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DEVELOPMENT OF A HAND PUSH-TYPE CASSAVA HARVESTER

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ABSTRACT
Cassava harvesting especially on large scale involves first, cutting the stem at a predetermined height above the ground and preserving it for the next planting season, after which a preferred method of uprooting the tubers is employed. It is categorised as the most difficult and challenging aspect in its production process. Most practiced world over, especially in Africa and Nigeria in particular, is the manual system of uprooting by hand which is tedious and mostly characterised with defects on farmers over time. Some of these defects include; blistered/callus palms, arched spinal cord and waist pain, amongst others. Root tuber damage, land mass and the farmers financial status are major considerations in the choice and adoption of a method of harvesting, (manual, semi-mechanised or mechanised) with respect to the end use of the harvested produce and availability/accessibility of resources. These and more led to the development of a hand push-type cassava harvester, incorporated with a cabin to protect the operator from unfavourable weather conditions and driven manually on two wheels. The mechanism of a simple machine such as the lever was employed in driving and powering the machine and its major components, adopting the first and second class lever principle in the design. The machine, comprising of three main mechanisms to carry out the following operations; stem cutting, soil loosening and tuber harvesting was successfully designed, fabricated and tested.

Key words: Development, Hand Push-Type, Cassava Harvester, Nigeria.

1 INTRODUCTION

Cassava, *Manihot esculanta* is a tropical, herbaceous crop, with a tuberous starchy root of the family Euphorbiaceae (Akinwonmi and Andoh, 2013). It is an essential source of food and income and classified as one of the three world's most important food crops, amongst rice and maize (IFAD et al., 2008). Cassava is ranked as the fourth supplier of dietary energy in the tropics (after rice, sugar and maize) and the ninth globally. Its cultivation and processing provide household food security, income and employment opportunities for hundreds of millions of people across the globe, mostly in Africa, Asia and the America. Worldwide, cassava provides the livelihood for millions of farmers and traders (FAO and IFAD, 2001). It is a basic staple food for millions of people in the tropical and subtropical regions, as well as being a major source of raw material as flour and starch for numerous industrial applications and animal feed (Anderson et al., 2004; FAO and IFAD, 2001).

Cassava is known to be exceptionally tolerant to high soil acidity and low levels of some basic soil nutrients (Phosphorus). It is also known to be a very drought-tolerant and water-efficient crop. Thus, cassava can compete with other more valuable crops such as maize, soybean and vegetables mainly in areas of acidic and low-fertility soils, and those with low or unpredictable rainfall (Howeler, 2012). The Federal Government of Nigeria recent directive on the substitution of 10% of wheat flour with cassava flour by flour millers, has further led to the surge in demand of cassava produce from between 200,000 and 300,000 tonnes to the tune of 600,000 tonnes per day (Olukunle, 2005). All these facts points to opportunities that abound in the area of cassava production, but, these opportunities cannot be fully exploited using the traditional harvesting and processing methods currently in use in the country which is generally adjudged as arduous, labour intensive, time consuming and unsuitable for large scale production (Adetan et al., 2003; Quaye et al., 2009; Agbetoye, 2005).

Lack of access to mechanised and improved farming systems to support production and processing of cassava is impeding the development of the cassava market in Nigeria. This technological gap has left farmers with little or no option but to produce cassava on a low scale, mainly for subsistence and local markets which is archaic, arduous, mundane and highly labour intensive. Although the continent and Nigeria in particular is ranked the highest producer of cassava in the world, in terms of classification of its yield, it is ranked below the fiftieth (50th) position, leaving much to be desired beyond its production status (Nweke et al., 2002). These therefore, buttresses the objective of this work; to review the efforts made, and currently being made towards an efficient and less cost effective mechanised system of cassava harvesting.

Cassava is basically harvested firstly by cutting off the stalks 20 – 30 cm above the ground, which is done manually using a machete with the remaining stump left to enable pulling the roots (tubers) off the ground. Where the soil is too hard, the roots can be lifted out of the ground using a pointed metal bar or metal fork attached to a wooden stick used as a lever. There are basically three methods generally employed in harvesting cassava. They are traditional or manual method, semi-mechanised system and mechanised harvesting. The traditional system employs uprooting tubers with bare hands and sometimes with the aid of a hoe or cutlass. Where the soil is hard, especially during peak dry season, the roots are lifted out of the ground manually using a pointed metal bar or metal fork attached to a wooden stick used as a lever. A major challenge with this method is the defects it poses to farmers, tedium, drudgery, and tuber damage associated with this harvesting method (Bobobee, 2014). The present situation in the country whereby limited quantities of cassava-based product are exported is largely due to the inability of these products to meet basic local demands, let alone international demands and standards for healthy foods (Adetunji and Quadri, 2011). Therefore, buttressing the need for a review of the efforts made towards an efficient and less cost effective semi-mechanised combined system of cassava harvesting.

