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Research Article

Design of a Cassava Uprooting Device

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Abstract: This study analyses the design of a simple, efficient, cheap and affordable cassava uprooting device for local cassava growing farmers. Processes involved in uprooting cassava were found out from local farmers, studied and mechanized using bevel gears, cams and followers, chain and sprockets. The principle of moments was used as a basis for the design. The effort applied by the foot of the operator is significantly magnified to overcome the load (cassava in the ground) at the extreme end of the device .The free body diagram of the frame helped to determine the average force needed to press the pedal by the foot. From the analysis, a little effort of 334.49 N can overcome about 2000 N of force and this gives a mechanical advantage of about 6. The bending moment diagram and the shear force diagrams helped to determine the part of the device which is subjected to greater force and where shear and bending can easily take place. Mild steel is used as the material for the device because it is cheap and easily available. Advantages of this design include faster uprooting with high productivity, less energy expended, reduction in the risk of health hazards of developing blisters in the palms, callus palms, arched spinal cord and waste pains over time.

Keywords: Bending moment, bevel gears, cassava, effort, mechanical advantage, shear force

INTRODUCTION

Cassava (*Manihot esculenta*), also called yuca or manioc, a woody shrub of the Euphorbiaceae (spurge family) native to South America, is extensively cultivated as an annual crop in tropical and subtropical regions for its edible starchy tuberous root, a major source of carbohydrates. Nigeria is the world's largest producer of cassava. Cassava is the third-largest source of carbohydrates for meals in the world.

Phillips (1983) it is classified as sweet or bitter, depending on the level of toxic cyanogenic glucosides; improper preparation of bitter cassava causes a disease called konzo. Claude and Denis (1990). Nevertheless, farmers often prefer the bitter varieties because they deter pests, animals and thieves. Chiwona-Karltun *et al*. (2002) Cassava is sometimes spelled *cassaba* or *cassada*. Darwin and Charles (1839) In English-language publications, the plant may be occasionally called by local names, such as *mandioca*, *aipim*, or *macaxeira* (Brazil), *yuca* (El Salvador, Bolivia, Costa Rica, Colombia, Cuba, Ecuador, the Dominican Republic, Haiti, Panama, Peru, Puerto Rico, Venezuela), *mandi´o* (Paraguay), *akpu*, *ege*, *ugburu*, *nto-roro* or *ukuduk* (Nigeria), *bankye* (Ghana), *bananku* (Mali and other parts of West Africa), *mogo* or *mihogo* (Swahili-speaking Africa), *pondu* in (Lingala-speaking Africa), *kappa* (India), *maniokka* (Sri Lanka), *singkong* (Indonesia), *ubi kayu* (Malaysia), *kamoteng kahoy* or *balanghoy* (Philippines), *mushu* (China), *man sampalang* (Thailand), *karapendalam* (Telegu), *củ sắn* or *khoai mì* (Vietnam) and *manioke*, *tapioka* or *manioka* (Polynesia) (Gade, 2002). Cassava (Manihot esculenta) belongs to the group of Carbohydrates, a major source of calories and a staple food for millions of people over the world and Ghana in particular as it is processed into flour, starch, snacks baked foods, fufu and banku which are local delicacies. Cassava is also processed into gari, eba, lafun and akpu which are local delicacies in Nigeria, Ghana and other West African countries. Cassava is one of the important root crops grown in Africa and many parts of the world. In the past, maize was Africa's most important food crop, however, maize production in Africa is risky due to unpredictable rainfall and it is not financially feasible to depend on irrigation. For this reason and perceived others, Cassava (*Manihot esculenta*, *Crantz*) became the most important food crop in Africa. Cassava as a food crop could plays a vital role in the food security of the world because of its capacity to yield under marginal soil conditions and its tolerance to drought. Cassava originated in South America, where its tubers have been used throughout the ages as a basic food; from there it spread to regions of the world. Cassava leaves have a high protein content (20-25% of dry leaves), while cassava roots have 25-30% starch but are

