, considering the angle of contact and coefficient of friction as shown in Equation 11

$$2.3log\frac{\mathrm{T}_1}{\mathrm{T}^2}\mu\theta \qquad (11)$$

$2.3log\frac{\mathrm{T}_1}{\mathrm{T}^2}0.5 \times 3.14$

$2.3log\frac{\mathrm{T}_1}{\mathrm{T}^2} = 1.57$

$\frac{\mathrm{T}_1}{\mathrm{T}^2} = e^{0.683}$

$$\frac{T_1}{T^2} = 1.98$$

$$T_1 = 1.98T_2$$

$$T_1 - T_2 = 1627.18$$

$$1.98\,T_2 - T_2 = 1627.18$$

$$0.98T_2 = \quad 1627.18$$

$$T_2 = \frac{1627.18}{0.98}$$

$$T_2 = 1660.4\,N$$

From expression $T_1 = 1.98\ T_2$

$$1.98 \times 1660.4$$

$$T_1 = 3287.6\,N$$

Power transmitted by belt as described in Equation 3.4

$$P = (T_1 - T_2)\,V$$

$$= (3287.6 - 166.4) \times 2.98$$

$$= 4849W$$

$$P = 4.85\,kW$$

The Seed Hopper

Volume of the hopper was calculated using the volume of a frustum of a pyramid formula as shown in Equation 12 (Olalusi *et al.*, 2022). The volume calculated is the maximum volume of the seed each hopper can occupy.

$$V_h = \frac{h}{2}(A_1 + A_2 + \sqrt{A^1 + A^2}) \qquad (12)$$

where,

V_h = Volume of the hopper (cm^3), h = Vertical height section (m), A_1 = Area of Upper base (m^2)

A_2 = Area of lower base (m^2), The area of the upper base (A_1) was obtained as follows

$$Upper\ base = Length\ \times Breadth$$

$$= 305\ mm\ \times 305\ mm$$

$$= 93,025\ mm^2$$

$$0.093\ m^2$$

Also, the area of the lower base (A_2) was obtained as follows

$lower\ base = length \times breadth$

$= 150\ mm \times 150\ mm$

$= 22{,}500\ mm^2$

$= 0.023\ m^2$

But h = 350 mm

= 0.35 m

Therefore;

$V = \frac{0.35}{2}\left[(0.093 + 0.023) + \sqrt{(0.093 \times 0.023)}\right]$

$= 0.117(0.116 + 0.046)$

$= 0.019\ m^3$

Seed Spacing

The intra row spacing for the cowpea planter was obtained by considering the circumference of ground wheel which determined the number holes on the seed plate to achieve the desired plant spacing. While the inter row spacing was determined by measuring the ground width between the two ground wheels. Jakusko and Mustapha (2013) predicted the inter and intra row spacing of cowpea to be 60 cm and 30 cm respectively.

Seed Tube

The seed tubes were fabricated using hollow pipe of 25 mm diameter each and 330 mm long. Holes were made in the metering houses at the metering mechanism. When powered, the seed drops into the seed tube and then deposits into the opened furrow.

Metering disc

The metering disc was developed from a Teflon material, to ensures efficient seed dispensing with benefits such as low friction, chemical resistance, durability, non-stick properties, temperature resistance, and lightweight construction. The size and number of holes required by the metering disc was determined by considering the Geometric Mean Diameter (G.M.D) of the Cowpea seed using expression given by (Gautam., 2017) in Equation (13).

$$D_g = (LWT)^{1/3} \quad (13)$$

where;

L = Length 9.92 mm, *W* = Width =6.87 mm, *T* = Thickness = 6.06 mm

$D_g = (9.92 \times 6.87 \times 6.06)^{1/3}$

$D_g = (412.9914)^{1/3}$

$D_g = 7.45\ mm$

For two seeds to drop per hole at a time,

$7.45 \times 2 = 14.9\ mm$

Therefore, an average G.M.D seed of 14.9 mm diameter was used to creates holes on the seed plate which allowed two seeds droppings per hole. The seed plate was made from Teflon with a dimension of 150 mm in diameter and 5 mm in thickness. It has 3 holes equally spaced on its surface, which allow the passage of cowpea seed to the delivery chute. The holes with the above calculation were designed to pick an average of two seeds and drop them at an intra-row spacing of 30 cm and inter-row spacing of 60 cm. The plate is placed horizontally in the seed metering mechanism, driven by two bevel gears arranged in a perpendicular form, which takes power from the prime mover.

