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DEVELOPMENT AND PERFORMANCE EVALUATION OF A COWPEA HARVESTER

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ABSTRACT

A cowpea harvester was designed, constructed and evaluated for its performance. The machine was fabricated with high carbon steel with an output capacity of 120kg/h. The performance of the harvester was evaluated at two crop moisture content 15.17% and 17.47% and two main shaft speeds of 540 rpm and 1000 rpm. At moisture content of 15.17% and machine speed 540rpm, the machine exhibits the highest functional efficiency of 93.75%, quality performance efficiency of 81.21%, field loss of 3.4% and shattered loss of 6.66%. The machine is statically and dynamically stable hence able to withstand vibration.

Keywords: development, performance, evaluation, cowpea and harvester.

1. INTRODUCTION

Cowpea (*Vigna Unguiculata* L. Walp), an annual legume that is commonly referred to as Southern Pea, black eye pea, Crowder Pea, Lubia, niebe, coupe of frijole originated in Africa, Latin America, South east Asia and in the Southern United States (Davis *et al.*, 2009).

Its important use as a grain crop, animal fodder, or as a vegetable has been making its development and processing germane concerns to the professionals in charge. As earlier mentioned, cowpea can be used at all stages of growth. The tender green leaves are important food source in Africa and are also prepared as a port herb; immature snapped pods are used in the same way as snap beans, often mixed with other foods. Green cowpea seeds are boiled as a fresh vegetable or may be combined or frozen and the dry mature seeds are also suitable for boiling and canning (Davis *et al*, 2009; Quick, *et al*). Due to this economic importance of cowpea, the agronomist have been working tremendously for the improvement in its growth and yield but lots have to be done in the development of its harvest and post harvest technologies. To solve the problem of food security and poverty, increasing cowpea production requires the need for the development of a mechanical cowpea harvester as millions of African farmers grow cowpea, some two hundred million Africans consume cowpea and majority of these farmers are women (Melta, *et al*, 1995)

The bean harvester of which several types are commonly employed will work well with cowpeas planted in rows. According to specialists of the United Sates Department of Agriculture, the most successful of these harvesters are constructed in such a way that the vines cutting off the stems beneath the surface of the soil (Blair 2001).

A mechanical harvester is specifically designed to mechanically pick the leguminous crops with hand picked quality tool. The picking tools are a plurality of elongated resilient fingers which are disposed on an endless moving belt for gentle combing the crops the plants. The harvester is adopted to be placed behind a towing vehicle like a tractor with crop pick-up point in vertical alignment with the main tractor axis for ensuring good operator's visibility. The prior art harvesters for mechanical harvesting of leguminous vegetables like green beans , English peas and the like, generally compose a plant alignment device which delivers the plant into a rotating drum (Wilkipedia, 2009). This concept of mechanical harvest of leguminous crops by the use of picking fingers on a rotating drum is acceptable for every limited number of crops. The crops are resilient enough to resist damage through the collection process or require further processing or of the type where certain amounts of damage can accepted where such techniques have been employed for leguminous crops like cowpea, the damage and discard rate has approached 40% of the harvested crops unlike the 10% or less discard rate for hand picked crops. This improves discard rate of handpicking continues to justify manual harvest but this is only moderate for small scale farming.

Cowpea can be harvested at three different stages; green snaps, green mature and dry (Mississippi, 1986). Depending on the temperature, fresh market (green-mature) peas are ready for harvest 16 to17 days after 60 to 70 days of planting and the harvest date for green snap pods is normally specified by the processor. According to I.I.T.A, (1981) as quoted by Faleye and Atere (2009), frequent picking (harvest) of cowpea at harvest time stimulates further flowering. Harvest can also be done when the pods are mature at a moisture content of 17.20% dry basis. (Frazer, 1978)

All these necessitate the development of a locally made cowpea mechanical harvester that will be suitable for our own local cowpea and soil conditions for large scale production.

Therefore, this study was carried out with the following objectives;

i. To design a mechanically drawn cowpea harvester.
ii. Fabricate the machine with locally available materials.
iii. And carry out the performance evaluation of the machine.