2. Methodology

2.1 Machine Description and Components

The machine consists of three mechanisms for soil loosening, stem cutting and tuber harvesting (Figure 1). All three mechanisms where fastened to the frame by means of temporal fasteners (Bolts and nuts). This was necessary for ease of transport and maintenance. The mechanism of a simple machine as the lever was employed in driving and powering all mechanisms of the machine. In the design of the cassava harvester, just the first and second class lever principles were applied. The first class principle of levers having the fulcrum in between the load and the effort was applied in the design and fabrication of the uprooting mechanism, the scraper and secateurs. While the second class lever principle was adopted in driving the machine, with the load in between the effort and the fulcrum. The major components of the harvester are; the machine frame, the wheels, pruning shears (secateurs), lever controls, griping jaw, soil loosening component (scraper) and the harvester cab (Figure 2).

2.1.1 Machine Frame

The machine frame is a skeletal structure on which all other components are assembled. The frame with dimensions of 120 cm length and 80 cm width was designed to accommodate the loads, vibrations and stresses from the various machine elements without failure, and also to allow for easy uprooting of tubers with root spreads of over 60 cm. Selection of material for the frame was on the basis of its strength, rigidity, cost and availability.

2.1.2 The Wheels

The machine was designed to be driven on two-wheels, situated at the front adopting a second class lever principle, transmitting power obtained from human push effort. A wheel diameter of 400 m was used in order to give significant ground clearance between the ridge top and the machine frame. Rigid stands with circular base at the rear were incorporated to keep the machine balanced during idle time and during harvesting.

2.1.3 Pruning Shears (Secateurs)

They consist of two blades, pivotally connected at a point on the machine frame for cutting cassava stem before harvesting. Interacting edges of both blades were sharped to ease cutting, with one shearing blade firmly fixed to the frame. This mechanism was employed to convert and transmit the force produced from the vertical motion of the lever arm to horizontal motion/force to the cutting blade. Maximum allowable opening position of 60° between blades and 10 cm apart was given to accommodate stems larger than 50 mm in diameter.

2.1.4 Griping jaw

The griping jaw with a serrated groove/single or jagged edge, was designed to accommodate a wide variety of stem girts between 20 – 70 mm, with little or no slip. This component is tasked with the responsibility of uprooting the tubers off the ground by gripping the stem at its base, close to ground surface, displacing the tubers from the soil at an increasing angle from applied force transmitted from the uprooting lever.

2.1.5 Soil loosening Component (Scraper)

The soil loosening component was built in form of a digger, with twin prongs of length 15 cm, firmly fastened on a carbon steel metal bar frame of length 50 cm, made from high carbon steel sheets, for ease of penetrating the soil without deformation. They are used to loosen hard compact soils, to a depth of about 10 cm below the soil surface, to ease uprooting and to minimize root breakage in hard soils during uprooting.

2.1.6 Harvester Cab

This component is designed to provide shelter for the operator from harsh weather conditions, like intense sunlight and rain. The cabin frame was made from mild steel angle irons and its cover/roof from tarpaulin.

2.2 Mode of Operation

The machine was taken to the field and tested on completion of fabrication. Testing of the machine was achieved for each mechanism systematically from cutting, to soil loosening and then harvesting. This was done by conveying the machine to the field, randomly selected matured cassava stands with varying stem diameters, positioned each stalk to be cut in between the cutting blades, then clutch down the cutting lever intermittently until the stem was cut. Next, the soil loosening diggers were engaged to break up the soil to a required depth so as to ease uprooting, where uprooting seemed more difficult. Thereafter, the uprooting mechanism was engaged by positioning the griping jaw at the base of the already coppiced stem, so as to grip the stem properly at the node closest to ground to prevent slip, after which a downward force was applied to the uprooting lever with a good mechanical advantage to uproot the cassava tuber from the ground.