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low in protein (1-3%). High yielding cassava varieties usually have high HCN contents, limiting the use of roots and leaves for animal feed. Drying or ensiling of cassava leaves and roots will markedly reduce their HCN content. Many studies have shown the effect of different processing methods on the chemical contents and nutritional values of cassava leaves and roots (Pham, 2001); the use of cassava root and leaves for feeding pigs (Le Duc and Nguyen, 2002); young stems and leaves for feeding cows (Doan, 2001); the use of cassava dried leaf powder as animal feed for chickens and pigs (Duong *et al*., 1998); feeding cassava leaves to silkworms (Khanh *et al*., 2004); Cassava seed is up to 12 mm long. Cassava is generally planted as a cutting because seed germination is less than 50%.

Scientific classification of cassava:

Kingdom	**:** Plantae
(Unranked)	**:** Angiosperms
(Unranked)	**:** Eudicots
(Unranked)	**:** Rosids
Order	**:** Malpighiales
Family	**:** Euphorbiaceae
Subfamily	**:** Crotonoideae
Tribe	**:** Manihoteae
Genus	**:** Manihot
Species	**:** M. esculenta
Binomial name	**:** Manihot esculenta

Right from creation, man has been on the lookout for a better and easy way of carrying out difficult activities. This desire has led to many modern technologies that are seen around us today. Agriculture for instance, has seen various technologies especially in the area of cereal and grain crop harvesting. Currently, combined harvesters are in vogue for mechanized farming all over the world.

Technological development for cassava harvesting: Engineers at home and abroad have made many attempts towards the development of cassava uprooting devices. These include manual devices such as cutlasses and hoes and semi-mechanized devices such as Prairie mouldboard ploughs with different structural configurations such as:

- Inverting the whole ridge and roots with a mouldboard plough body
- Pulling a mouldboard share (with the board removed) below the soil level
- Using a mouldboard plough to split the ridge along the crest
- Pulling specially designed blades to cut below the tubers
- Using animal and tractor-drawn single disc ploughs and mouldboard ploughs to harvest cassava

Further work on the machine led to the development of a single-row harvester with two gangs of reciprocating Power Take off (P.T.O.) driven diggers, which digs on two opposite sides of the ridge from the furrow bottom in order to uproot the Cassava root cluster. The P.T.O. machine is very expensive and difficult to use Bernado *et al*. (2010).

The combine harvester, or simply combine, is a machine that harvests grain crops. It combines into a single operation process that previously required three separate operations (reaping, threshing and winnowing). Among the crops harvested with a combine are wheat, oats, rye, barley, corn (maize), soybeans and flax.

Notwithstanding the technological improvement so far, little has been done in the area of root crop harvesting. Traditionally, root crops are harvested using cutlasses, hoes, diggers, digger-pickers and by hand. It is now the most widely cultivated crop in Africa and is grown by subsistence farmers, who depend on seasonal rainfall. Cassava as a food crop helps in sustaining food security but efficient mechanical uprooting, storage and processing technologies need experts' attention Cassava is typically grown by small-scale farmers using traditional methods and can do well even on land that is not suitable for other crops. Cassava is propagated by cutting a mature stem into sections of approximately 15 cm and planting these prior to the wet season. The roots are harvestable after 6 to 12 months and can be harvested any time in the following 2 years. The most difficult operation in cassava production is cassava harvesting. The reasons being that Cassava is harvested by hand; in addition, there is the difficulty in the design of the digging blades because of the indeterminate shape and geometry of the tubers in the soil.

Manual harvesting of cassava involves the following steps:

- Plucking off the upper parts of the stems with the leaves before harvest
- Cutting of the stem about 0.3 m above the soil surface and collecting the stems as planting material
- The loosening of the soil at the cassava root zone
- Lifting the cassava root system out of the soil and separating the root system from adhering soil before collecting tubers, loading them on to transport vehicles and transporting them as required

Existing manual harvesting techniques lead to drudgery, wastage and also consume a lot of time and farm labor, which is scarce and costly. Cassava harvesting is still done manually in Ghana, Nigeria, Thailand and other parts of the world. Manual harvesting of cassava does not fit well with the modern processing factories. This is as a result of the low productivity associated with manual uprooting of cassava. The cost of manual harvesting is high; it takes about 25 to 35 men days to harvest a hectare of cassava.