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1. Cutter bar
2. Conveyor pulley
3. Reel
4. Conveyor canvas
5. Tank
6. Wheel
7. Bearing
8. Pitman mechanism
9. Spider connector flange
10. Crank

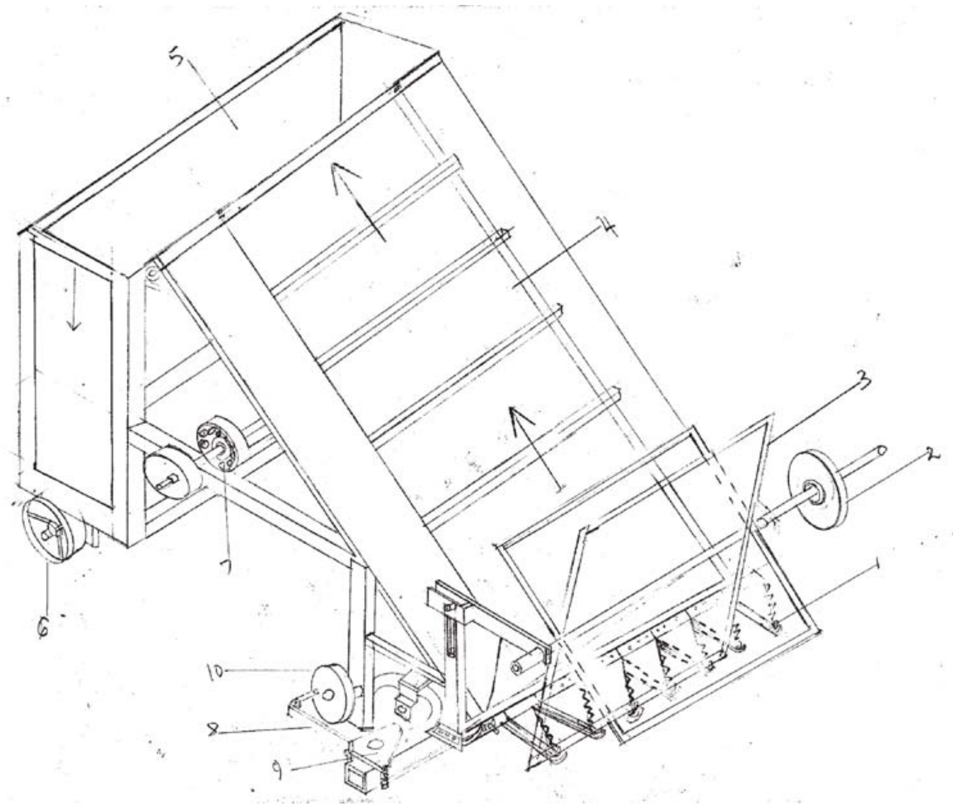
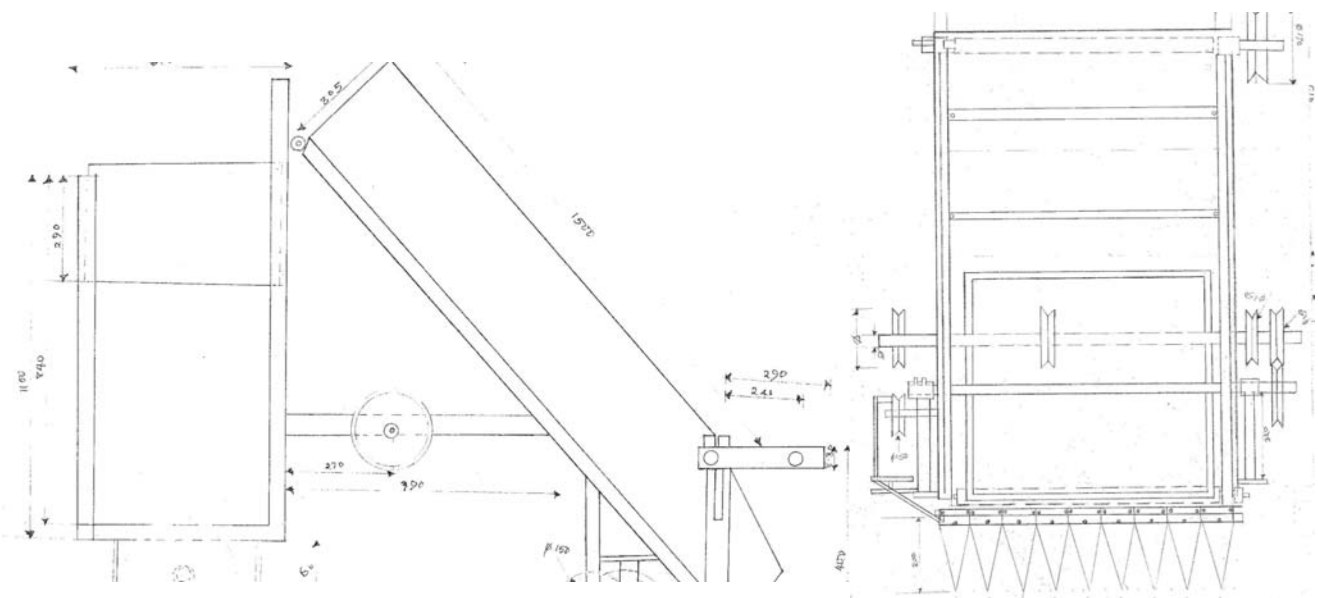


