MATTER: International Journal of Science and Technology
ISSN 2454-5880

ATSYO et al., 2020

Volume 6 Issue 2, pp. 102-118

Date of Publication: 21st Sept, 2020

DOI-https://doi.org/10.20319/mijst.2020.62.102118

This paper can be cited as: ATSYO, S. Y., KORKMAZ, C., OZLUOYMAK, O. B. & GUZEL, E. (2020). A Review of Physical and Mechanical Properties of Cassava Related to Harvesting Machines. MATTER: International Journal of Science and Technology, 6(2), 102-118.

A REVIEW OF PHYSICAL AND MECHANICAL PROPERTIES OF CASSAVA RELATED TO HARVESTING MACHINES

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Abstract

For many years now, harvesting of cassava is difficult because there has not been a well-designed machine to harvest, separate, and convey the crop in a one-time operation. In all the unit operations in cassava production, several machines and types of equipment have been mechanized successfully. However, cassava harvesting and peeling have remained a global *challenge to engineers involved in machine design. In light of this, some pieces of literature on the physico-mechanical properties of cassava were qualitatively reviewed. The study presents harvesting methods for cassava around the globe, considering its merits and limitations for future development. We found out that cutting shear stress and force increased with increasing cassava tuber age because of an increase in density and starch content. Additionally, the ratio of the peel of cassava tuber ranges from 0.106 to 0.215. The frictional properties of cassava are essential to design and develop machines for post-harvest operations of cassava roots. Whereas, the angle of repose for the unpeeled cassava is required for the design of the hopper and that of the peeled is required for the design of the chute. The manual, semi-manual and fully mechanized harvesting methods require the capacity of about 22-51 man h/ha, 16-45 man h/ha, and 1-4 man h/ha respectively. The fully mechanized method is very efficient, and the field is ploughed alongside harvesting which saves time, fuel, and cost of operation. Even though less research is carried out on cassava harvesting mechanization compared to other crops, the current development is a harvesting machine hitched to a tractor with a conveyor unit powered by the PTO system. The knowledge of this review would be a blueprint for engineers in designing cassava mechanical harvesters.*

Keywords

Cassava, Engineering Properties, Harvesting, Mechanical Harvester, Tuber

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1. Introduction

Cassava (Manihot esculenta) was originated from South America and is widely consumed in Africa and Asia (Wickens & Onwueme, 1979). The plant is tropical in nature and its root system is fibrous. However, the cassava roots grow into several tubers beneath the soil surface called secondary thickening. The roots grow radially and the base of the plant develops many tubers as shown in Figure 1. Even though other parts of the plant are useful but economically, the root is an integral part of the crop (Adetan et al., 2003).

It is a food security crop in Africa and is of much interest that the continent produces more cassava than the rest of the world and Nigeria is the largest producer accounting for 59.5 million tonnes of the crop per year (FAOSTAT, 2018). The increment of cassava production is a result of famine, hunger, drought, and the ability of the crop to resist pests and diseases (Hillocks, 2009).

The engineering properties of all crops are vital as part of the initial stages in machine design. Thus for years now, a lot of scientists have had an interest in determining the engineering properties of biological materials (Akcali et al., 2006; Mohsenin, 1986; Simonyan, 2015).

