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## Development, Fabrication and Performance Evaluation of a Yam Harvester for Yams Planted in Mounds

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**Abstract:** A yam tuber harvester was designed and developed to harvest tubers in mounds and its performance evaluated. It is a three-point hitch system with PTO drive train consisting of a digging fork, the lifting cam, transit bin, collection bin, spring loaded depth control wheels, transport wheels and the power drive train. Its performance was conducted on the plain ground and field lay-out measured 15.78 m x 5.14 m with thirty (30) mounds arranged in three rows. The harvester was tested at tractor forward speeds of 1.5 km/h, 2.0 km/h and 2.5 km/h respectively. The machine parameters such as fork dwell, rise and fall distances, harvesting efficiency, effective field capacity, theoretical field capacity, field efficiency and effect of speed on dwell, rise and fall distances of its digging fork were determined to be 912 mm and 740 mm, 70%, 0.09 ha/h, 0.13 ha/h, 69.2% and ANOVA at $p \leq 0.05$ showed that speed had effect on dwell, rise and fall distances harvester digging fork. The optimum performance of the harvester was at the tractor forward speed of 2.0 km/h and rate of harvesting of 900 tubers per hour. Recommendation was provided about further evaluations.

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**Keywords**: Digging Fork; Harvesting Rate; Inter-Mound Spacing; Mound Basal Diameter; Yam Harvester

### 1. Introduction

Yam tuber (*Dioscorea spp.*) world production of about 98% is dominated in West Africa FAOSTAT (2021), where it serves as staple food of many homes in Nigeria, Ghana, Cote d'Ivore Benin, and Togo which can be prepared in the form of *pondo, amala, fufu* and porridge, boiled or roasted and eaten for its nutritional value and also used for medicinal purposes. Yam plays significant roles in socio-cultural activities such as cultural festivals, marriage ceremonies, naming ceremonies and burial ceremonies. It can also be used for entertainment or as honorarium to very important visitors and personalities. Yams are the fifth most harvested crops in Nigeria, after cassava, maize, guinea-corn/sorghum, and beans/cowpeas and most commonly harvested tuber crops after cassava (Becvarova and Verter, 2015). The average yield of sweet potato and yams is 14.5 tonnes/ha to be followed by cassava which is 9.6 tonnes/ha on the field worldwide (Iwo *et al*., 2012).

Generally, Yam is traditionally planted in mounds in Nigeria and the sizes of the mounds vary from place to place: from 500 to 1,000 mm in diameter and density of 3,000 to 13,000 and 12,244 per hectare have been reported by Daisy (1987) and Daudu (2003) which will depend on the location, mound basal diameter, inter-mound and intra-mound spacing and the hydromorphic nature of the soil (Awulu *et al.*, 2013). The cultural method of planting yams in mounds of field layouts of scattered and alternate rows is a constraint to its mechanization because no tractor or machinery can go through the farm without destroying the tubers in the mounds. Some yam varieties such as *cv. Anacha, cv. Gbangu and cv pepa* that grows vertically in the mound from top to the bottom without branching are more amenable to mechanization, if planted in mounds arranged in rows will enhance the mechanization of yam tuber harvesting (Itodo and Daudu, 2013).

The traditional method of harvesting yam tubers is by using hoes, chisel, pick-axe and other farming equipment to dig around the plant to cut out soils and the equipment is used to push it up and sometimes need repetitive efforts to pull the tuber out of the mound with hand. With these, many work forces are required for harvesting considerable large portion of farm land and this usually increase the labour cost and time spent for harvesting. Harvesting ranked the second most likely operation the yam farmers desire to be mechanized. Development of a harvesting machine will reduce 60 man-day/ha human labour requirement of harvesting yam tubers by 50% to increase output and save time. Unless this is done, yam production will remain unattractive (Itodo and Daudu, 2003).

Although yam harvesting has received little research attention, published empirical works within the context African yam tuber harvesting in the World were mainly field research. To the best of our knowledge, none of these studies came up with known African yam tuber harvester in the market. Efforts at the mechanization of yam crop harvesting have been made but only little have been achieved because there has been problem of soil clods separation and sometimes the machine got stuck in the ground due to admission of large volume of soils into the digging blade which results to its deformation during harvesting operation. There is therefore, much more innovation required to produce an effective yam harvester. This study is one of such efforts to incorporate cams to control the movement the digging fork which will selectively harvest yam tubers in mounds.