One major challenge associated with this important food crop the world over, is difficulty in uprooting it. Currently, this is done manually by hands and consequently farmers develop blisters in their palms, callus palms, arched spinal cord and waste pains over time. Manual uprooting is slow with low output and productivity but an uprooting device will be faster with high productivity. It is against this background that an easy way of uprooting cassava locally is being considered in this paper. The objective of this paper is therefore to design a simple, efficient, cheap and affordable device to facilitate easy uprooting of cassava for local farmers.

MATERIALS AND METHODS

This project has been carried out using analytical and design concepts. The Cassava growing farmers were visited to find out and study the processes involved in uprooting Cassava. This study was conducted at Tarkwa municipality, Western region, Ghana in May 2011. The following steps were discovered:

- Plucking off the upper parts of the stems with the leaves before harvest
- Cutting of the stem about 0.3 m above the soil surface and collecting the stems as planting material
- The loosening of the soil at the cassava root zone
- Lifting the Cassava root system out of the soil and separating the root system from adhering soil before collecting tubers, loading them on to transport vehicles and transporting them as required

It was then discovered that the processes involved in loosening the soil at the Cassava root zone and lifting the Cassava root system out of the soil could be mechanized by using bevel gears and cam mechanism with spring loaded followers which is the basis of this design.

Designed cassava uprooting device:

Principles of operation: If a body is in equilibrium under the action of a number of forces, the algebraic sum of the moments of the forces about any point is equal to zero. In other words if an object is balanced, then the sum of the clockwise moments about a pivot is equal to the sum of the anticlockwise moments about the same pivot:

Moment of Force = Force × Perpendicular Distance

The cassava harvester was designed based on the principle of moment of a force to maximize mechanical advantage such that relatively small amount of effort applied at one end of a fulcrum is able to overcome a greater load on the other end. Here the foot pedal represents one end of the fulcrum where the load will be supported and the cassava stem represents the other end of the fulcrum where greater load will be overcome. The effort applied by the operator is significantly magnified to overcome the load (cassava in the ground) at the extreme end of the device. The device ensures productivity by uprooting two cassava stumps at a time. A simple gripping mechanism made of rugged cotton twill which relies on friction for its application is also adopted for easy and effective operation. Hand-operated chain is drive incorporated to help generate rotary motion of the cams. This motion is what is converted to vertical and horizontal reciprocating motion bringing about shaking and fragmentation of the ground during harvesting. Ball and socket joint has been employed at the pivot support to provide a greater degree of freedom at the pivot support. This type of joint was chosen due to its simplicity and wide degree of freedom of movement it offers. The belt tensioner is for the adjustment of the belt tension.

Chain drive unit: Chains are used mainly to transmit power from one shaft to another by means of teethed wheels called sprocket. The chains are made up of number of rigid links which are hinged together by pin joints in order to provide the necessary flexibility for wrapping around the driving and driven wheels. Chain drive was selected for the design due to the following reasons:

- It is constrained to move together without slipping to ensure perfect velocity ratio
- It may be used for both short and long distances
- It gives less load on the shaft due to its relatively light weight
- It gives a high transmission efficiency up to 98% (Khurmi, 2010)

Main frame: This serves as the main beam of the lever mechanism which was employed in the design. Carbon steel was selected for the design on the basis of strength and rigidity. In order to maximize mechanical advantage of the device the distance from the foot pedal to the fulcrum (effort distance) was chosen to be 2 m. This way the average load (2 × 1000 N) that is required to uproot two cassava stumps at a time was overcome (Campbell, 1990). The load arm for each cassava load is designed to be 35 cm.