Figure-1. Cowpea harvester.



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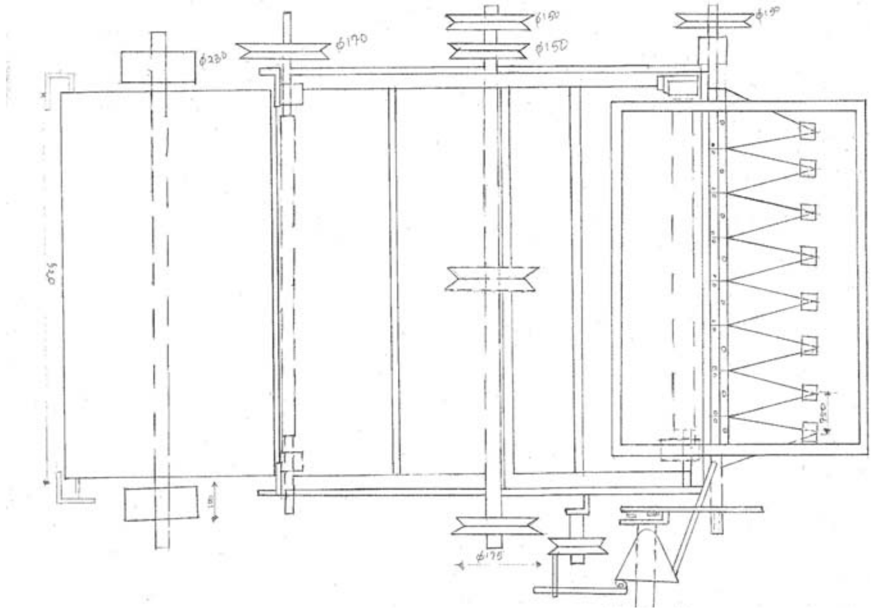

Figure-2. Orthographic view of the cowpea harvester.

2. MATERIALS AND METHODS

2.1 Machine description and operations

The cowpea harvester comprises of the reel, the cutter bar, conveyor and the transmission unit. The reel is positioned above the knife where it rotates and gathers the crops into the machine as the cut is made. The position of the reel is adjusted to accommodate different straw lengths and crop conditions. The cutter bar is similar to that of mowing machine. Its series of finger are spaced at equal intervals. The conveyor is located at the rear of the cutter bar. It carries the cut crops upwards to the storage tank located at the rear of the conveyor. The conveyor is made up of canvas fitted with metal cross slats. The power rating of the machine is 3.75kW (5hp) and this is taken from the PTO of the tractor.

2.2 Design methodology

The design of the component-units of the machine was carried out putting into consideration, the specific functions of each component units. The main units are: the reel, cutter bar, the conveyor, power requirement and the operating capacity.