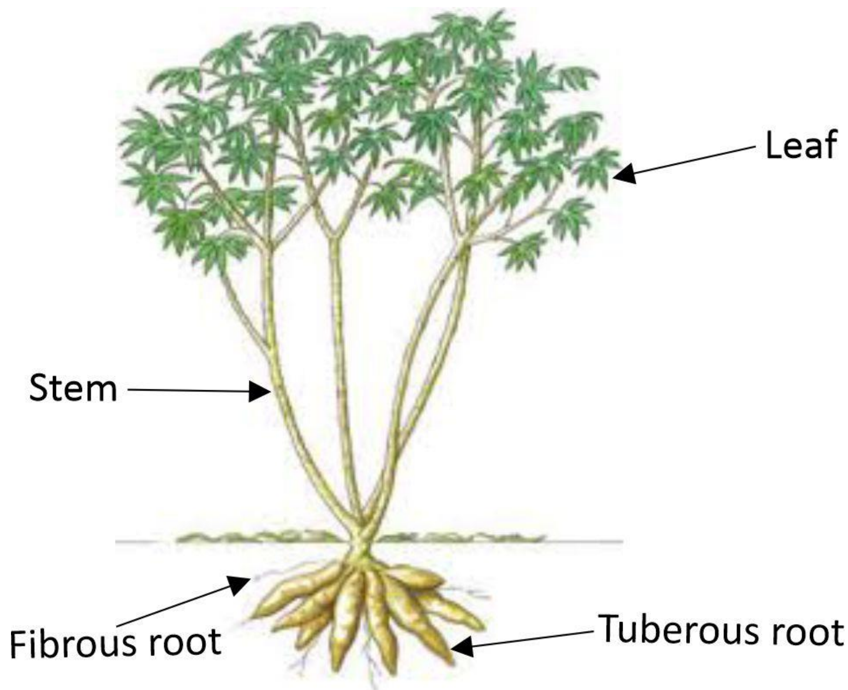

Figure 1: *Cassava Plant*

1.1 Morphology of Cassava Tuber

Figure 2(a) and (b) show the morphology and transverse section of a cassava root tuber respectively. The roots are long depending on the type of variety, rough surface, and are all joint to the stem of the plant in the soil. Generally, the apex of the root tuber is large, followed by the middle portion whiles the bottom is the smallest in diameter. Nevertheless, the central core of the tuber in its transverse section shows the pith. Around the pith is the starchy flesh which comprises of the main part of the tuber. Usually, this portion is either white or cream and enclosed by a thin cambium layer. The peel of the tuber covers the cambium layer and it entails a corky periderm on the outward and cortex on the inward (Adetan et al., 2003; Wickens & Onwueme, 1979).

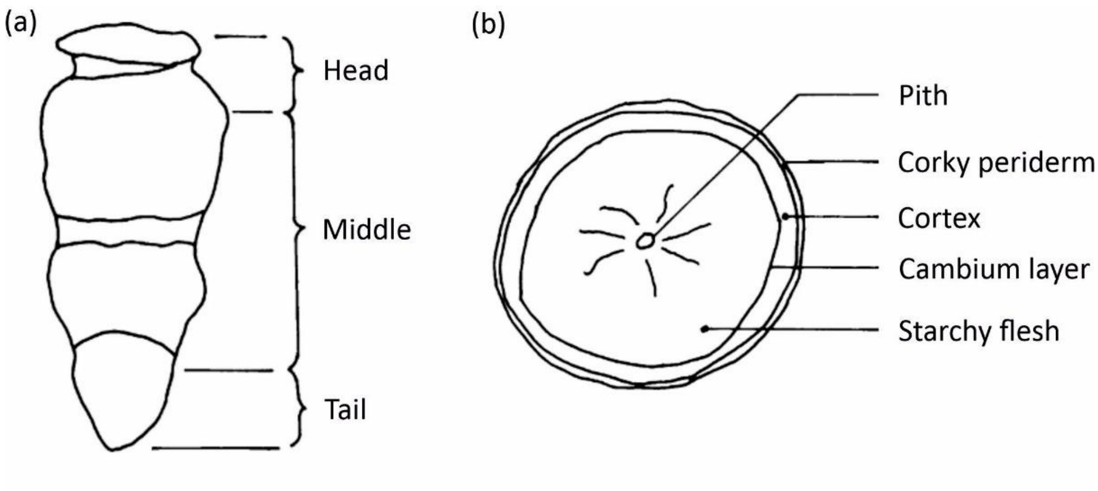

Figure 2: *Morphology of Cassava: (a) Common Morphology (b) Transverse Section (Adetan et al., 2003)*

1.2 Utilization of Cassava

Cassava roots have a high percentage of carbohydrates that is an important source of dietary energy. It is sometimes consumed freshly after cooking. The crop can also be processed into other by-products or used as feed for livestock. Some of the processed products include flour, cassava chips, starch, granulated roasted cassava "Gari", drinks, fermented pastes and among others. The starch is also used for pharmaceuticals, production of ethanol, plywood, and paper. Others grow the crop for its leaves, which comprises 25% of protein. For instance, in Asia high-tech starch is used for preparing feedstock, fructose, alcohol, candies, and other by-products. Because of the numerous usage of the crop, the trend has changed from domestic to industrial production around the globe. (Howeler et al., 2013).