Cam unit: Harvesting of cassava requires an amount of shaking to fragment the soil, to achieve this; three disc cams with spring loaded followers were introduced. A cam is a machine component that either rotates or moves back and forth (reciprocates) to create a prescribed motion in a contacting element known as a follower. The shape of the contacting surface of the cam is determined by the prescribed motion and the profile of the follower. Cam-follower mechanisms are particularly useful when a simple motion of one part of a machine is to be converted to a more complicated prescribed motion of another part, one that must be accurately timed with respect to the simple motion and may include periods of rest (dwells). In all cam systems, it is important that the follower is always in contact and following the motion of the cam. This was achieved by the use of spring force to constrain the follower to the cam as it rotates. Plate cam was chosen for the design due to its simplicity in construction and operation. The plate cam is mounted perpendicular to the axis of rotation. The cams used were made from a chilled iron. Such cams have high resistance against wear and they are relatively cheaper.

Gear unit: In order to transmit the rotary motion of the main shaft to the horizontal cam and spring unit bevel gears are employed. Bevel gears are useful when the direction of a shaft's rotation needs to be changed. They are usually mounted on shafts that are 90º apart, but can be designed to work at other angles as well. In this design the angle between shafts is 90º. These spiral teeth on the bevel gears engage just like helical teeth: the contact starts at one end of the gear and progressively spreads across the whole tooth. In order for gears to achieve their intended performance, life and reliability, the selection of a suitable gear material is very important. High load capacity requires a tough, hard material that is difficult to machine. Cast iron was selected because it is suitable for the working condition of the device. It is also easily obtainable and less expensive.

Gear selection: The purpose of the gear in this design is to change the rotary motion of the shaft into reciprocating motion of the springs.

Gear type	: Mitre Bevel Gear
Material	: High Strength Steel
Yield strength	: 1000 MPa
Velocity ratio required	: 1:1
Required diameter	: 90 mm each

Select a module of 2.5 for strength and economy.

Number of teeth for each gear $= \frac{D}{m} = \frac{90}{2.5} = 36$

Bearings: A bearing is a machine element which supports another moving machine element known as journal. It permits a relative motion between the contact surfaces of the members, while carrying the load (Khurmi and Gupta, 2005).

A cast iron bearing is commonly used with a hardened steel shaft because the coefficient of friction of the shaft is relatively lower than that of the bearing. The cast iron glazes over and therefore wear becomes negligible. In this design three plain bearings made of cast iron were used; two for the horizontal shaft and one for the vertical shaft. Plain bearings, in general, are the least expensive type of bearing. They are also compact, lightweight and have a high load-carrying capacity. One ball bearing made of cast iron has been used for the sprocket. Ball bearings are generally good for moderate to high speed and load conditions.

Shaft: In all, two shafts were used in this design, the horizontal and vertical shafts all of which are selected from steel material. The selection of steel was based on its mechanical properties such as modulus of elasticity, hardness and rigidity. Steel is the common name for a large family of iron alloys which are easily malleable after the molten stage. Steels are commonly made from iron ore, coal and limestone. Steels can either be cast directly to shape, or into ingots which are reheated and hot worked into a wrought shape by forging, extrusion, rolling, or other processes.

Design calculations: The average force required to uproot one cassava plant is 1000 N and the average human force is 600 N (Campbell, 1990). Hence, it requires 2000 N force to uproot two plants of cassava:

$$\sum MR = 0 \tag{1}$$

$$= 2x + 21\times1.45 + 21\times1.25 - 171.2\times0.15 - 2000\times0.35 = 668.98$$

$$X = 334.49 \text{ N}$$

Equating upward forces to downward forces:

R = 334.49+21+21+171.2+2000
R = 2547.7 N

From this analysis, a little effort of 334.49 N can overcome about 2000 N of force

Mechanical advantage of device = $\frac{Load}{Effort}$ = 5.98:1 or 598%

Design of main frame:
Modes of failure:

- Bending
- Shear
- Torsion (Minimal)

Material:
High Strength Steel, Yield Strength: 1000 MPa
Allowable Stress: 833.3 MPa
Safety Factor: 1.2 with known loading conditions

From singularity functions,

$\sum M(x)$ = 334.5(x) + 21(x-0.55) + 21(x-0.75) - 2547.7(x-2) + 171.2(x-2.15) +2000(x-2.35)

V(x) = 334.5 + 21(x-0.55) + 21(x-0.75) -2547.7(x-2) + 171.2(x- 2.15) + 2000(x-2.35)

