The Development of an Indigenous Potato Digger in Nigeria

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Abstract: **Potato is the world's fourth-largest food crop. The traditional method of harvesting with spades, digging hoes, digging forks has proven to be laborious, and time consuming with low output. Some mechanical equipment for the harvesting of potato are either not suitable to the soil condition or difficult to procure in Sub-Sahara Africa. This work focused on the development of an indigenous potato diggerto solve the aforementioned challenges. The design parameters determined are the diameter of the conveyor shaft, power requirement, conveyor capacity length of chain, diameter of driven sprocket, and output speed from gearbox. The semi-mounted potato digger was successfully designed and fabricated using the readily available materials. The implement has a 2.365kW power requirement while the calculated conveyor shaft diameter is 30.9 mm diameter. The digger was designed to work under common soil conditions in the tropics. At 10km/hr tractor speed, the digging and conveyor efficiencies obtained were 97.6% and 63.5% respectively while the theoretical and effective field capacities were 1.1ha/hr and 0.604ha/hr respectively.**

Keywords: **Design, fabrication, harvesting, indigenous potato digger, potato.**

I. INTRODUCTION

Potato (*Solanumtuberosum L.*) is the world's fourth-largest food crop. It provides high nutrition and is an adaptive specie for climate change. Potatoes use less water per nutrient production than all other major sources of food and it is grown across Africa. Potato offers more food per area per unit than any other major staple crop. Potatoes are the perfect food and one of the few things that can happen is that it embraces life on its own. As a result, potato has a significant impact on supplying families with nutrition, growing household income, and delivering surplus to the wider market (Vita and IPF, 2014).

Between 1990's to 2007, the world's potato production increased by nearly 21 percent. Ironically, developing countries showed a massive increase in harvested tubers at around 94 percent (FAO, 2008). For table consumption or as processed products, potatoes can be served.In addition to being a source of carbohydrates, it also contains a high content of protein, vitamin C, fiber, minerals and has a low-fat content. Because of the value of potatoes for various reasons, including agriculture, the environment, and global food security, the FAO proclaimed 2008 to be the "International Year of Potatoes," with the main goals of supporting the sustainable development of potato-based systems and the potato industry and enhancing the well-being of both producers and consumers (FAO, 2008).Potato is a major food crop grown in over 100 countries around the world. More than one billion people consume potato worldwide, according to the (FAO, 2008).It is a high-quality vegetable cum food crop that is used to produce over 100 forms of recipes. Potato protein content has a high biological value relative to cereals and is considered better than milk. Potato thus supplements meat and milk products by reducing energy consumption and also reducing the cost of food (Shrinivas, 2011).

The potato (*Solanumtuberosum*) is an annual herbaceous crop that grows up to 100 cm in height and produces a tuber–also called potato–so rich in starch that after maize, wheat and rice it ranks as the fourth most important food crop in the world. The potato belongs to the family of flowering plants "nightshade," which shares the genus *Solanum* with at least 1000 other species, including tomatoes and eggplants.As the potato plant grows, its compound leaves starch formed to the ends of its underground stems (or stolon). The stems thicken to form near the surface of the soil a few or as many as 20 tubers. The number of tubers that eventually grow depends on the moisture and nutrients available to the soil. Tubers can vary in shape and size, weighing up to 300 g each as a rule.The leaves and stems of the plant die down to the soil level at the end of the growing season and its new tubers are detached from their stolons. Then the tubers act as a store of nutrients that allows the plant to withstand the cold and then re-grow and reproduce. Every tuber is arranged in a spiral pattern around its surface from two to as many as 10 buds (or "eyes").The buds develop shoots that grow into new plants once again when conditions become favourable. A raw tuber of potatoes is rich in micronutrients, the essential vitamins, and minerals for wellbeing. A medium-sized potato has high potassium levels and almost half of the daily adult vitamin C requirement. It is also a good source of vitamin B and minerals such as magnesium and phosphorus (Ismail *et al*., 2015).

The potato provides high nutrition and is a climate change adaptive species. Potatoes use less water per diet than all other major food sources and can be grown throughout Africa.Potato offers more food per area per unit than any other major staple crop. They are the perfect food and one of the

few that can sustain life on their own. This, therefore, has a significant impact on providing family nutrition, growing household income, and supplying the wider market with a surplus. Also,potato is considered to be one of the most essential crops of vegetables, providing carbohydrates to humans. It is listed as the first grain crop substitute to address food shortages in some countries. The average world potato production was 290.34 million tonnes of various potato varieties in the last decade(Vita and IPF, 2014; Samy*et al*., 2006).