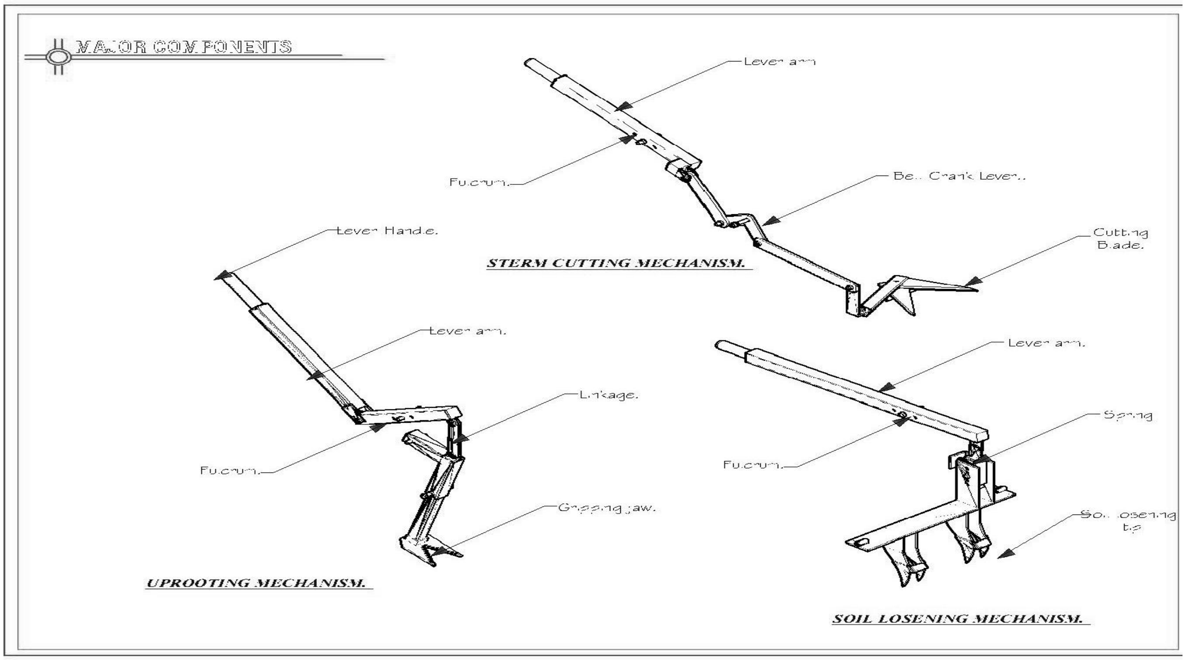

Figure 1: Mechanisms of the Push-Type Cassava Harvester

2.3 Preliminary Investigations

The following Preliminary investigation was conducted on relevant physical properties of the soil, cassava stem and tuber, essential in the design of the component parts of the harvester (Tables 1 and 2):

Moisture Content: Moisture content was determined for both the soil and the cassava stem. The soils moisture content was investigated in order to design an experiment to evaluate the machines performance for soil loosening and tuber uprooting, on varying moisture levels and recommend the soils moisture content in which the machine will perform optimally during harvesting. The soils moisture content was determined and classified by randomly collecting nine (9) different soil samples from the cassava field (Table 1). The classification was based on three treatments; Class A – Ten litres of water applied to the soil, Class B – Application of five litres of water and Class C – Control system (No water added). In order to minimise the possibility of errors, three replicates of soil sample were randomly collected for all three treatments at depths of 0 – 10, 10 – 20 and 20 – 30 cm (Smith et al., 1994). Collected soil samples were oven dried at a temperature of 1500 for 8 hours, after which were re-weighed and recorded. The soil moisture content was determined for all three treatments using equation 1 (Smith et al., 1994).

Moisture content in the stem was determined as a variable to investigate the effects of varying moisture levels in the stem to its cutting efficiency. Moisture content in the stem was determined by randomly collecting stem samples of length 15 cm from fifty (50) cassava stands from the demonstration farm. Each stalk sample was numbered and weighed on a Ohaus precision digital lab scale before oven dried at a temperature of 150o for 18 hrs. Dry stalk samples were then carefully collected, re-weighed and recorded and the moisture determined. Equation 2 was used to determine the moisture content in the stem. On successful determination of the moisture content in the stems, samples were then classified into three moisture content categories of 40 – 55% (stalks affected by fire from indiscriminate bush burning), 55 – 70% and 70 – 85%.

$$MC_{(d.b)}\ \% = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \quad (1)$$

$$MC_{(d.b)}\ \% = \frac{W_w - W_d}{W_w} \times 100 \quad (2)$$

Where,

MC(d.b) % = Percentage Moisture content in dry basis

W1 = weight of sampling bag

W2 = weight of sampling bag and soil

W3 = weight of sampling bag and oven dried soil

W_w= weight of wet stalk

W_d= weight of oven dried stalk

Stem Girth/Diameter: This was determined from Fifty (50) randomly selected stem samples from the field, by measuring and recording diameters of each sample, using a Vernier calliper. The mean stem diameter was also calculated and recorded (Table 2).