At
X = 0, M = 0, V = 334.5 N
X = 0.55 m, M = 183.975 N, V = 355.5 N
X = 0.75 m, M = 255 Nm, V = 376.5 N
X = 2 m, M = 725.7 Nm, V = 2171.2N
X = 2.15 m, M = 1164.33 Nm, V = 2000 N
x= 2.35 m, M = 0, V = 0

The design equation is given as:

$$\tau_{max} \leq \tau_a \tag{2}$$

From the maximum normal shear stress theory:

$$\tau_{max} \leq \frac{1}{2}\sqrt{\beta^2 + 4\tau^2} \tag{3}$$

But $\beta = \frac{32M}{\pi d^3(1-R)}$

$$\tau = \frac{128(1-R)V}{81\pi d^2(1-R^4)(1-R)}$$

where,
M = Max bending moment
d = Outer diameter of hollow section
R = Ratio of outer to inner diameter
β = Bending stress
V = Max shear force

$$\tau_{max} = \frac{1}{2}\sqrt{\left[\left[\frac{32M}{\pi d^3(1-R)}\right]^2 + \left[\frac{128(1-R)V}{81\pi d^2(1-R^4)(1-R)}\right]^2\right]} \leq \tau_a \tag{4}$$

Solving the above equation and taking R = $\frac{d1}{d}$ = 0.6
D = 54 mm, hence,
d1 = 0.6×54 = 32.4 mm (inner diameter).

This diameter will be able to withstand any failure combined stresses due to shear and bending.

Shaft design:
Material: High strength Steel, yield strength = 1000 MPa with a safety factor of 2 the allowable

Stress is 500 MPa. Let R, the ratio of outer (d) to inner diameter (d1) be 0.6

The design equation is given by, $\tau_{max} \leq \tau_a$

$$\tau d = \frac{1}{2}\sqrt{\beta^2 + 4\tau^2} \tag{5}$$

$$\beta = \frac{32M}{\pi d^2(1-R^4)}$$

$$\tau = \frac{128(1-R^3)V}{81d^3(1-R^4)(1-R)}$$

$$\sqrt{\left[\left[\frac{32M}{\pi d^2(1-R^4)}\right]^2 + \left[\frac{128(1-R^3)V}{81d^3(1-R^4)(1-R)}\right]^2\right]} \leq 2x\tau_a \tag{6}$$

$$\sqrt{\left[\left[\frac{3225.9}{\pi d^2(1-0.6^4)}\right]^2 + \left[\frac{128(1-0.6^3)X131.8}{81d^3(1-0.6^4)(1-0.6)}\right]^2\right]} \leq 2x500 \text{ MPa}$$

here, variables denote their usual meaning. Solving (6), d = 18 mm, d1 = 0.6×18 = 11 mm

Cam profile: A disc cam is considered with a spring-loaded flat faced follower. The cam describes a simple harmonic motion.

Table 1: ANSI standard chain dimensions

Number	Layers	Weight per feet	Pitch	Working load	Sprocket thickness
40	Single	6.13 N	12.7	810 lb	0.284

Sprocket and chain parameters: Greater speed will not be required so a velocity ratio of 1:2 is considered in this design. The small sprocket has a diameter of 100 mm and the bigger sprocket has a diameter of (2×100 = 200 mm). A module of 2.5 is arbitrarily chosen for strength and economic reasons. Hence,

$$M = \frac{D}{N} \tag{7}$$

$$N = \frac{D}{m}$$

$$N1 = \frac{100}{2.5} = 40 \text{ teeth}$$

$$N2 = \frac{200}{2.5} = 80 \text{ teeth}$$

Centre distance of sprocket is 150 cm. From ANSI standard chain dimensions (Table 1), a number 40 chain with the following parameters is chosen.

An idler is introduced to regulate belt tension since the centre to centre distance of sprockets is greater than 60×pitch.