## 2. Materials and Methods

### 2.1 Description of Yam Harvester

The yam tuber harvester in figure (1) is a three-point hitch system with PTO drive train consisting of a digging fork, the lifting cam, transit bin, collection bin, spring loaded depth control wheels, transport wheels and the power drive train. The digging fork has nine (9) tines with chisel ends bent at an angle of 35° for easy soil penetration. The digging fork is bolted to a holder that can be adjusted at the angles of 20°, 22.5° and 25° and depths of 40 mm, 45 mm and 50 mm to achieve different penetration depths. The tines of the digging fork are spaced to allow for separation of the harvested tubers from soil clods. It is pivoted in such a way that action of the cams which are fixed on a driving shaft connected to chain and sprocket drive causes the fork to dwell, rise and fall. The digging fork is positioned such that its tines cut beneath the yam tuber in the mound without damaging the tuber. The adjustable transit bin with two side walls is inclined at an angle of 35° to the horizontal with both ends opened to allow for the intake and discharge of its contents into a collection bin. Its base floor of iron pipes are spaced to allow the tubers to be separated from the clods during harvesting process. The transport wheels are made of rubber tires and they are fixed to the rear for movement of the harvester during operations. There are two adjustable depth wheels made of coulter which are bolted to rectangular thick metal plates fixed in front of the frame at both sides of the digging fork for depth control and for cutting tuber vines and mass of soil before the mound is shattered at the downward movement the digging fork. The digging fork at its highest rise is expected to deliver the entire mass of yam tubers and some attached soils into the pipe rods of the transit bin that will sift the loose free flowing soils as well as clods and stones and delivers the harvested tubers into the collection bin. The collection bin has two (2) reeds arranged in opposite slant direction which helps in lowering the tubers without injuries to its floor. The base of the collection bin is spaced steel pipes which further contribute to separation of soil clods that might have escaped the transit bin. The physical and specifications of the harvester are shown in Table 1.

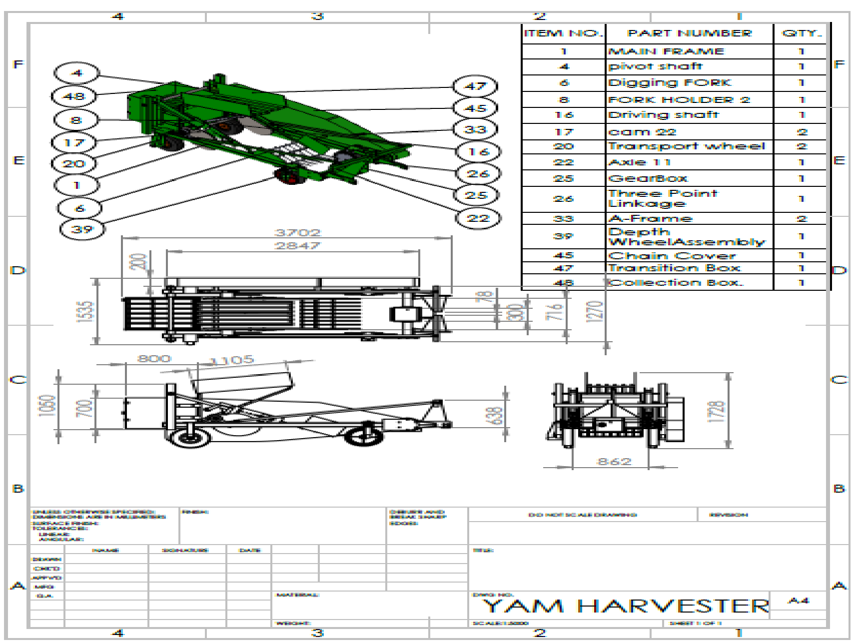


**Figure (1): Views of the Developed Yam Harvester**

2.2 Design Analysis of Harvester

The components of the harvester that were designed are the digging fork, lifting cam, drive train and the power requirement of the harvester.

The main design assumptions of the yam harvester were:

1. The harvester will be driven from the tractor PTO shaft at a speed of 540 rpm.
2. The overall length of the harvester is sufficient to be mounted and carried on the 3-point link of a tractor or trailed on transport wheels.
3. The harvester is to shatter mound, picks up yam tuber and drops it in the collection bin at mound basal diameter and inter-mound spacing within 500 mm and 1,000 mm (Awulu *et al.*, 2013 and Daudu, 2003).
4. A complete revolution of the cam follower should translate into a digger movement of 1.5 m.

2.3 Design Calculations

2.3.1 Design of digging fork

In this design, 20° and 600 mm were chosen for inclination angle and rear height respectively. The working length ($L_d$) and width ($W_d$) of the digging fork was determined from "equations 1 and 2" respectively.

$$L_d = \frac{H}{Sin\ \alpha} = \frac{H + \Delta}{Sin\ \alpha} \qquad (1)$$

Where:

$L_d$ is the working length, mm

H is height of the rear of the digger, mm

$\alpha$ is angle of inclination to the horizontal, degree

$\Delta$ is clearance, mm

$$L_d = \frac{H + \Delta}{Sin\ \alpha} = \frac{600 + 13}{Sin\ 20^o} = 671\ mm$$

$$W_d = n(s + d_r) \qquad (2)$$

Where:

$W_d$ is the working width, mm

n is number of tines

$d_r$ is the diameter of tine, mm

s is distance between tines, mm

$$W_d = 9(65 + 20) = 765\ mm$$

2.3.2 Design of the lifting cam

Design of cam and follower parameters were used to determine the cam profile which gave exact dwell, rise and fall of the follower where the digging fork is linked (Figure 2). The displacement, time taken for each displacement and acceleration were determined from "equations 3, 4 and 5" respectively (Blanco *et al.*, 2015; Rothbert, 2004; Hareesha, 2013; Gokarneshan and Kumar, 2013).