Furrow Opener

Furrow opener is a component attached to the frame holding the wheel presser of the planter to open the soil for the metered seed. It was fabricated using a mild steel sheet of 305 mm length, 125 mm breadth and 2.5 mm thickness. This material was used due to its availability, affordability, machinability, and ability to withstand frictional forces encountered by the soil.

Furrow Closer

The furrow closers/wheel presser is a component that covers the metered seed through compaction. It was constructed using a mild steel plate with the dimensions of $170 \times 95 \times 30\ mm$ for the diameter, height and thickness respectively. It is positioned at the back of furrow openers to ensure proper covering and compaction of the soil over the planted seed.

Frame

It is the skeletal platform of the planter on which all components were mounted. It was made of 50×50×5 mm mild steel angle iron welded together to form a rectangular chassis to which 30 mm shaft diameter was attached to both rear ends and linked to the transport wheels. At the edge of the frame is a base on which the prime mover was mounted.

Wheel

The wheels were located at both ends of the frame. They were made of 40mm×5mm mild steel flat bar with a 880 mm diameter to enhance stability. Rigid wheels were used as they withstand deflection and enable easy traction.

Handle

Attached to the frame is the handle for the movement control of the machine. A mild steel of 700 mm×500 mm in height and width, respectively, was fabricated for effective gripping by the operator. Figures 2 and 3 show the orthographic and isometric view of hand guided two row motorized cowpea planter respectively. The existing cowpea planter does not have gear reduction to reduce the speed generated from the prime mover to walking speed for adequate placement of seeds. also, the metering mechanism, precisely the seed plate, was not designed and calibrated to give uniform plant spacing for the seeds. Therefore, a gear reduction of 1:20 was introduced and well well-designed and calibrated seed plate was developed and incorporated into the modified cowpea planter to address the identified grey area of the existing cowpea planter. The existing cowpea planter gave the maximum field efficiency and effective field capacity of 71 % and 0.057 ha/h, respectively. This is low when compared to the effective field capacity of 0.1818ha/h and field efficiency of 81% of the modified cowpea planter.

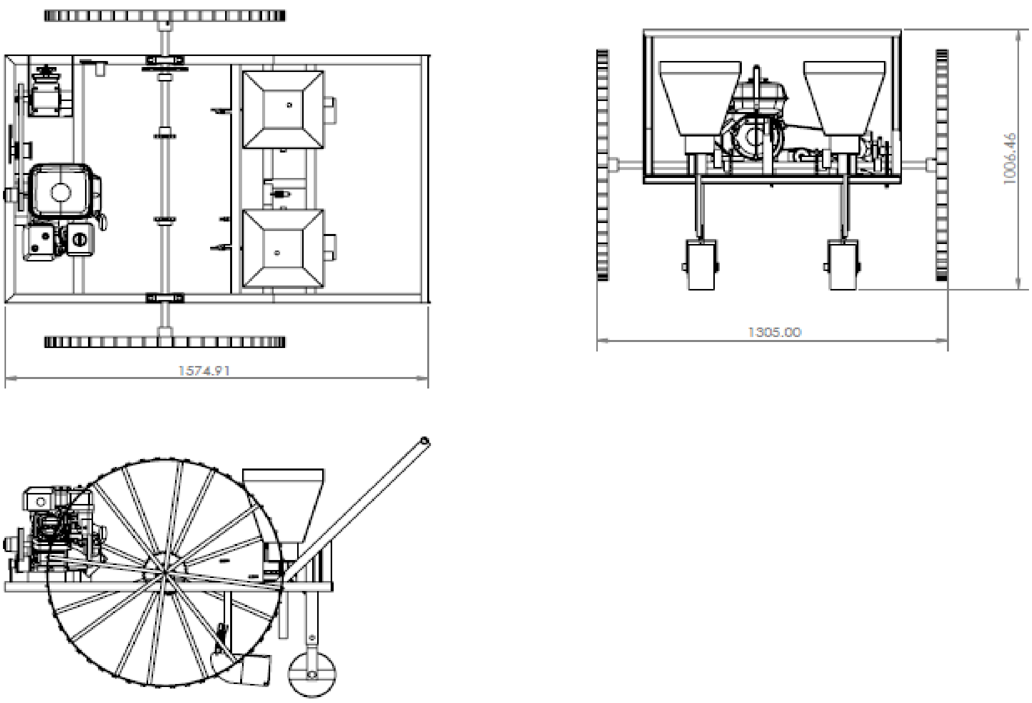
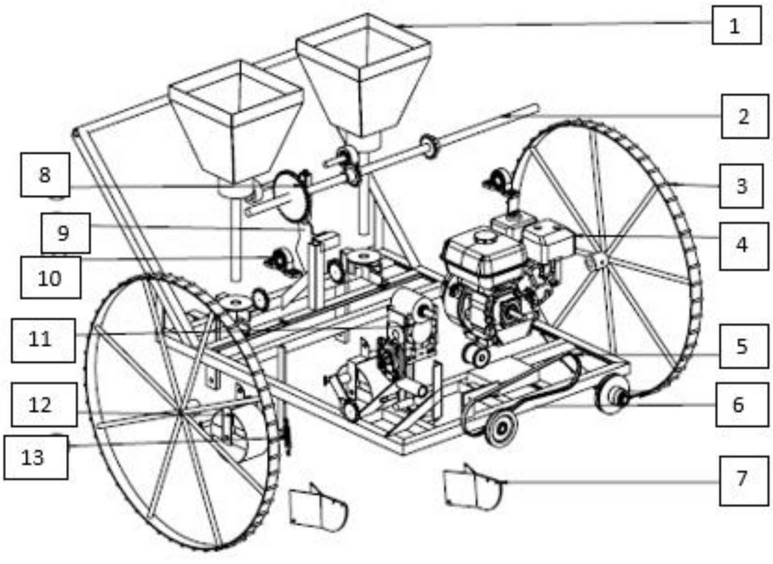