Thus,

$$150 \text{ cm} \geq 60 \times 12.7$$

Length of chain:

$$L = 2C + \frac{P(N1+N2)}{2} + \frac{P^{2(N1+N1)}}{4\pi^2 C} \tag{8}$$

where,

C = centre distance of sprocket

P = pitch

$$L = 2 \times 1500 + \frac{12.7(80+40)}{2} + \frac{12.7^{2(80+40)}}{4\pi^2 X\ 1500}$$

$$L = 3762.1 \text{ mm} = 3.7621 \text{ m}$$

Weight of chain = 6.13×3.7621

N = 23.06

RESULTS AND DISCUSSION

As could be seen, Fig. 1-3 shows the cassava seeds, plants and plantation. The uprooted cassava roots are shown in Fig. 4, while the various products from cassava are shown in Fig. 5 to 8. The existing harvesting methods are shown in Fig. 9 to 10. The loosening of the soil at the cassava root zone by

Fig. 1: Cassava seeds

Fig. 2: Cassava plants

Fig. 3: Cassava plantation

Fig. 4: Cassava uprooted roots

Fig. 5: Heavy cassava cake

Fig. 6: Peeled cassava roots ready for cooking

Fig. 7: Cassava bread

Fig. 8: Preserved cassava leaves

Fig. 9: Combine harvester

Fig. 10: Combine unloading harvester

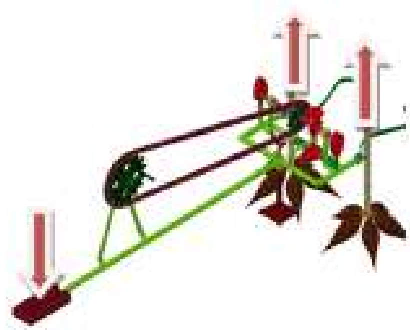

Fig. 11: Principle of operation

Fig. 12: Free body diagram of the main frame

shaking the cassava stem and the lifting of the cassava root system out of the soil have been achieved in the design by the spring loaded cams which are driven by

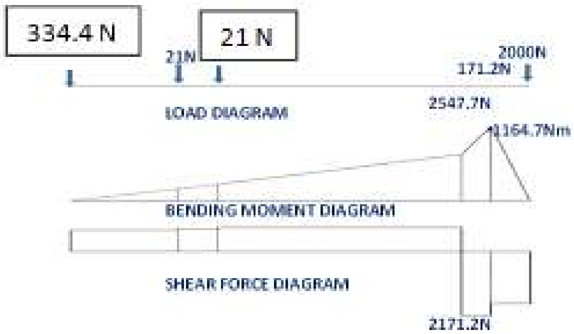

Fig. 13: Bending moment and shear force diagrams

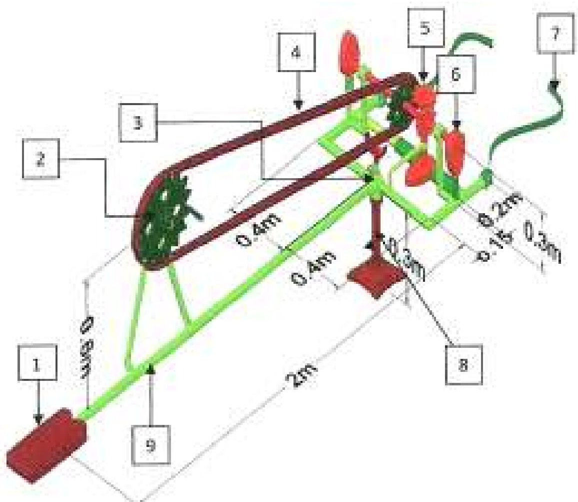

Fig. 14: 3-Dimensional view of the cassava uprooting device

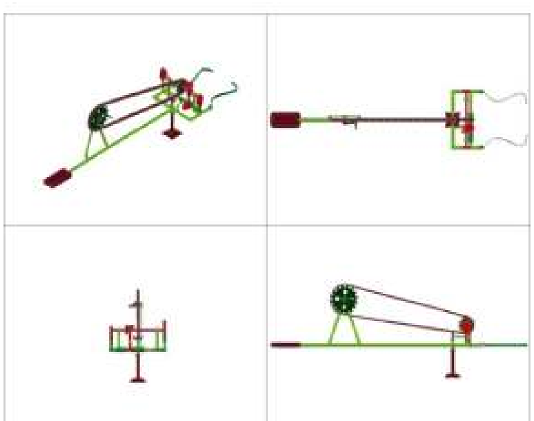

Fig. 15: Orthographic projection of the cassava uprooting device

the two bevel gears through the chain and sprocket. The effort applied by the foot of the operator is significantly magnified to overcome the load (cassava in the ground)