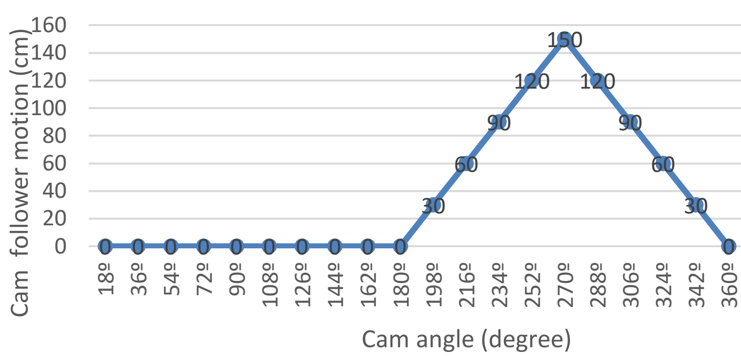


Fig. 2a: Cam Displacement Diagram

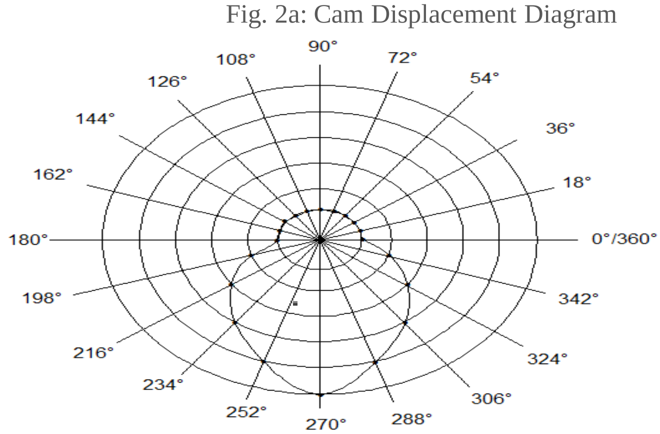


Fig. 2b: Cam Profile

**Figure (2): Cam Displacement and Profile Diagram**

**D1: Cam follower displacements (S)**

$$S = k(\theta_2 - \theta_1) \quad (3)$$

Where;

S is the follower displacement in mm

$k$ is the ratio of cam movement (Δs), mm and cam angle (Δϴ), degree

θ is cam rotation angle, degree

**Dwell segment 1**: From 0 to 750 mm (Fork dwell = linear downward motion of fork = mound basal diameter)

$$S_1 = \frac{75}{18}(180^o - 0^o) = 750\,mm$$

**Rise segment 2**: From 750 mm to 1,125 mm (Fork upward motion to drop harvested tuber = ½ inter-mound spacing)

$$S_2 = \frac{825}{198}(270^o - 180^o) = 375\,mm$$

**Fall segment 3:** From 1,125 to 1,500 mm (Fork downward motion to shatter next yam mound = ½ inter- mound spacing)

$$S_3 = \frac{1{,}200}{288}(360^o - 270^o) = 375\,mm$$

Total displacement for dwell, rise and fall = 750 + 375 + 375 = 1,500 mm

**D2: Time (t) taken for the follower cam displacement**

$$t = \frac{\omega}{\varphi} \quad (4)$$

Where:

t is time for follower displacement, s

$\omega$ is cam translation, mm

$\varphi$ is cam speed, m/s

Time ($t_1$) taken during the dwell of the follower:

Distance covered by the follower during the dwell = 75 cm

Cam speed = 45 rpm = 1.13 m/s

$$t_1 = \frac{75\,cm}{45\,rpm} = 1.67\,s$$

Time ($t_2$) taken during the rise of the follower:

Distance covered by the follower during the rise = 37.5 cm

$$t_2 = \frac{37.5\,cm}{45\,rpm} = 0.83\,s$$

Time ($t_3$) taken during the fall of the follower:

Distance covered by the follower during the fall = 37.5 cm

$$t_3 = \frac{37.5\,cm}{45\,rpm} = 0.83\,s$$

Total time taken to complete one revolution of dwell, rise and fall = 1.67 + 0.83 + 0.83 = 3.33 s.

**D3: Accelerations (A) of the follower**

$$A = \frac{V}{t} \quad (5)$$

Where:

A is cam acceleration, m/s$^2$

V is cam speed, m/s

T is time, s

Acceleration ($A_1$) during the dwell:

Speed of cam = 45 rpm

Time taken during the dwell = 1.67 s

$$A_1 = \frac{1.13\,m/s}{1.67\,s} = 0.68\frac{m}{s^2}$$

Acceleration ($A_2$) during the rise:

Time taken during the rise = 0.83 s

$$A_2 = \frac{1.13\,m/s}{0.83\,sec,} = 1.36\frac{m}{s^2}$$

Acceleration ($A_3$) during the fall:

Time taken during the fall = 0.83 s

$$A_3 = \frac{1.13\,m/s}{-0.83\,sec,} = -\,1.36\frac{m}{s^2}$$

2.3.3 Design and selection of drive train

The yam harvester is driven from the power-take-off shaft of the tractor at the speed of 540 rpm. The driver sprocket has 12 teeth and is linked to the driven sprocket by a chain. In designing chain and sprocket drive, speed reduction from driver sprocket to the driven sprocket is desired. Available information for the proper design and selection of chain and sprocket drive are as follows:

i. Source of power :Tractor PTO
ii. Driven equipment :Yam Harvester
iii. Input Horsepower available :5.24
iv. Driving shaft size :1.7 inches
v. Driving shaft speed :270 rpm
vi. Driven shaft size :Was selected
vii. Driven shaft speed :Was determined
viii. No. of small sprocket teeth, $Z_1$ :12
ix. Gear ratio :1:6
x. Smaller sprocket weight :Was selected
xi. No. of big sprocket teeth, $Z_2$ :Was determined
xii. Big sprocket weight :Was selected
xiii. Center distance :Was determined
xiv. Drive arrangement :Horizontal shafts
xv. Space limitations :Yes
xvi. Operating environment :Agricultural field (20°- 40°c)
xvii. Lubrication :Was selected

i. Determination of number of teeth and revolution of the big sprocket

The driven sprocket number of teeth and revolution can be determined on the basis of desired gear ratio of 1:6 in "equations 6".