Root Yield per Plant: The root yield is achieved by individually quantifying the mass of each harvested cassava tuber, using a conventional weighing scale

Root Spread (cm)This is the horizontal distance between the ends of the tubers along the horizontal, from one end to the other, determined with the aid of a measuring tape.

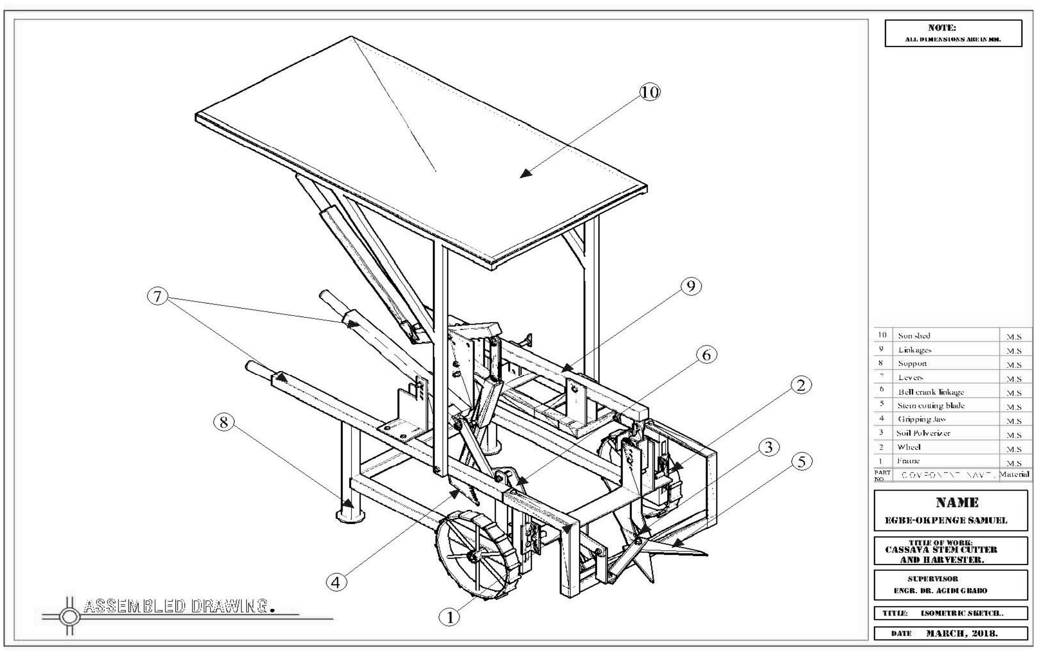

Figure 2: Assembly Drawing of the Developed Push-Type Cassava Harvester

Table 1. Summary of Results for Soil Moisture Content

Class	Replication			Mean
	Sample 1(%)	Sample 2 (%)	Sample 3 (%)	
A	16.9	18.4	19.2	18.17
B	10.5	11.8	10.1	10.80
C	1.5	1.87	2.45	1.94

3. Design Considerations

3.1 General Design Considerations

The following design considerations were adopted in the design and fabrication of the machine;

Material selection for fabrication was from readily available sources, such as to minimize production cost, so as to ease replacement of parts.

Effort and energy requirement to drive the machine and increase mechanical advantage.

Adaptability of the harvester to varying planting systems (on mounds or flat surfaces) and to common recommended varieties, made possible by inclusion of adjustable mechanisms on both the harvester mechanism, the soil loosening mechanism and the cutting mechanism.

The machine was designed to achieve an appreciable reduction in overall purchasing/rental cost (affordable to local farmers) of similar imported devices and decrease in root losses.

Dimensions of the machine frame were chosen, such that can conveniently allow for inter-row movement within the farm and to ergonomically fit at least 90% of its intended users.

Temporal fasteners (bolts and nuts) were used in assembling the machine. This is to ease maintenance, replacement of parts, export purposes and also, to facilitate safe conveyance of the machine from one location to another.