2.2.1 Capacity/ volume

The cowpea harvester was designed to harvest all forms of legumes. The capacity of the machine was calculated by using the formula below;

$$EFC = \frac{SWE}{10} \qquad \text{........ 1}$$

Where;

EFC = Effective Field Capacity
S = Speed of travel (km/h)
W = Implement width
E = Field efficiency (%)

2.2.2 The pulley diameter

The power source for the machine is 7.25W diesel Engine and the revolution of set to 2500rpm. The diameter of the engine pulley is 250mm. the speed transmitted to the driven pulley is 1500rpm

$$D = \frac{ds}{V} \qquad \text{........ 2}$$

Where:

D = Diameter of driven pulley
d = diameter of driving pulley
V= speed transmitted to driven pulley
S = Speed if driving pulley
D = 30mm

2.2.3 Shaft diameter

The shaft diameter, using the American society of mechanical Engineer's code - equation for solid shaped having little or are axial loading, the diameter was calculated as:

$$d^3 = \frac{16}{\pi ss}\sqrt{M^3 + T^2} \qquad \text{....... 3}$$

Where:

d = the shaft diameter
M = maximum bending moment (NM)
T = Maximum torque (NM)
Ss = Yield strength (Pascal)
Ti = Constant
D = 27mm, therefore a 25mm diameter was used

2.2.4 Power requirement
The power required to operate the machine was determine by using the formula

$$P = TW_a \qquad .... 4$$

But $$W_a = \frac{2\pi N}{60} \qquad .... 5$$

Where:

P = power (watt)

$W_a =$ Angular speed (rad/Sec)
W = speed = 1800rpm
T = Torque = 105Nm
N= Speed in rpm

2.2.5 Cutter bar (reciprocating mechanism)
In one revolution of the land wheel of diameter dw, it travels a linear distance of $T_l$dw, the wheel transmits motion to the crank. For fast operations, it is desirable to step up the speed. However, for efficient power transmission, the rotational speed of the crank should not exceed five times the rotational speed of the wheel (PSC, 1986). Hence in one revolution of the wheel, the crank makes 5 revolutions and hence, the reciprocating blade makes 10 strokes. Therefore in 0.5 revolution of the crank, that is one stroke of the blade, the blade travels a linear distance equal to the diameter of the crank, dc, and the wheel travels a distance $\pi d_w / \omega$ 6

Therefore, the distance moved by the wheel, D1, after the blade has complete S strokes is given by

$$D_l = \frac{\pi d_w}{\omega} \qquad .... 7$$

Also the rotational speed of the land wheel is 80rpm. Hence the rotational speed of the crank is 350 rpm.

2.2.6 The conveyor
The design of the machine conveyor was carried out using the following equations as outlined by PSG (1986):

$$W_u = CFL(G_b \cos\sigma + G_{ru}) + HG_b \qquad .... 8$$

Where:

Wu = resistance of the belt on the bottom run (kgf)
C = Frictional resistance factor (C = 9.20)
F = friction between idler and belt
L = conveyor length (m)
G_b = weight of belt meter (kgf/m)
σ = inclination of the conveyor
G_{ru} = Weight of straight idlers on the bottom run/meter length
H = Height through which material is conveyed (m)
Belt Tension:

$$T_1 = P_1\left[\frac{e^{\mu\alpha}}{e^{\mu\alpha-1}}\right] \qquad .... 9$$

$$T_2 = T_a - P_2$$

Where;

T_1 = tension at head end
T_2 = tension at tail end
P_1 = power rating for the conveyor
P_2 =Tractor (PTO) Power
μ = co-efficient of friction between belt and pulley
α = angle of lap over pulley in radians
T_a = Maximum tension of the conveyor
T_1 = 256N and T_2 = 188w

2.2.7 Design specification
Capacity = 120kg/h
Size:

Overall dimension = (1 x 1.5 x 3.4) m
Cutter bar = (0.11 x 1) m
Conveyor = (1.2 x 2.3) m

2.2.8 Constructional materials:
High carbon steel and Mild steel

2.3 Performance evaluation
The test methodology for the cowpea harvester was carried out as follows:

A plot of land measuring 3m by 26m each was prepared, tilled and planted with two varieties of cowpea; (Ife Brown and TVX 32.4) obtained from the Agricultural Development Project centre, A completely randomized design with six replicates (12 plots) was used for the experiment. After maturation, some samples of the cowpea were taken at random to determine the moisture content of the pods. Six plots were harvested immediately and after 2 weeks, the moisture content of the remaining plots was determined randomly before harvest. This was done to vary the moisture content of the crops. During harvest, the machine was made to pass through each plot three times since the width of the cutter bar is one meter.