$$Gear\ Ratio, i = \frac{Z_2}{Z_1} or \frac{n_1}{n_2} \quad (6)$$

where,
$Z_1$ = driver sprocket's number of teeth
$Z_2$ = driven sprocket's number of teeth
$n_1$ = Driver Sprocket Revolution
$n_2$ = Driven Sprocket Revolution

$$6 = \frac{Z_2}{12}$$

$$\text{Driven Sprocket no. of teeth } Z_2 = 6 \; X \; 12 = 72 \; teeth$$

$$\text{Driven Sprocket } Revolution, n_2 = \frac{n_1}{i} = \frac{270}{6} = 45 \; rpm$$

ii. Selection of an appropriate service factor

The service factor for a yam harvester, driven by an internal combustion engine with moderate shock load is 1.4.

iii. Determination of the design horsepower

Horsepower rating for 12 teeth for 300 rpm of the small sprocket gives 5.24 horsepower as input horsepower.

Design horsepower = Input hp x service factor
Design horsepower = 5.24 x 1.4 = 7.34

Horsepower Ratings for 7.34, the design horsepower at 270 rpm is within No.60-chains. ASME/ANSI horsepower rating for No.60-chain transmits 9.25 horsepower at 300 rpm on a 21-tooth. For the purpose of this design, 12-tooth sprocket that will transmit 270 rpm was available.

iv. Selection of sprocket hub size and bore

American Standard No.60 small sprocket-12 teeth operating at maximum speed of 1,050 rpm will have maximum hub diameter and bore of 2 inches (50 mm) and 1.3 inches (33 mm) respectively that will accommodate the driver shaft of 33 mm diameter and driven sprocket-72 teeth operating at 45 rpm, bore of 45 mm was chosen to fit in the driven shaft.

v. Determination of the center distance and chain length

Center distance for pulsating drives was computed from "equation 7"

C = D + d/2 (7)

where,
C is the centre distance, inches
D is the diameter of larger sprocket, inches
D is the diameter of smaller sprocket, inches

The outside diameter for 72-tooth 2 inches sprocket is 47.01 inches and 12-tooth sprocket is 8.67 inches.

C = 47.01 + 8.67/2 = 51.35 inches.

An acceptable start would be to select 52 inches in No.60-chain for 1 inch. Equation 8 can be used to determine chain length;

$$L = 2C + \frac{N-n}{2} + \frac{0.1013(N-n)^2}{4C} \qquad (8)$$

Where,
L is the length of chain, pitches
C is the shaft center distance, pitches
N is the number of teeth in larger sprocket
n is the number of teeth in smaller sprocket

$$L = 2 \; X \; 52 + \frac{60}{2} + \frac{0.1013(60)^2}{4 \; X \; 52} = 135.75 \; pitches = 136 \; Links$$

Based on the 12/72 tooth sprockets and a center distance of 52 inches (1.3 m) and a chain 136 pitches long including connecting link is required.

2.3.4 Determination of power requirement of the harvester

The power of the harvester is the total power required to harvest yam tubers, which is equal to the power for digging and lifting soil and yam tubers out of the mounds and was determined from "equations 9".

$$P_h = R_{GS} V \qquad (9)$$

Where;
$P_h$ is power requirement of the harvester, W
$R_{GS}$ was computed from "equation 10".

$$R_{Gs} = a \; X \; b \; X \; \rho_{soil} \; X \tan(\alpha + \theta_I) \qquad (10)$$

Where,
$R_{GS}$ is power required to lift soil, W
□ is depth of soil layer; 40 mm
□ is width of soil layer; 765 mm
θ is penetration depth; 20 mm
α is angle of inclination to the horizontal; 12° and most satisfy condition in "equation 11".

□ ≤ □□ − Ø (11)

Where;
Ø is the angle of friction between the soil and blade material: 16° – 19° (Bravo, *et al*., 2014), and
V was computed from "equations 12".

$$V = \frac{4}{6}\left[\frac{1}{2} W_O\right]^3 \pi \qquad (12)$$

Where,
V is the volume of unit mass of mound, $m^3$
$W_O$ is the width of mound, m and

$R_{GS}$ = 40 x 765 x 12,590 g/$m^3$ x tan (12 + 20)
= 0.4 x 0.8 x 12,590 x 0.66 = 2,659

$$V = \frac{4}{6}\left[\frac{1}{2} \; X \; 0.97\right]^3 \pi = 0.751 \; m^3$$

$P_h$ = 2,659 x 0.751 = 1,996W = 2.0 kW

**2.4 Process of Fabrication of the Harvester Components**

The materials used for fabrication of the machine were sourced locally. Drawing of the parts was done using SolidWorks 2017 Version Software and all dimensions were given on the drawing print-out for guidance. For this research, there were few manufacturing processes that have been applied to achieve the desired result. Most of the components were fabricated in the workshop while standard components were purchased based on what was designed and fitted directly to the yam harvester or with slight modifications as presented in Table 2. Such parts are; pillow-block bearings, cam lifting shaft, pivot shaft, small sprocket, chain, rotary hoe cultivator gear box, axle and 3-piont link, depth wheel tyres, transport wheel tyres. Chain and sprocket drive train was introduced to replace the two (2) land wheels that were designed to provide power to the cam lifting shaft and the in-cooperation of PTO drive were adapted for the design. Many techniques are implemented in order to fabricate the machine parts and components.