Fig.16: Chain drive

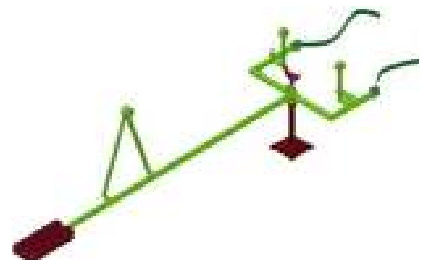

Fig. 17: Main frame

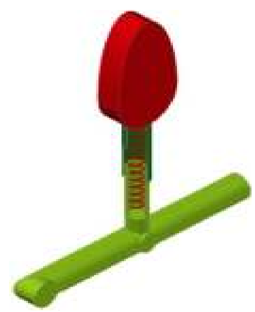

Fig. 18: Cam unit and spring follower

Fig. 19: Bevel gears

at the extreme end of the device as shown in Fig. 11. The free body diagram of the frame in Fig. 12 helped to determine the average force needed to press the pedal by the foot. From the analysis in Fig. 12, a little effort of 334.49N can overcome about 2000N of force and this gives a mechanical advantage of about 6. The bending moment diagram and the shear force diagrams in Fig. 13 helped to determine the part of the device which is subjected to greater force and where shear and bending can easily take place.

Fig. 20: Horizontal and vertical shafts

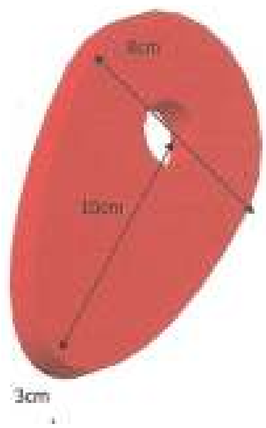

Fig. 21: Disc cam

Table 2: Parts list

Parts No.	Description	Material	Qty.
1	Foot pedal	Mild steel	1
2	Sprocket	Mild steel	1
3	Tensioner	Mild steel	1
4	Chain	Steel	1
5	Bevel gear unit	Constructional steel	2
6	Disc cam	Hard wood	3
7	Gripping unit	Fibre rope	2
8	Support	Mild steel	1
9	Main frame	Mild steel	1

It is discovered that the design is simple from the views shown in Fig. 14 and 15. Also, cheap as shown from the parts components shown in Fig. 16 to 20 and Fig. 21. The designed device is efficient and affordable as could be seen from the readily available materials used as shown in Table 2.

CONCLUSION

The designed Cassava device has confirmed the working principle. It has been designed to make its operation easier and efficient. The study shows that the operational analysis is easy to understand and the cam shaft operation and the bevel gear analysis are simple. The machine requires less human energy and the movement of the mechanisms is relatively smooth. It is therefore, appropriate for high productivity, while the accuracy is reliable. The various parts of the device are easy to manufacture in the workshop but requires good technical skills in engineering drawing and machine design. The device is cheap, affordable and does not contain intricate and expensive parts. It is therefore easy to construct. The benefits of this design include:

- Less energy expended
- Increase in the number of Cassava roots uprooted
- Saving time
- Reduction in the risk of health hazards of developing blisters in the palms, callus palms, arched spinal cord and waste pains over time
- Higher output and productivity
- Enhancement in the easy way of uprooting Cassava

RECOMMENDATIONS

- The device is recommended to the Cassava growing farmers to enhance and enjoy the benefits.
- This designed is limited to lose to moderately loose and moist soil, it is therefore pertinent that further research work be carried out to make the design applicable to other types of soil structures.
- This design is capable of uprooting two stands of cassava planted in rows at a time; further research should be carried out to design a device that will uproot one cassava stand not planted in rows at a time.

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