Though in Africa cassava is often consumed domestically, the high consumption rate has changed the demand to be processed to other by-products. For instance, a beverage-based company in Ghana (Kasapreko) has collaborated with Caltech Ventures; a mechanized agricultural farm to produce more cassava for ethanol production. Besides, liquefied Carbon Dioxide (CO_2) and electricity can be generated from the crop.

1.3 Post-Harvest Handling Practices of Cassava

Hillocks, (2009) reported that the perishability of cassava right after harvest and its cyanogenic glucoside draws attention for processing the crop into other by-products. Increasing the potential market for cassava largely depends on how the crop is processed and improved to meet both local and international markets with a flexible cost of production.

Freshly harvested cassava tuber starts deteriorating immediately after harvest and has a shelf-life of approximately three days because of its 70% moisture content (Kolawole et al., 2011). Due to this, the ideal way to prolong the shelf-life and possibly mitigate post-harvest losses of cassava is processing. Besides, indigenous farmers preserve the crop naturally by leaving the plant on the field and harvest when needed. The success of storage methods depends on the condition of the cassava roots. Damaged roots deteriorate more rapidly and have a shorter post-harvest life. Mechanical damage occurs during the harvesting of the roots, when the roots are pulled out of the ground, because of the breaking off the root tip and bruising of the neck of the root where it is attached to the plant. Deterioration starts at such sites of physical damage (Wickens & Onwueme, 1979).

However, harvesting on time and proper post-harvest practices have a great impact on the lives of farmers. Using the right tool or equipment has also proven to reduce losses amicably.

2. Engineering Properties Of Cassava

Mohsenin, (1986) reported that to design every machine the first step is to determine its engineering properties. These properties are beneficial in the design of equipment employed in the field of agricultural processing and farm machinery. The unit operations such as grading, drying, cleaning, storage, milling, handling, and transportation, thermal processing of foods are among the important operations in agricultural processing. In these operations, while handling of grains and other commodities, the properties that play an important role are physical, mechanical, frictional, rheological, aero and hydrodynamic, electrical and optical properties of the bio-materials. Information on these properties is of great importance for engineers, food scientists, and processors towards the efficient development of machines. For the sake of this article, the physico-mechanical properties are discussed.

2.1 Physical Properties

The knowledge of density and the specific gravity of cassava is needed in calculating thermal diffusivity in heat transfer. These help to figure out Reynolds number in pneumatic and hydraulic handling of produce thereby anticipating the structure and composition. Also, the shape, size, volume, area, colour, and appearance of cassava are important in the analysis of the behaviour of the product in the handling of materials (Mohsenin, 1986).

Designing components such as hoppers, chutes, screw conveyors, storage bins, pneumatic conveyors, the coefficient of friction, and angle of repose are determined. The sphericity of regular agricultural produce is between 0.32 and 1.00. Therefore, the lower the sphericity of the produce, the regular the produce. Since the sphericity of the cassava varieties tested were high, ranging from 0.73 to 0.84. It is reported that cassava is irregular in shape. (Simonyan, 2015).

Subsequently, Adetan et al. (2003) showed that 0.106 to 0.215 makes the proportion of peel for the cassava tuber. The rest of the physical properties are shown in Table 1.

2.2 Mechanical Properties

Mechanical properties are defined as those that affect the behaviour of the agricultural material under an applied force. The mechanical properties such as hardness, compressive strength, impact and shear resistance as shown in Table 1 affect a series of agricultural production. Data on these properties are useful for application in designing equipment for handling, milling, storage, transportation and food processing.

When the moisture content is lower, the tuber is harder and the ability to resists cutting and abrasion increases. This simply means that mechanical property depends on moisture content. (Kolawole et al., 2007).

Oupathum et al. (2019) stated that the shearing stress and the specific shearing energy increase as the knife bevel angle increases from 20 to 40 degrees. Lomchangkum et al. (2020) also determined that the maximum cutting shear stress and force increased with increasing tuber age due to the increase in density and starch content.