**2.5 Assembling of Parts of Harvester**

This is joining process where parts were brought together by fasteners such as nuts and bolts to form the complete unit of yam harvester. The welded square steel tubing section formed the rectangular frame for coupling the other parts of the machine such as the digging fork, gear box and axle and 3-point link, depth wheels, transport wheels, disc coulters, collection bin, transit bin. The assembly was done in steps;

**1st Step:** Two (2) lifting cams were welded to the stainless steel shaft at a predetermined interval and two (2) pillow-block bearings were force fitted to it and bolted to the frame. Two (2) land wheels were attached to shaft extreme ends and keyed.

**2nd Step**: Pivot shaft was passed through the two (2) fork holders and were bolted on the upper part of vertical standards situated at the rear of the frame.

**3rd Step:** Two (2) standard tricycle tyres were fixed on the transport wheel holder and welded on the rear of the frame.

**4th Step:** The digging fork was bolted to its holders

**5th Step:** One smaller square pipes was fixed into another bigger pipe with spring inside and the assembly was completed by fixing of the wheel and the coulter on the holders. Two (2) depth wheel assemblies were bolted side-by-side with the digging fork in front of the frame.

**6th Step:** Collection bin unit was bolted on the vertical standards at the rear of the frame.

**7th Step:** Transit bin unit was welded on the vertical standards directly above the collection bin such that it moves up and down. The adjustment device was also bolted to control the up and down movements of the transit bin.

**8th Step:** This is the adjustment step of the fabrication after the test-run of the harvester. Here, cam, 3-piont links, axle, gear, chain and sprockets were in-cooperated as can be seen in Plate 1. These parts were attached to the frame by bolts and nuts. The whole harvester was coated and painted to prevent corrosion and for attractiveness.

**2.6 Pre-test of the Yam Harvester**

The yam harvester was first tested for functionality on the 14th July, 2017 at University of Agriculture, Makurdi Nigeria. The assembled harvester was mounted on a tractor, operated at a low forward speed and the power was transmitted from the land wheel to the cam lifting shaft and cams directly attached to it thereby rotating the shaft together with the cams which with their configurations, caused the digging fork to dwell, rise and fall. The harvester was run 3 times for each tractor speed of 1.5 km/h, 2.0 km/h and 2.5 km/h on plain leveled ground to determine the distances covered as the lifting cam raises and falls the digging fork for dwell, rise and fall which were recorded. The average distances covered by the three tractors forward speeds for dwell and rise and fall were 1,170 mm and 1,183 mm respectively. These distances were more than the recommended for yam mound basal diameter and inter-mound spacing. Therefore, there was need to re-design the cam and digging fork and to in cooperate PTO drive gears, chain and sprocket drive train in the machine (Plate 1b). The harvester was again re-tested after adjustment to run 30 times on flat ground at UDECO Engineering Company Workshop, Makurdi on 7th December, 2020 with the same tractor speeds at 1.5 km/h, 2.0 km/h and 2.5 km/h respectively and fork distances were measured.

**2.7 Field Lay-Out**

Plain field at UDECO Engineering Workshop, Makurdi Benue State, Nigeria was first ploughed to loosen the soil surface on 15th December, 2021. The soils were raised up to form ten (10) artificial mounds of three (3) rows giving the total number of thirty (30) mounds in the test field. The basal diameter and inter-mound spacing between the mounds and time for one (1) revolution were measured using measuring tape and stop watch to be 912 mm and 740 mm and 3.33 as was determined during plain ground pre-test of the yam harvester. Intra-mound spacing of 600 mm was given to allow for tractor tyre passage. Buffer zones of 210 mm each were created at the beginning and at the end of the field for tractor turning and test field was measured to be 5.14 m x 15.78 m. Thirty (30) yam tubers of *cv gbangu* were purchased at North bank market, Makurdi Benue State, Nigeria. The tubers were transported to the field and each tuber was buried in each of the mound.

(a) First Assembled Yam Harvester

(b) Re-designed Yam Harvester

**Plate 1: Pictures of the Yam Harvester**

**2.8 Field Test**

The developed yam harvester was introduced on the prepared field on 17th December, 2021. The yam harvester was attached to the tractor three-point hitch and connected to tractor PTO through the use of a universal joint where it received power (Plate 2). The tractor was moved into the test field and set to ensure that mounds are placed between the tyres and the digging fork was at its lowest point just touching the base of the first mound. The tractor was operated at a low speed of 1.5 km/h and the PTO gear was engaged to transmit power from the drive train to the cam lifting shaft thereby rotating the cam where the digging fork shattered the mounds, lifted tubers from mounds and some were dropped them into the collection bin. The procedure was repeated for tractor forward speeds of 2.0 km/h and 2.5 km/h on the other rows. The number of lifted and exposed tubers per row for each tractor speed were counted and recorded.