Nigeria, the most populous country in Africa, enjoys a pride of place in the potato region. It is the fourth largest potato producer in sub-Saharan Africa, has nearly as much land under potato as Germany, and over the past decade potato output has grown sevenfold, reaching 843000 tons in 2007.The key potato-growing area is the Jos Plateau, where altitudes ranging from 1200 to 1400 m and summer temperatures rarely above 35 ° C make a temperate climate ideal for potato-growing.Nigeria records one of the world's lowest average potato yield/hectare, little more than 3.1 t/ha. Potato consumption is also very low, barely 3.2kg per capita per year. However, Nigeria's taste for potatoes, especially in rapidly growing urban areas, is increasing. Since 2000, imports of raw and processed potatoes have risen from less than 9,000 tonnes to 40,000 tonnes a year. Despite the progress made in Nigeria's potato growth, some constraints still exist that restrict its production. These include inadequate seed supply, poor storage, disease, and pest management, high production input costs, climate constraints, marketing issues, and inadequate research funding(Ugonna*et al*., 2013). However, Nigeria has problems with the production and storage of potatoes. Collecting these problems leads to a reduction in crop yield and an increase in waste value as the mean of potato production is 24 tons /ha, but in developed countries, this number amounts to 50 tons /ha (Tarkesh, 2005).The main factors of low activity at harvest time and after harvest are the lack of physiological maturity, unavailability of labour during harvest season, unsuitable harvesting methods, gradation, transportation, packaging and inaccessibility in a proper technical storehouse (Modareserazavi, 1996).During the investigation, potato wastage values were 48 percent from harvest to consumption, and harvest equipment wastes were declared 1.72 percent. Mechanical potato harvest relative to manual harvest causes 65 percent frugality at harvest time and 45 percent at harvest cost (Nasre, 2003).

Harvesting the potato crop is one of the critical parts of the entire potato production and marketing operation. Crop yield and quality cannot be increased during harvest, but they can be decreased, sometimes drastically.In Nigeria, potato harvesting is done manually using small hoes, forks or potato harvester to lift the tubers from the soil. Potato is harvested between 65-95 Days after Planting (DAP) depending on the variety, physiological stage of seed potato planted and growing conditions. Alpha and RC777-3 varieties mature between 85-95 Days after Planting. Early maturing varieties are ready for harvest between 65-75 Days after Planting. These are done with a lot of care to avoid physical damage to the potato tubers as it affects the market price. The potato yield in Nigeria is more in Jos Plateau State and some of the LGAs where potatoes are grown in large quantities are Bokkos, Mangu and B/Ladi with an average yield of about 2800kg, 2950kg and 2886kg respectively. Although from the FAO report of 2009, Nigeria 3.1t/ha, this has not changed much as the total State production rate is 2.1t/ha. The main cause of loss of quality occurs when proper procedures are not performed during harvest. Some cultural practices, such as excess nitrogen, excess water, and poor aeration of the soil, may predispose tubers to more severe damage. Furthermore, during drilling, washing, and shipping activities, most of the actual damage occurs.The time of harvesting depends on the varieties grown. Potato crop should be planted with a marketable variety of known maturity periods. The crop should be planted at the correct spacing of 70 by 30cm and ridges of 25-30cm height (Ugonna*et al*., 2013; Arthur*et al*., 2017).

Potatoes are generally lifted with spades, digging hoes, digging forks as used for manual tillage or with animal drawn potato ploughs. A number of animal drawn and tractor mounted tools and equipment have been developed for lifting or harvesting operations (CGIAR, 2017).

Potato harvesting is one of the most critical operations to be carried out to have a good yield of potatoes. It has a direct effect on the swelling of the potato. Bruising has a major effect on the selling of potatoes. The mechanical bruising may occur when the wheels of tractors roll during harvesting on the rows of potatoes (Samy*et al*., 2006).Manual method of harvesting potato is inefficient in a large production of potato and post-harvest loss (20 -25%) is one of the major problems in potato production. Among this is physical damage due to the digging (lifting) of the tubers by hoe or local plough, thereby, reduces the production of potato. Also, most potato diggers are imported which are not adapted to local conditions. Hence, there is need for design and fabrication of an indigenous potato digger.

