Design, Development, and Performance Evaluation of Cassava Peeler

Bisrat Mekonnen Werku

A Thesis Submitted to

Department of Mechanical System and Vehicle Engineering

School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master of science in Agricultural Machinery Engineering

Office of Graduate Studies
Adama Science and Technology University

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Advisor: Dr. Amana Wako Koroso (PhD)

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STATEMENT OF THE AUTHOR

I hereby declare that this Master Thesis which is entitled "Design, Development and Performance Evaluation of Cassava Peeler" is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged.

Bisrat Mekonnen Werku	________________________	______________________
Name of the Student	Signature	Date

ADVISOR APPROVAL SHEET

This is to certify that the thesis entitled "Design, Development and Performance Evaluation of Cassava Peeler" submitted in partial fulfillment of the requirements for the MSc degree in Agricultural Machinery Engineering, the Graduate Program of the Department of Mechanical System and Vehicle Engineering, and has been carried out by Bisrat Mekonnen Werku Id. No. 19239/12, under my supervision.

Therefore, I recommend that the student has fulfilled the requirements, and hence here he can submit the thesis to the department.

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Advisor	Signature	Date

APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the thesis entitled "Design, Development and Performance Evaluation of Cassava Peeler" which was prepared by Bisrat Mekonnen Werku have read and evaluated the thesis and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for in partial fulfillment of the requirement of the degree of Master of Science in Agricultural Machinery Engineering

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External Examiner	Signature	Date
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School Dean	Signature	Date
Postgraduate Dean	Signature	Date

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ACRONYMS AND ABBREVIATIONS

ABMA	American Bearing Manufacturers Association
AOAC	Association of Official Agricultural Chemists
AMD	Arithmetic Mean Deviation
ASMBE	American Society of Mechanical and Biological Engineers
CATIA	Computer-Aided Three-Dimensional Interactive Application
ETB	Ethiopian Birr
FAO	Food and Agriculture Organization
FIIRO	Federal Institute of Industrial Research Oshodi
GME	Geometric Mean Deviation
HCN	Hydrogen Cyanide
IITA	International Institute of Tropical Agriculture
ISO	International Organization for Standardization
ITSI-SU	Innovative Technology for Science Inquiry Scale-Up
MARC	Melkassa Agricultural Research Center
NaOH	Sodium Hydro Oxide
NCAM	National Centre for Agricultural Mechanization
NED	Newell Dun Ford Engineering
NGO	Non-Governmental Organization
PPM	Parts Per Million
RPM	Revolution per Minutes
Sec	Seconds
SNNPR	Southern Nation, Nationality and Peoples Region
SRDGBB	Single Row Deep Groove Ball Bearing
SSA	Sub-Saharan Africa
Std	Standard

ABSTRACT

Cassava (Manihot esculenta) is one of the most important tuber crops that constitute a considerable portion of the daily diet of the peoples in Southern, southwestern, eastern, and northwestern parts of Ethiopia. Currently, the plant is being distributed throughout the country as a tool to tackle food insecurity. This is because cassava grows well in an area characterized by low rainfall and less fertile soil. However, to change cassava tubers to shelf-stable food staff there is a set of unit operations that must have to be performed, of which, cassava peeling is the one rather difficult or risky to carryout manually. Manual peeling is characterized by low output, labor-intensive, and backbreaking activity usually undertaken by women and children. In line with this, the newly harvested cassava tubers should have to be processed within two days that is difficult to accomplish manually for mass production. The objective of this study was to design, develop and evaluate the performance of an electrical motor-operated cassava peeler. A 1hp single-phase electrical motor was used to rotate a 30mm diameter shaft which was rigidly fixed to the cylindrical peeling drum being mounted on the frame made of 40 hollow square sections. The power of the motor was transferred to the peeling unit using a belt and pulley. The speed of the motor was reduced using speed reduction gear having a speed reduction ratio of 50:1. The drum was made of perforated stainless steel sheet metal to have a total volume of $1.11\times10^{-1}m.^{3}$ *20%, 15%, and 10% of the volume of the drum was occupied by 15kg, 10kg, and 7.5kg of cassava tuber respectively and it was rotated at 60rpm and 30rpm for 7 minutes. Parameters such as peeling efficiency, percentage flesh loss, and throughput capacity were used to evaluate the machine performance. Randomized block design at two levels of drum speed and three levels of percentage drum fill was used to test the machine and collected data were analyzed using SPSS statistical software. For 7 minutes of peeling operation, the force required to peel cassava was 0.16N, the torque due to load on the drum was 0.04Nm, and the power required to drive the drum was 0.25W. The developed cassava-peeling machine has a peeling efficiency of 82.83%, percentage flesh loss of 4.03%, and throughput put capacity of* $120kghr^{-1}$ *when the drum was filled 20% and rotated at 60 revolutions per minute. Therefore, the analyses of results and cost-benefit ratio of 1:4.85 confirmed that the electrical motor-operated cassava peeling machine is highly economical and safe to be used by the local cassava producers and consumers.*

Keywords: Cassava, Electrical Motor, Peeling Machine, and Performance Evaluation.