Figure 2: Orthographic view of a modified hand-guided two-row motorized cowpea planter



Item No	Part	Quantity
13	Soil presser	2
12	Soil presser frame	2
11	Reduction gear	2
10	Pillow bearings	4
9	Chain	3
8	Sprocket	6
7	Furrow opener	2
6	Belt	1
5	Main frame	1
4	GX 200 prime mover	1
3	Gauge wheel	1
2	Shaft	1
1	Hopper	2

RESULTS AND DISCUSSION

Modification of a Hand-Guided Motorized Two-Row Cowpea Planter

Modification of a hand-guided motorized two row cowpea planter was done as shown in Plate.1. In summary a gear reduction with speed ratio of 1:20 was introduced to the machine to reduce the speed generated by the engine to walking speed, the seed plate has four holes of 12 mm diameter each on its surface and the engine of 6.5 hp. Table 1 shows the average values of the results obtained from the performance evaluation of the modified hand-guided cowpea planter.

Table 1: Average Values of the Result Obtained from Performance Evaluation of Modified Hand Guided Two-Row Motorized Cowpea Planter

Plot	Speed of Operation (km/h)	Theoretical Field Capacity (a/h)	Effective Field Capacity (ha/h)	Field Efficiency (%)	Fuel Consumption (l/ha)	Percentage Seed Germination (%)
A_1	0.192	0.1922	0.1389	72	6.55	92.31
A_2	0.214	0.2136	0.1729	81	6.93	84.62
A_3	0.228	0.2278	0.1818	80	7.50	92.31

Plate 1: Pictorial view of a modified hand-guided motorized two-row cowpea planter.

It was observed that the operation speed affects the parameters evaluated. As operation speed increased from 0.192 to 0.228 km/h, theoretical field capacity (ha/h), effective field capacity and fuel consumption (l/ha) increased from (0.1922 – 0.2278 ha/h; 0.1389 - 0.1818 ha/h and 6.55 – 7.50 l/ha) respectively. the highest field efficiency was obtained at an operation speed of 0.214 km/h, while percentage seed germination ranged from 84.62 – 92.31% and the total area covered during the operation was 0.0267 ha. Based on different methods of planting, the machine performed better as it gave 92.31% of seed germination.

CONCLUSION

The modification of the hand-guided motorized two-row cowpea planter has significantly improved its operational efficiency and ease of use. Introducing of gear reduction mechanism, optimizing the seed metering system, and enhancing the power transmission unit enables the planter to offer better seed spacing and reduced labour intensity for farmers. From the results obtained during the performance evaluation of the machine, the highest values of theoretical and effective field capacity, fuel consumption and percentage seed germination of the machine were 0.2278 ha/h, 0.1818 ha/h, 7.50 l/ha, and 92.31 % at an operation speed of 0.228 km/h, respectively. The machine's ability to provide adequate seed placement at a walking speed contributes to improved crop yield and overall agricultural productivity. The use of locally available materials ensures cost-effectiveness and ease of maintenance, making it a viable option for smallholder farmers.

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