II. MATERIALS AND METHODS

The implement consists of five major components which are the digging unit, conveyor, gearbox, links, and frame.

A. Materials

Components of the potato digger such asdigging shovels, universal joint are made of stainless owing to their frequent exposure to moisture and wear.Other components of the digger such as conveyor, frame, links are made of mild steel due to its availability and ease of machining.

B. Design procedure

1. Design consideration

In the design of the potato digger, the following factors were considered; the physical, mechanical and agronomic

properties of potato such as size, planting depth, planting space, weight, and shear strength. Other factors considered are size of the machine, portability, availability of materials, and strength.

2. Design Calculations

a. Determination of power requirement

The total power, P required by the potato digger is given as:

P = Drawbar Power + Power required to drive the conveyor (1)

The Drawbar Power, P_1 = draft × forward speed (2)

Draft = soil penetration resistance × effective width × depth of digging (3)

The power required for conveying the potato,

$$P_2 = \frac{2\pi NT}{60} \quad (4)$$

Torque, T =Total weight of the conveyor and potato × radius of rotation, R.

Total weight, W = mass of rods × no of rods× gravity.

And, mass of rod = density x volume

And, volume $= \frac{\pi d^2}{4} l$

b. Determination of output speed from gear box, N₂.

The gear box delivers output speed in ratio 1:1. The output speed is 540rpm which is the same speed from the tractor's PTO drive.

c. Determination driven sprocket diameter

The driven sprocket diameter, D_2 was determined using:

$$D_2 = \frac{N_1 D_1}{N_2} \quad (5)$$

Where, N_1 = speed of driving sprocket (540rpm)

D_1 = diameter of driving sprocket

N_2 = speed of driven sprocket

d. Determination of conveyor shaft diameter

The conveyor shaft diameter, d was determined using:

$$d^3 = \frac{16}{\pi\sigma_s}\sqrt{(k_b m_b)^2 + (k_t m_t)^2}, \text{ (Hall } et\ al.\text{, 1980)} \quad (6)$$

Where, d = diameter of the shaft

K_b = combined shocked and fatigue factor applied to the bending moment = 1.5

K_t= combination minor shock and fatigue factor applied to torsional moment = 1.0

σ_s= allowable shear strength $= 40 \times 10^6\ N/m^2$

e. Determination for the length of chain, L

The length of the chain, L was calculated using:

$$L = \frac{\pi}{2}(D_2 + D_1) + \frac{(D_2+D_1)^2}{4C} + 2C \quad (7)$$

Where,

D_1 =Diameter of the driving sprocket

D_2 =Diameter of the driven sprocket

C =Centre distance between the two chains

f. Determination for conveyor capacity

The capacity of the conveyor was determined using:

Conveyor capacity = surface area × thickness

Surface area = length × breadth

3. Design Drawing

The isometric view of the machine was made with Autodesk Inventor 2017. The exploded, orthographic, parts details and other views were also draw.

C. Fabrication procedure and finishing operations

The potato digger was fabricated in the departmental workshop, using readily available materials in which some of the component parts were fabricated and some were purchased. Afterward, the potato digger was assembled through the process of welding and bolting. The operations explained below were carried out in fabrication of the potato digger.

1. Fabricated components

a. Frame

The frame is the border that enclosed all the parts of the machine and served as a support to the other component of the machine. The frame used is rectangular in shape and made of 5mm thick mild steel angle bar and flat bar. In order to fabricate the frame, cutting machine was used to cut the parts of the frame, mostly mild steel plate into required size. The plate was then drilled for the placement of bearing and shaft.

b. Conveyor

The potato conveyor helps in the separation of the sand from the potato and also helps in the transfer of the harvested potato to the rear of the potato digger. 12mm rod was used for the conveyor. The rod was cut into 900mm length, it was then cut into 48 pieces and welded to a small metal plate which was then, welded to the chain.

c. Digging Shovel

The digging shovel is the part of the digger that digs the potato from the ground. The length of the shovel assembly is 1000mm. Each shovel was fabricated from a 5mm thick plate. The plate was cut into 200mm x 70mm arranged on 10mm

thick plate and another plate was used to support the shovel at bottom which is 3mm plate..

d. The links

These are the parts of the potato digger through which the implement is coupled to the tractor. Flat bar of dimension 15mm x 1500mm was used to make the stand and was cut into 700mm each.Square bar was used to make the beam and flat bar was used to make the top links and attached to the beam.