**Plate 2: Yam Harvester Mounted on a Tractor**

**2.9 Performance Evaluation of the Harvester**

**2.9.1 Determination of digging fork dwell, rise and fall distances**

The results obtained during plain ground test were analysed using ANOVA at $p \leq 0.05$ (Table 6) to determine if the tractor speed had significant effect on the dwell, rise and fall distances covered by the digging fork and Table 4 is the summary of the results. The DNMRT at $p \leq 0.05$ was used to separate the means as presented in Table 7.

**2.9.2 Determination of harvesting efficiency, tuber harvesting rate, harvester theoretical capacity, effective field capacity and field efficiency**

The harvester was also evaluated in a field with thirty (30) yam tubers buried in artificial mounds as recorded in Table 5 were analyzed using "equations 13, 14, 15, 16 and 17".

i. Tubers Harvesting Efficiency, $\eta_h$

$$= \frac{No.of\ Tubers\ Lifted}{No.of\ Buried\ Tubers} X100 \qquad (13)$$

$$Tubers\ \ Harvesting\ Efficiency, \eta_h = \frac{21}{30} X\ 100$$
$$= \ 70\%$$

$$ii. Harvesting\ Rate, R_h$$
$$= \frac{Length\ of\ Field}{Mound\ and\ inter\_mound\ spacing} X\ Time \quad (14)$$
$$Harvesting\ Rate, R_h = \frac{15.78}{1.65} X\ 33.3\ X\ 3{,}600h$$
$$= 0.09\ ha/h$$

$$iii. Theoretical\ Field\ Capacity, T_{fc}$$
$$= T_l + T_t + T_{off} \qquad (15)$$

Where,
$T_l$ is the rate of field coverage for lifting tubers, ha/h
$T_t$ is the rate of field coverage for turning, ha/h
$T_{off}$ is the rate of field coverage for off-loading tubers, ha/h

$$Theoretical\ Field\ Capacity, T_{fc}$$
$$= 0.09 + 0.01 + 0.03$$
$$= 0.13\ \ ha/h$$

$$iv.\ Effective\ Field\ Capacity, E_{fc} = R_h \qquad (16)$$

Where,
$R_h$ *is the rate of harvesting tubers from the mounds, ha/h*

$$Effective\ Field\ Capacity, E_{fc} = 0.09\ ha/h$$
$$v. Field\ Efficiency, F_e = \frac{E_{fc}}{T_{fc}} X\ 100\% \qquad (17)$$
$$Field\ Efficiency, F_e = \frac{0.09\ ha/h}{0.13\ \ ha/h} X\ 100 = 69.2\%$$

## 3. Results

Results are presented in Tables 1, 2, 3, 4, 5, 6 and 7 respectively.

**Table 1: Physical and Technical Specifications of the Harvester**

| Component | Specification | Symbol | Value |
|---|---|---|---|
| **Harvester** | Overall length | $L_h$ | 3.7 m |
| | Overall width | $W_h$ | 1.5 m |
| | Overall height | $H_h$ | 1.7m |
| | Overall weight | | 459 Kg |
| | Power requirement | $P_h$ | 2.0 Kw |
| **Cam** | Operating speed | | 45rpm(1.13 m/s) |
| | Dwell distance | | 0.75 m |
| | Rise and fall distance | | 0.75 m |
| **Chain and sprocket drive** | Dia. of driver sprocket | $D_1$ | 160 mm |
| | Dia. of driven sprocket | $D_2$ | 870 mm |
| | Driver sprocket no. of teeth | $Z_1$ | 12 |
| | Driven sprocket no. of teeth | $Z_2$ | 72 |
| | Gear ratio | i | 6 |
| | Speed of driver sprocket | | 270 rpm |
| | Speed of driven sprocket | | 45 rpm |
| | Centre distance | C | 1.3 m |
| | Length of chain | L | 3.5 m |
| **Frame** | Hollow cross section | | 90 x 90 x 5 mm |
| **Depth wheel** | Diameter | $d_{dw}$ | 400 mm |
| **Coulter** | Diameter | | 420 mm |
| **Transport wheel** | Diameter | $d_{tw}$ | 400 mm |
| **Differential** | Input speed | | 540 rpm |
| | Output speed | | 270 rpm |
| **Digging fork** | Working length | $L_d$ | 671 mm |
| | Working width | $W_d$ | 765 mm |
| | Maximum working depth | | 50 mm |
| | Number of tines | n | 9 |
| | Diameter of tine | $d_u$ | 20 mm |
| | Distance between tines | s | 65 mm |
| | Angle of inclination to the horizontal | α | $12^o$ |
| | Clearance | Δ | 13 mm |
| **Tuber transit bin** | L x w x h | | 1.1 x 0.5 x 0.3 m |
| | Volume | | $0.03\ m^3$ |
| | Number of pipes | | 6 |
| Tuber collection bin | L x w x h | | 0.74 x 0.8 x 0.7 m |
| | Volume | | $0.14\ m^3$ |