The harvester and soil loosening component levers were built to operate on a first class lever principle (with the fulcrum between the load and the force), while the machine frame was made to run on a Second class principle on two front wheels (with the load situated between the force and the fulcrum). This is to ease movement, turning and manoeuvring the machine on the farm.

3.2 Anthropometric and Ergonomic Considerations

Anthropometry is the science which deals with the size and shape of people within a population (Fernandez and Marley, 1998). The application of anthropometry, in this design is to incorporate the relevant human dimensions, with an aim to accommodate at least 90% of potential users, taking into account both static (height) and dynamic factors (body movements, reach distances and movement patterns. Ergonomics was considered in the design of the structural composition of the machine (ease of reach and operation of control mechanisms), taking into consideration proposed operators physiological and biomechanical capabilities in order to optimize the efficiency and productivity of the harvester, in assuring the safety, health, and wellbeing of the operators (Kaankuka et al., 2016).

3.3 Functional Design Considerations

Soil factors: Soil moisture content (db): This was considered in the design because, higher soil moistures, requires less force to overcome in uprooting and vice-versa. At harvest, soil moisture was found to range between 1.5 – 20% on Sandy-loam and clay-loam which are the most recommended soils for cassava cultivation (Agbetoye et al., 2000).

Forces of cohesion existing in the soil affects the ease of uprooting and determines the use of the soil loosening component to break the forces. These forces ranged between 9.6 – 15.5 N/mm2 (Smith et al., 1994).

Angle of shearing resistance determining the lift angle of the tubers. Implying that uprooting is best achieved overcoming the soil forces at angles ranging from 45o above (Smith et al., 1994).
Crop factors: Root tuber yield per plant which is relevant in the choice and selection of durable materials for fabrication and further guides in dimensions of the machine. Root tuber yield was found between 5.84 – 14.7 kg (Amponsah et al., 2017; Udensi et al., 2011). And also measured with a weighing scale and was found to range from 3 – 12.78 kg.
Root depth: applicable in the design for the cutting depth of the soil-loosening component and the force requirement to completely uproot a tuber. This was with respect to planting orientation, nature of soil and variety (Udensi et al., 2011).
Stem girt was considered in the design of cutting mechanism, thickness of blade, cutting angle, shearing force required and maximum opening distance between blades. It also aided in the determination of the groove angle and length of the griping jaw.
Root spread/diameter per stand: regarded as the distance between the tips of the farthest tubers from the stem. A determinant factor in the choice of the machine frame width, to avoid obstructions in uprooting the tubers completely above the ground surface.
Machine factors: Available power: designed to be derived from human push force. Energy requirement to drive the harvester was determined from the principle of moments. Where the entire weight of the machine is 45 kg, the energy required to drive was found as 126 N, at a mechanical advantage of 3.5
Uprooting Force Requirement: this aided the design for the length of lever arms (mechanical advantage) required to overcome the maximum required uprooting force under varied soil types and conditions, depths and Planting Orientations as asserted by Agbetoye et al., (2014) and Amponsah et al., (2017).
Lifting Angle: A lifting angle of 450 was adopted as opined by Agbetoye et al., (2000) and Ogunjirin et al., (2016) that, uprooting at increasing angles from the horizontal, reduces the likelihood of tuber breakage in the soil. This determined the angle of inclination of the griping jaw arm from the fulcrum.

Table 2: Results for Preliminary Investigation of Cassava Physical Properties

Properties	Sample Size	Minimum	Maximum	Mean
Stem Diameter (mm)	50	2.08	4.31	2.82
Moisture Content (%)	50	45.84	81.02	68.97
Tuber Depth (cm)	50	10.82	29.48	16.59
Yield per Plant (kg)	50	2.19	8.93	4.86
Root Spread (cm)	50	21.38	69.55	44.83

4. Conclusion

A simple semi-mechanised hand push-type cassava harvester was designed and fabricated to cut cassava stems, loosen the soil were uprooting seems difficult, so as to minimize tuber damage during uprooting tubers. The machine basically works on a principle of levers, to operate and manoeuvre all mechanisms. Relevant properties of the soil (moisture content), crop (stem girth, tuber spread/diameter and yield per plant) and machine factors (available power to operate the machine, uprooting force and lifting angle) were taken into consideration with anthropometry, aiding the design and selection of materials for fabrication of the machine to perform efficiently.

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