2. Purchased components of the potato digger

Apart from the parts above that were fabricated in the workshop, the following components were purchased and fitted directly to the potato digger or modified.

a. Bearings

There are four flanges bearing placed at the sides of the frame that support shaft for in a horizontal position. Then, one pillow-block bearing was used to support the shaft from the gear box. The pillow-block bearing has an extra ordinary function and performance, it is multi-functional usage i.e. its gives room for adjustment, tilting and tightening in order to positioning the shaft into the required position. The bearing has internal diameter of 30mm which is proportional to the external diameter of the shaft held in it. The bearing is able to provide enough stability for the shaft. The bearing were bolted to the frame with the aid of bolts and nut with washer in order to ensure proper tightening and positioning of the bearing, to prevent it from slacking during the operation.

b. Shaft

The shaft is one of the main component parts of the machine. Shaft of 2.438m was purchased and the diameter is 32mm which was machined to 30mm to suit the size of the bearing for firm holding. The shaft was cut into three (3) and two of shaft cut was used for the conveyor and the other one was attached to the gear box.

c. Chain and sprockets

The chain is one of the component parts of the machine. Chain of 6m length was purchased and was divided into two which were used to make conveyor by wedding of the iron rod of 12mm with it. The 4m length of chain was used to transmit the power from the gear box to the conveyor in plate 3.4 below. Also, four sprockets of 200mm diameter were used to make the conveyor with the support of the chain. Two sprockets of one 100mm and 200mm were used as driven and driving respectively.

d. Gear box

Gear box was purchased which was used to transmit the power coming from the tractor to the machine and to convert the power to right angle for rotation of the conveyor. Two angle bars was drilled and welded to the beam then, bolted to the gear box for firm holding.

Apart from the major components above, M10 and M12 bolt and nuts were used for almost all the part of the machine for easy assembly and disassembly.Washers were also used for all bolted joint to ensure proper tightening and prevent the joint from slacking.

3. Assembly Procedure

Finally, after the process of marking out, cutting, grinding, drilling, machining of both the fabricated parts and the purchased parts, the potato digger was assembled thus. Four sprockets were placed in the conveyor chain and two shafts were placed to the sprockets to assemble the conveyor.The conveyor was then placed to the frame and four flange bearings were bolted to the side of the frame for firm holding of the shafts after which the digger was then bolted to the frame. After this, the beam was bolted to the stands. The gear box was then placed on the beam and bolted. Also, the 3-point hitch was fixed by bolted to the frame and beam. The shaft from the gear box was fixed to the pillow bearing and bolted to then beam after which the chain and sprockets that transmit power from the gear box to the conveyor were fixed. The universal joint was thereafter fixed to the PTO shaft of the gear box as shown in the Fig. 3 below.

D. Testing Procedure

The potato digger was tested in stationary position (preliminary test) and also tested on the field as explained below.

1. Preliminary test of the potato digger

The potato digger was coupled to the tractor through the use of universal joint, which connected the gear box shaft and the tractor PTO shaft together in order to drive the potato conveyor and to know the speed of the conveyor. Preliminary test was done in stationary position of both the tractor and the potato digger. During the preliminary test, the tractor was started and the PTO shaft was engaged. The tractor was set at different speeds of 10, 12.5, 15, 17.5 and 20km/hr, respectively.Tachometer was used to determine the test parameters such as the PTO speed, input gear speed, output gear speed, and conveyor speed.

2. Field test of the potato digger

The potato digger was then transported to potato farm for testing. The length of the potato field was measured to be 26m and three (3) rows of ridges were used for the testing. Sweet potato variety was obtained from central market of Ado-Ekiti, Ekiti State, Nigeria. 126 tubers of potatoes were buried into the ridges at recommended planting depth of potato. The potato digger was lowered on the farm and the tractor was set at forward speed of 10km/hr. 123 pieces of potatoes were dug out of the ridges with the used of the potato digger. 80 pieces of potatoes were conveyed to the rear of the potato digger with the help of the conveyor.

III. RESULTS AND DISCUSSION

Having used the equations and the methods above, the following values were obtained. Total power requirement was calculated to be 2.365kW. Also, 200 mm, 30.9 mm, 3173.15 mm, 13168800 mm³ were obtained as driven sprocket diameter, conveyor shaft diameter, length of chain, conveyor capacity, respectively. Therefore, to in order to guide against factors of safety and fatigue that may arise, 32 mm diameter was used for the shaft. Also, 3200 mm used as the length of chain this compares to the standard length of chain.