For each plot the weight of cowpea harvested by the machine was weighed and the ones not harvested were collected manually and weighed. Time taken for the machines to harvest each row of plot was recorded by the use of a stop-watch.

The harvesting efficiency, quality performance efficiency, field loss and the shattered loss were evaluated in each combination of variables. During the test period, the PTO main shaft speed was recorded using tachometer. The level of variables for testing the harvester is included in Table-1.

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Table-1. Experimental plan for evaluation of cowpea harvester.

S/No	Variables	Levels
1	Crop moisture content (%)	15.17 and 17.47
2	PTO speed (rpm)	540,1000

2.4 Determination of total losses and efficiencies

The following relationships were used to calculate the efficiencies and losses of the harvester:

a. Field Loss $(\%) = \frac{W_{nh}}{W_h + W_{cm}} X \quad 100$ 10

b. Shattered loss (%) = $\frac{W_g + W_{ep}}{W_h + W_{cm}}$ X 100 11

c. Functional Efficiency (%) = $\frac{W_h}{W_h + W_{cm}}$ X 100......... 12

d. Quality performance efficiency (%) = $\frac{W_{uh}}{W_h + W_{cm}}$ X 100 13

Where;

W_{nh} =the weight of pods not harvested by the machine

W_h = the weight of pods harvested by the machine.

W_{cm} = the weight of pods collected manually per plot.

W_g = the weight of grains collected on each plot.

W_{ep} = the weight of empty pod collected on each plot.

W_{uh} = the weight of unbruised pods harvested.

3. RESULTS AND DISCUSSIONS

The performance of the harvester was evaluated at two crop moisture content at dry wet basis and two main shaft speeds in terms functional efficiency, quality performance efficiency, field loss and shatter loss. Tables 2 and 3 showed the results of the performance test.

Table-2. Performance evaluation of cowpea harvester at PTO speed of 540rpm with 15.17% and 17.47% m.c.

Performance indicator	Ife brown 15.17%m.c	TVX 32.39 15.17%m.c	Ife brown 17.47%m.c	TVX 32.36 17.47m.c
Field loss %	3.40	5.25	8.95	11.33
Machine efficiency (%)	93.75	86.28	78.63	71.59
Quality performance efficiency (%)	81.21	76.33	66.39	60.93
Shattered loss (%)	6.66	10.36	3.21	5.11

Table-3. Performance evaluation of Cowpea harvest at PTO speed of 1000rpm with 15.7% and 17.47% m.c/

Performance indicator	Ife brown 15.17%m.c	TVX 32.39 15.17%m.c	Ife brown 17.47%m.c	TVX 32.36 17.47m.c
Field loss %	5.39	7.21	12.69	13.84
Machine efficiency (%)	85.62	82.40	70.44	65.28
Quality performance efficiency (%)	78.38	71.00	58.55	51.33
Shattered loss (%)	7.10	11.59	3.8	5.3

Tables 2 and 3 indicated the performance of the machine under the moisture content and machine speed. From the Table it was observed that the most suitable condition for harvesting cowpea are at 15.17% moisture content with 540 rpm PTO speed. The machine efficiency and quality performance efficiency reduced with increase in machine speed and moisture content. The machine efficiency and quality performance efficiency for Ife Brown ranged from 93.45% and 86.2% to 85.62% and 78.38% respectively at 15.17% and 17.47% moisture contents.

The field loss of the machine increases with decrease in the pod moisture contents and the machine speeds. Ife Brown exhibits the least field loss of 3.48% at low moisture content of 15.17% and machine speed of 540rpm.

The shattered loss of the machine also increases with decrease in the moisture content of the pods and increased with increase in the machine speeds. High moisture content reduces the shattering of the pods during harvest. This is a confirmation of the studies of Mehta *et al*. (1999) and Ajav and Igbeka (1995).

4. CONCLUSIONS

Machine functional efficiency, quality performance efficiency, field loss and the shattered loss are directly affected by the shaft speed and the pod moisture content. The best operating condition for the harvester was when the operating speed was set at 540rpm and moisture content maintained at 15.17%. The machine capacity was a function of the machine efficiency and time of operation, thus the machine is rated 120 kg/h. The machine is statistically and dynamically stable hence able to withstand vibrations.

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