Table 1: *Physical and Mechanical Properties of Cassava*

Physical Properties	Mechanical Properties
Dimension: length, width, thickness & diameter	Hardness
Shape	Compressive strength
Weight	Compressive stress
Density	Shear strength
Porosity	Tensile strength

Volume	Coefficient of expansion
Surface area	Impact resistance
Angle of repose	Shear resistance
Specific gravity	Compressibility
Drag coefficient	Elasticity
Moisture Content	Cutting Force
Static coefficient of friction	Bending Strength
Sliding coefficient of friction	Deformation

3. Harvesting Of Cassava

In reality, the difficult operation in cassava production is harvesting since it requires a lot of energy or man-power to harvest per plant. This is such that the highly perishable nature of the crop deteriorates as early as 1-3 days after harvest. It is therefore important to harvest cassava at the right time and in the proper manner (Agbetoye et al., 2003). Harvesting of cassava is in three folds, thus manual, semi-manual and mechanized methods.

3.1 Manual Harvesting

The manual method involves the hand where cutlass, hoe, mattock and other indigenous tools are used. This process is very difficult and is labour intensive when harvesting hectares of land. The stem of the cassava plant is cut slightly above the soil surface. Afterwards, the cassava root is uprooted from the soil by exerting force as shown in Figure 3 and 4 respectively. The cut stems reused for the next crop planting. (Mongkol et al., 2007). According to Amponsah et al. (2018) approximately 23-47 man h/ha is required for manual lifting of cassava with hands compared to the use of a hoe which requires between 42-51 man h/ha. On moderately dry soils, manual harvesting tools are preferable while soils with moderately higher moisture content are best for manual uprooting techniques for cassava.

Figure 3: *Manual Harvesting of Cassava with Cutlass, Hoe and Mattock*

Figure 4: *An Indigenous Cassava Lifter (Chalachai et al., 2013)*

3.2 Semi-Manual Harvesting

The semi-manual harvesting method employed the principle of lever and ensures that relatively less effort is needed to uproot the crop. The Council for Scientific and Industrial Research, Crop Research Institute (CSIR-CRI) Ghana, and the National Centre for Agricultural Mechanization (NCAM) Nigeria, designed a simple harvester as shown in Figures 5 and 6 respectively. With the advancement in technology, many of these harvesters are improvised around the world.

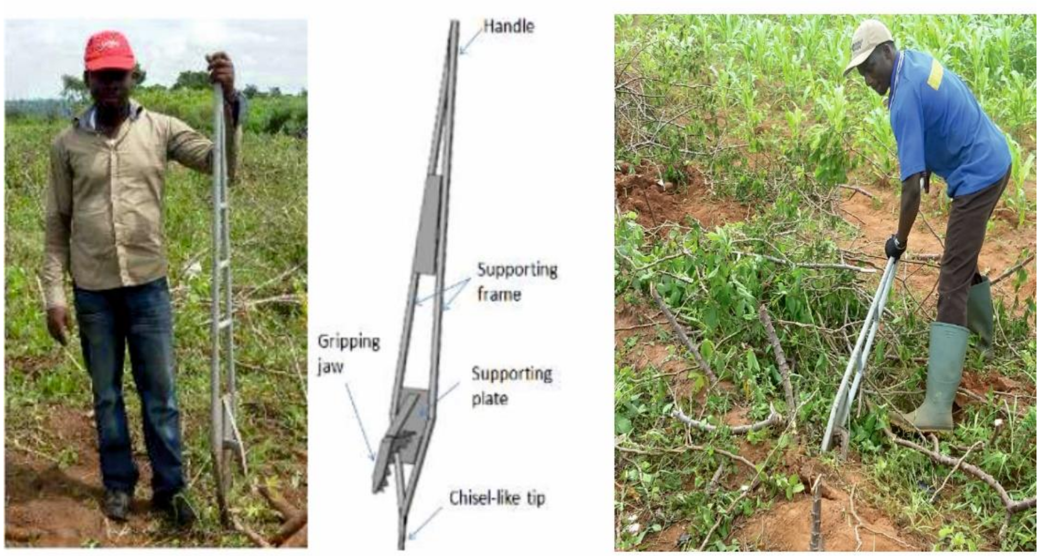

Figure 5: *Cassava Harvester designed by CRI (Shadrack et al., 2017)*

Figure 6: *Cassava harvester designed by NCAM (Amponsah et al., 2018)*

3.3 Mechanized Harvesting

These involve harvesting equipment hitched to a prime mover, often tractor, to uproot the crop. Nevertheless, in some cases, a little manual effort is still needed after the tuber is uprooted from the soil, especially the collection and separation of the tuber from the stem. The field is also required to be in good condition for optimum mechanical harvesting operations to be carried out (USDA, 2003).