The isometric view of the machine is shown in Fig. 1 below. Also, the frame component and the details of the top link are given in Figure 2.Fig. 3 shows the exploded view of the potato digger and the detail description of each component while the assembled potato digger is shown in Plate 1.

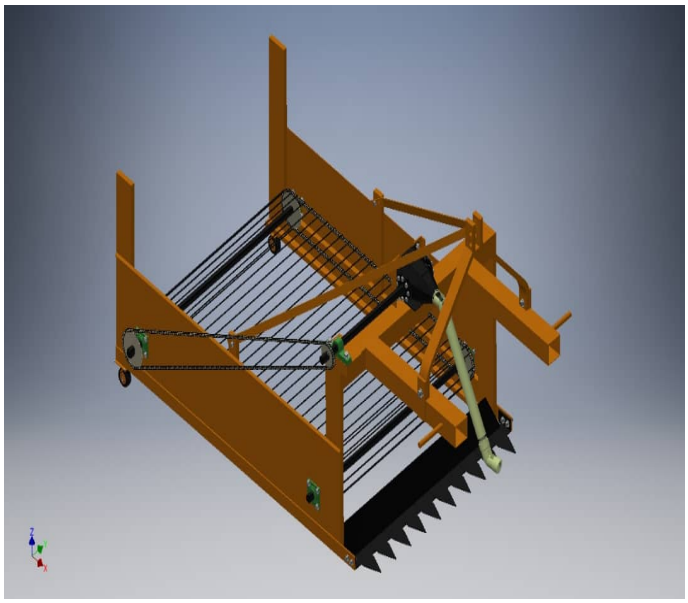


Figure 1: South East Isometric View of the Potato Digger

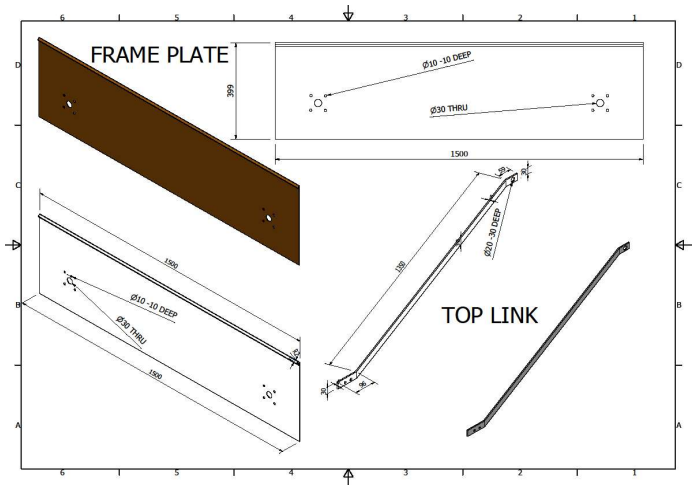
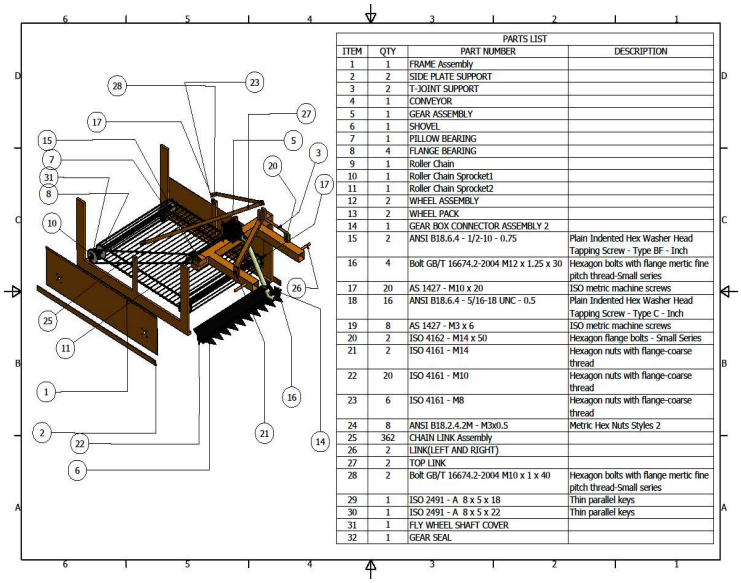