**Table 2: Description of Process of Fabrication of the Components**

| Component | Material | Process Description |
|---|---|---|
| **Main frame** | Mild steel, square hollow cross-section 90 x 90 x 5 mm | The section was marked to the required length and 2NOs sections cut to size and welded to each other at predetermined interval. |
| **Digging fork** | 1. Mild steel, 20 mm diameter rod<br>2. Mild steel plate | 1. Nine (9) lengths of 671 mm were marked and cut out of the 20 mm diameter rod.<br>2. Each length was welded to the edge of a plate of 765 mm x 50 mm at a spacing of 85 mm.<br>3. Holes of 20 mm were drilled on each end of fork for attachment to holder. |
| **Fork holder** | Mild steel, rectangular cross-section frame | The two (2) fork holder frames were marked and cut from a 70 x 70 x 3 mm and fixed to the pivot shaft at one end. |
| **Cam lifting shaft** | Stainless steel, Ø45 mm diameter solid cross-section rod | A Ø45 mm rod was marked 1,560 mm, cut and force-fitted to the two pillow-block bearings that were placed on the main frame of the machine. |
| **Pivot shaft** | Ø45 mm stainless steel solid cross-section rod | 1,600m m was marked out and both ends of the rod reduced to Ø32 mm diameter on a lathe machine and threaded. |
| **Cam** | Mild steel, 25 mm plate | The cam profile was marked on the plate, and the profile cut out of the plate and welded to the cam lifting shaft. |
| **Big Sprocket** | Mild Steel, 25 mm plate | 72-Teeth sprocket was designed and cut out from a card board paper and traced on the thick metal plate, flame cut and filed to get smooth surfaces. |
| **Axle** | The gear and axle of a disused rotary hoe cultivator | The gear and axle of a disused rotary hoe cultivator was removed by unscrewing the nuts and bolted to the harvester frame to replace land wheels and fitted with the driver sprocket of the harvester. |
| **3-point link** | The 3-point link of a disused rotary hoe cultivator | The 3-point link of a disused rotary hoe cultivator was marked cut and welded to the axle and cross bars were by it side attachment of some components. |
| **Tuber transit bin** | 1.Mild steel, 20 mm diameter pipe<br>2. Mild steel plate | 1. Six (6) 20 mm diameter pipe of 1,105 mm length were marked and cut and welded on two (2) 20 mm diameter pipe of 550 mm length at one end at spacing of 94 mm to form the bottom of the box.<br>2. Two (2) plates, each of 1,105 mm x 300 mm were cut out of a 2 mm sheet and welded to two sides of the pipes to form the sides of the box. |
| **Tuber transit bin** | 1.Mild steel, 20 mm diameter pipe<br>2. Mild steel plate | 1. Six (6) 20 mm diameter pipe of 1,105 mm length were marked and cut and welded on two (2) 20 mm diameter pipe of 550 mm length at one end at spacing of 94 mm to form the bottom of the box.<br>2. Two (2) plates, each of 1,105 mm x 300 mm were cut out of a 2 mm sheet and welded to two sides of the pipes to form the sides of the box. |
| **Collection bin** | 1. Mild steel pipe<br>2. A 2 mm mild steel sheet | 1. Twenty-four (24) 20 mm diameter pipes of appropriate lengths were marked, cut from a pipe and welded to achieve the configuration of the collection box.<br>2. Two plates, each of 800 mm x 700 mm and two other plates, each of 740 mm x 700 mm, were marked and cut from a 2 mm thick mild steel sheet and welded together to achieve the configuration of the collection bin. |
| **Vertical standard** | 90 x 70 x 5 mm hollow cross section plate | Two (2) 90 mm x 70 mm hollow cross section pipes of length 1,015 mm were marked and cut and welded to the frame of the harvester. |
| **Depth wheel holder** | 10 mm sheet plate, nuts and bolts | The 420 mm diameter coulter was marked, cut from a 10 mm thick plate, and fastened to a 400 mm diameter wheel and fastened to a spring of 65 mm diameter housed in a 70 mm x 70 mm hollow cross section pipe that was fastened to the frame of the harvester. |
| **Transport wheel holder** | 70 x 70 x 3 mm hollow cross section pipe & a tyre | Two (2) 70 x 70 mm hollow pipes were each cut from a 3 mm thick plate and provision for tyres of 400 mm diameter were made and fastened to the harvester. |

**Table 3: Calculated Cam and Follower Parameters**

| Parameter | Cam motion type | | | |
|---|---|---|---|---|
| | **Dwell** | **Rise** | **Fall** | **Total** |
| **Cam Movement (mm)** | 0 – 750 | 750 – 1,125 | 1,125 – 1,500 | 1,500 |
| **Cam angle (deg)** | 0 – 180 | 180 – 270 | 270 – 360 | 360 |
| **Cam follower displacement (mm)** | 750 | 375 | 375 | 1,500 |
| **Time taken for the displacement (s)** | 1.67 | 0.83 | 0.83 | 3.33 |
| **Acceleration at displacement (m/s)** | 0.68 | 1.36 | -1.36 | 3.40 |

**Table 4: Summary of Distances Covered by Harvester Fork during Pre-Test**

| Speed (km/h) | Dwell (mm) | Rise and Fall (mm) |
|---|---|---|
| 1.5 | 639 | 477 |
| 2.0 | 963 | 512 |
| 2.5 | 1,136 | 1,232 |
| **Mean** | **912.67** | **740.33** |