Mechanized harvesting of cassava is grouped into two; semi-mechanized and fully mechanized methods. Aside from digging of the cassava roots accomplished by the semi-mechanized method, the fully mechanized ones involve digging, uprooting, lifting of cassava roots to be transported by the conveyor.

3.3.1 Semi-mechanized Harvesters

Figures 7 and 8 show some of the cassava harvesters available in Thailand. They are grouped as fork blade and curve blade harvesters respectively. The comparison between these harvesters are shown in Table 2 (Chalachai et al., 2013).

Figure 7: *Fork Blade Harvester* (Chalachai et al., 2013)

Figure 8: *Curve Blade Harvester* (Chalachai et al., 2013)

Table 2: *Comparison of Tractor-Mounted Fork and Curve Blade Cassava Harvesters in Thailand (Chalachai et al., 2013)*

TYPE	ADVANTAGE	DISADVANTAGE
Fork Blade Harvester	Do not turn over the soil Can keep the root for 2-3 days The tractor does not break the root for the next row	More cassava loss in the soil Working width too small Need powerful tractor
Curve Blade Harvester	Easy to collect the cassava roots Not much loss of cassava in the soil Can use in a wide range of soil and with a small tractor	Tractor damages the root for the next row High root breaking loss Need more labour to collect the roots

In figure 9, it shows a mechanical harvester developed at the Leipzig University (LU), Germany. The cassava root is carefully loosened by the harvester and then lifted approximately 20 cm high. It is delivered to the transport unit made of two belts and a set of steel/plastic press rollers. The root clusters are detached with either hand or cutlass. It requires 55-80kW and has a field capacity of about 0.25-0.38 (Bobobee et al., 1994).

Figure 9: *Mechanical Cassava Harvester designed by Leipzig University (Bobobee et al., 1994)*

Figure 10 shows the cassava harvester model P900 conducted by some researchers in Latin America and the Caribbean to help research and development for semi-mechanized cassava harvesters. The performance of the prototype harvester was tested and evaluated in Columbia. Besides, the harvester has a cutting disk that enabled deep penetration into the soil where manual harvesting is intolerable. To ease the process of harvesting, the stems of the plant should be cut off before harvesting to a height of 20-40 cm (Ospina et al., 2002).

Figure 10: *Cassava Harvester Model P900 (Ospina et al., 2002)*

Figure 11, shows the mechanical harvester developed and manufactured in Ghana at the department of Agricultural & Biosystems Engineering, Kwame Nkrumah University of Science and Technology (KNUST). Its working depth ranges from 23-29 cm and has a field capacity of 0.4-0.52 ha/h (Amponsah et al., 2018).