Fig. 2: Frame plate and top link details



PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	FRAME Assembly	
2	2	SIDE PLATE SUPPORT	
3	2	T-JOINT SUPPORT	
4	1	CONVEYOR	
5	1	GEAR ASSEMBLY	
6	1	SHOVEL	
7	1	PILLOW BEARING	
8	4	FLANGE BEARING	
9	1	Roller Chain	
10	1	Roller Chain Sprocket1	
11	1	Roller Chain Sprocket2	
12	2	WHEEL ASSEMBLY	
13	2	WHEEL PACK	
14	1	GEAR BOX CONNECTOR ASSEMBLY 2	
15	2	ANSI B18.6.4 - 1/2-10 - 0.75	Plain Indented Hex Washer Head Tapping Screw - Type BF - Inch
16	4	Bolt GB/T 16674.2-2004 M12 x 1.25 x 30	Hexagon bolts with flange mertic fine pitch thread-Small series
17	20	AS 1427 - M10 x 20	ISO metric machine screws
18	16	ANSI B18.6.4 - 5/16-18 UNC - 0.5	Plain Indented Hex Washer Head Tapping Screw - Type C - Inch
19	8	AS 1427 - M3 x 6	ISO metric machine screws
20	2	ISO 4162 - M14 x 50	Hexagon flange bolts - Small Series
21	2	ISO 4161 - M14	Hexagon nuts with flange-coarse thread
22	20	ISO 4161 - M10	Hexagon nuts with flange-coarse thread
23	6	ISO 4161 - M8	Hexagon nuts with flange-coarse thread
24	8	ANSI B18.2.4.2M - M3x0.5	Metric Hex Nuts Styles 2
25	362	CHAIN LINK Assembly	
26	2	LINK(LEFT AND RIGHT)	
27	2	TOP LINK	
28	2	Bolt GB/T 16674.2-2004 M10 x 1 x 40	Hexagon bolts with flange mertic fine pitch thread-Small series
29	1	ISO 2491 - A 8 x 5 x 18	Thin parallel keys
30	1	ISO 2491 - A 8 x 5 x 22	Thin parallel keys
31	1	FLY WHEEL SHAFT COVER	
32	1	GEAR SEAL	

Fig. 3: Exploded view of the potato digger

Plate 1: The assembled potato digger

The results of the preliminary test carried out after the assemblage operation has been done successfully are presented in the Table 1 below while the field test results are shown in Table 2.

Table 1: Result of preliminary test of the potato digger

Tractor speed (km/hr)	P.T.O speed (rpm)	Input gear speed (rpm)	Output gear speed (rpm)	Conveyor speed (rpm)
10.0	280.9	280.9	184.5	91.7
12.5	353.3	353.3	224.9	110.1
15.0	422.3	422.3	263.7	129.2
17.5	493.2	493.2	312.5	158.4
20.0	556.3	556.3	346.8	175.6

Table 2: Result of Field Test of the Potato Digger

Parameters	Values
Tractor Speed	10km/hr
Field Length	126m
No of rows	3
No of planted potatoes	126
No of potatoes dug out	123
No of potatoes conveyed	80
Digging Efficiency	97.6%
Conveyor Efficiency Theoretical Field Capacity	63.5% 1.1ha/hr
Effective Field Capacity	0.604ha/hr

From the test of the potato digger carried out, the following observations were made:

i. The gear box delivered the expected speed designed for the digger.
ii. The conveyor speed increased proportionally to the speed of the tractor
iii. There was no noise or undue vibrations in the working of the conveyor and other rotating parts.
iv. The potato digger dug too much soil which was unable to move to the conveyor. This was due to inadequate clearance between the digger plate and conveyor unit.

IV. CONCLUSION AND RECOMMENDATION

The potato digger was successfully designed and fabricated using the readily available materials. The potato digger was tested and all component parts worked satisfactorily. The field tests showed that the digger has digging and conveyor efficiencies of 97.6% and 63.5% respectively while the theoretical and effective field capacities are 1.1ha/hr and 0.604ha/hr respectively. This shows that the potato digger has the capability of delivering high harvesting efficiency provided all necessary adjustments are adequately done.It is recommended that thorough performance evaluation of the potato digger be carried out using varying varieties and sizes of potato.

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