**Table 5: Field Test Result**

| Speed (km/h) | Number Buried | Tuber Lifted into Collection Bin | Tuber Lifted Percentage (%) | Tuber Exposed |
|---|---|---|---|---|
| 1.5 | 10 | 7 | 70 | 3 |
| 2.0 | 10 | 8 | 80 | 2 |
| 2.5 | 10 | 6 | 60 | 4 |
| **Total** | **30** | **21** | | **9** |

**Table 6: Summary of ANOVA of the Effect of Speeds on Distances of the Harvester Fork.**

| Distance | Source of variation | Df | SS | MS | F | Sig |
|---|---|---|---|---|---|---|
| **Dwell** | Speed | 2 | 1,273,046.70 | 636,523.33 | 44.42 | 0.000* |
| | Number of runs | 29 | 386,940.00 | 14,331.11 | | |
| | **Total** | **31** | **1,659,986.70** | | | |
| **Rise and fall** | Speed | 2 | 3,632,166.70 | 1,816,083.33 | 54.73 | 0.000* |
| | Number of runs | 29 | 895,930.00 | 33,182.59 | | |
| | **Total** | **31** | **4,528,096.70** | | | |

*Significant at $p \leq 0.05$

**Table 7: Mean Separation of Speeds on Distances of the Harvester fork**

| Tractor speed (km/h) | Dwell (m) | Rise and fall (m) |
|---|---|---|
| **1.5** | $0.64^a$ | $0.48^a$ |
| **2.0** | $0.96^b$ | $0.51^a$ |
| **2.5** | $1.14^c$ | $1.23^b$ |

Means with the same letter along the same column are not significantly different at $p \leq 0.05$ using the DNMRT

## 4. Discussion and Conclusions

Table 1 is the physical and technical specifications of the harvester and Table 2 is the description of process of fabrication of the components.

Results presented in Table 3 showed the calculated follower displacement for dwell, rise and fall to be 750 mm, 375 mm and 375 mm and the time taken for various displacements are 1.67s, 0.88 s and 0.88 s respectively. The total follower displacement and time of 1,500 mm and 3.33 seconds were taken to correspond with one (1) revolution of the digging fork that was expected to shatter the mound, lift the tuber from the mound and drop it into the collection bin.

The test results in Table 4 showed that at tractor forward speeds of 1.5 km/h, 2.0 km/h and 2.5 km/h gave the mean dwell, rise and fall distances of 912 mm and 740 mm. It was observed that the dwell, rise and fall distance calculated were 750 mm and 750 mm of harvester digging fork while plain field pre-test gave 912 mm and 740 mm which falls within the recommended mound basal diameter and inter-mound spacing provided by (Yulan *et al*., 2012) (Awulu *et al*., 2013).

Table 5 showed that the number of yam tuber lifted into the collection bin and tuber exposed were 7, 8, and 6 and 3, 2 and 4 with 70%, 80% and 60% at various tractor forward speeds of 1.5 km/h, 2.0 km/h and 2.5 km/h. Tractor forward speed of 2.0 km/h has successfully lifted 8 tubers into collection bin. The tuber harvesting efficiency, effective field efficiency, theoretical field efficiency and field efficiency of the yam harvester were calculated to be 70%, 0.09 ha/h, 0.13 ha/h and 69.2 % respectively.

Table 6 is the summary of ANOVA of the effect of tractor speed on the distance moved by the yam harvester during plain ground for dwell, rise and fall of its digging fork. It showed that the speed had a significant effect on the dwell, rise and fall distances moved by the fork blade of the harvester. The dwell of the digging fork was significantly different at the speeds investigated. However, the distance moved during the rise and fall of the fork blade at the tractor speeds of 1.5 and 2.0 km/h were not significantly different. Speed significantly affects the performance of yam harvesters (Itodo and Daudu, 2007) because it determines how long the digging fork will dwell on the ground to shatter the mound, lift the harvested tuber into the collection bin and falls again to dwell and harvest from the next consecutive mound.

In Table 7 the distances covered by the digging fork on the ground were 0.64 m, 0.96 m and 1.14 m at the tractor speeds of 1.5 km/h, 2.0 km/h and 2.5 km/h respectively. The distance moved by the harvester during the rise and fall of the digging fork at the speeds of 1.5 km/h, 2.0 km/h and 2.5 km/h were 0.48 m, 0.51 m and 1.23 m respectively. The dwell, rise and fall distances increased with increasing tractor speed.

It was therefore concluded that:

1. A prototype yam harvester for yams planted in mounds was developed and its performance evaluated successfully.
2. The yam harvester parameters for the digging fork on the ground and rise and fall were 0.64 m, 0.96 m and 1.14 m and 0.48 m, 0.51 m and 1.23 m at the tractor speeds of 1.5 km/h, 2.0 km/h and 2.5 km/h respectively. The tractor forward speed has significant affects on the performance of yam harvesters.
3. The tractor forward speed of 2.0km/hr gave the best dwell, rise and fall distances moved by the digging fork of the harvester.
4. The harvester harvesting rate is 0.09 ha/h.
5. The yam harvester has a 70% harvesting efficiency.
6. The yam harvester field efficiency is 69.2%.
7. The harvester was under evaluated due to lack of time, hence the need for further evaluations.

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