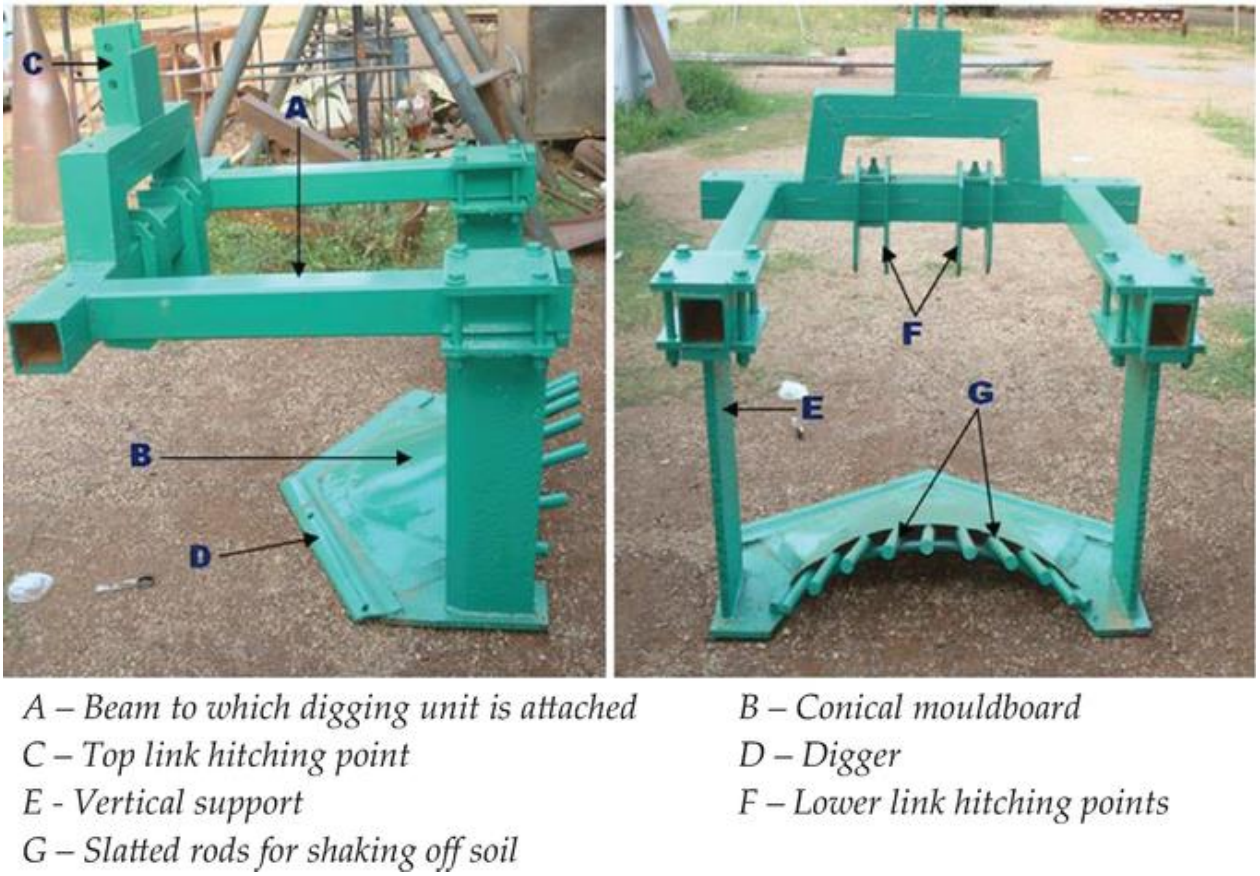

Figure 11: *Mechanical Cassava Harvester designed by KNUST* (Amponsah et al., 2018)

3.3.2 Fully Mechanized Harvesters

Thangdee, (2012) developed a cassava harvester and conveyor unit as shown in figure 12. After the test and evaluation of the harvester, it has been demonstrated that such integration can address the problems in collecting and conveying cassava from the ground. The outcome of such research can be used for further development of appropriate mechanization. Based on the test evaluation, the harvester has a field capacity of 0.05ha/h, 59.10% field efficiency and 3.23% loss caused by conveying the cassava root.

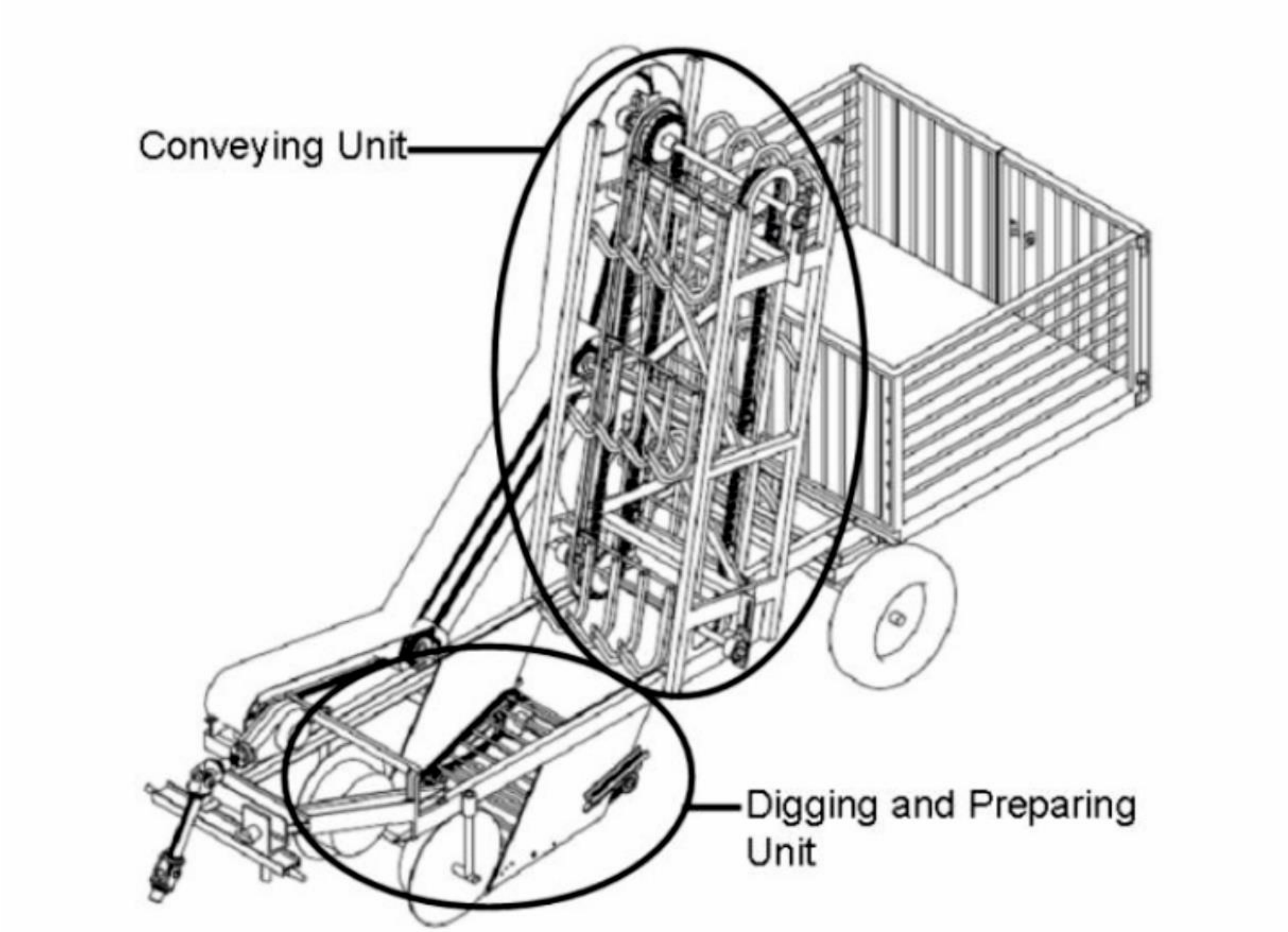

Figure 12: *Mechanized harvester designed by (Thangdee, 2012)*

Table 3: *Comparison of the Mechanized Harvesters*

Mechanized Cassava Harvesters	Merits	Limitations
Cassava Harvester by LU	It uses a hydraulic system	It still requires human labour to detach the cassava root during harvesting
Model P900 Harvester	It has a shock absorber It has a cutting disk to facilitate harvesting	There is no hydraulic system to facilitate the up and down movement of the harvester It requires extra labour to collect the cassava after harvest
Cassava Harvester by KNUST	Simple design	Also, there is no hydraulic

	Works better when crops are grown on ridges	system Absence of a conveying unit
Cassava Harvester by Thangdee	There is a conveying unit It is operated by the PTO system of the tractor.	Cutting of the stem of the plant must be done before harvesting the root crop

4. Conclusion

It can be seen from the above that cassava serves several purposes and there is an absolute need to develop efficient and more ergonomic harvesting and processing machines for this root crop. The inadequacy of an appropriate mechanical harvester is because of the complexity of the crop based on factors such as the soil conditions, the shape of tubers in the soil, and the high draught requirement of machines to pull the root from the soil. However, for the successful development of cassava harvesters, more research should be focused on soil loosening in the root zone and lifting out the tubers with minimal damage. Additionally, a cutting machine with a means of a conveyor should be designed to be attached in front of the tractor purposely for cutting the stem of the plant. At the rear of the tractor, the harvester can equally be hitched to aid a unit harvesting process.

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