CHAPTER ONE

1. INTRODUCTION

1.1. Background and Justifications

Among many developing tropical economies today, cassava (*Manihot esculenta Krantz*) has become a very essential tuber crop. It is the fourth most important crop for farmers in the tropics and sub-tropics after rice, wheat, and sugar. Cassava is consumed by up to a billion people globally (FAOSTAT, 2019). Cassava is a perennial woody shrub with an edible root, which grows in tropical and subtropical areas of the world. Further, it is believed to be first domesticated in South America, and its cultivation has spread throughout the humid tropics and subtropics (Adebayo *et al.*, 2018). It was also first introduced into Africa in the Congo Basin by the Portuguese around 1558 (Samuel *et al.*, 2017).

Over 26 million hectares of cassava were planted worldwide in 2017, with about 76% in Africa (FAOSTAT, 2019). Cassava requires less labor than other staple crops; however; it requires considerable post-harvest labor because the roots are highly perishable and must be processed into a storable form immediately after harvest (FAOSTAT, 2019). In 2018, global production of cassava root was about 278 million tons, with Nigeria as the world's largest producer, having 21% of the world total. Other major cassava growers were Thailand, the Democratic Republic of the Congo, Brazil, and Indonesia (FAOSTAT, 2019).

In sub-Saharan Africa (SSA), cassava is mainly a subsistence crop grown for food by small-scale farmers who sell the surplus. It grows well in poor soils with limited labor requirements. Cassava is usually intercropped with vegetable plantation crops such as sweet potato, maize, groundnut, or other legumes.

Cassava is one of the important roots and tuber crops supporting a considerable portion of the Ethiopian population. Cassava is grown by small-scale subsistence farmers under resource-poor conditions and used as a major staple diet in the south, southwest, eastern and northwest parts of the country (Samuel *et al.*, 2017). Compared to cereal crops, cassavas is a high yielder, environmentally friendly, and is low-cost energy to the human diet (Okigbo, 1980). In Ethiopia, cassava grows in vast areas mainly in Southern Region. It was believed that cassava was introduced by some NGOs to drought-prone areas of the southern part of the country such as Amaro, Gamogoffa, Sidama, Wolayta, and Gedeo, primarily to fill the gap for subsistence farmers due to the failure of other crops because of drought (Amsalu, 2006). In these areas, farmers usually grow cassava in small irregular scattered plots either sole or intercropped mainly with enset, maize, and sweet potato. In 2013, the average total coverage and production of cassava per annum in Southern region of Ethiopia was 195,055 hectares with the yield of 501,278.5 tones (Tesfaye et al., 2017). Its use as a potential food crop in Ethiopia has been appreciated since the 1984 famine (Amsalu, 2006).

Cassavas have significant contributions towards food security, income generation, resource base conservation, and ensuring sustainable food availability throughout the year. Cassava is referred to as a food security crop (Barratt *et al*., 2006), which can be left in the ground for extended periods of up to two years until required. It is also one of the most important starchy food and its tuberous roots are a valuable source of cheap calories, especially in developing countries like Ethiopia where calorie deficiency and malnutrition are widespread (Amsalu, 2006).

One very important quality of cassavas root that has made it an important food security crop mostly among low-income countries is its ability to grow fully well in poor soil and another important quality is its inherent ability to stay for a long period in the soil even after maturity without undergoing degradation of some kind (Oyedele *et al* ., 2019). According to Samuel *et al*. (2017), four types of Ethiopian traditional recipes with two levels of cassava blending with cereals at the proportion of 50% and 70% are injera, Dabo, Anebabero, and Porridge.

Freshly harvested cassava tuber start deteriorating almost immediately after harvest and can only last for about three days (Kolawole *et al*., 2011). After harvesting cassava roots, are processed by various methods into different products. The various unit operations involved include peeling, slicing, grating, fermenting, drying, and other final processes. Out of the above-listed cassava processing unit operations, peeling is a very difficult task to carry out manually due to the irregularity of the shape of the cassava tuber. Alternatively, farmers prefer to delay the harvest of the tubers until it is needed, thereby leaving it in the ground for up to two years and beyond since it stores well in-ground.

Apart from food, cassava is very versatile and its derivatives and starch are applicable in many types of products such as sweeteners, glues, plywood, textiles, paper, biodegradable products, monosodium glutamate, and drugs. Cassava leaves and peels are used in animal feed and alcohol production (IITA, 2009).

There is much variation in the nutrient quality of the cassava root. In the tropical regions, cassava is the most important root crop and that used as a cheap source of energy; the calorific value of cassava is high compared to most starchy crops (Okigbo, 1980). The starch content of the fresh cassava root is about 30% and gives the highest yield of starch per unit area of any crop known (Tonukari, 2004). The protein content is extremely low, however; it ranges between 1-3% (Buitrago, 1990 and Salcedo *et al*., 2010). The cassava root contains mineral elements in considerable amounts that are useful in the human diet. The root contains significant amounts of iron, phosphorus, and calcium and is relatively rich in vitamin C (Enidiok *et al*., 2008).

Cassava plants are generally categorized as bitter and sweet, depending upon their cyanide content. The low-HCN or sweet cassava has less than 50 ppm of cyanogen equivalents, while the high-HCN or bitter cassava has more than 100 ppm (Wilson and Dufour, 2002). Chemically cassava is composed of water (60%) and starch with minor amounts of protein, fiber, minerals, vitamins, and toxic component HCN (Tewe and Olumide, 2004). The presence of this toxic component needs a special processing procedure to make the product safe for human consumption. Initially, harvested cassava tubers must be peeled to remove the inedible outer parts of the root consisting of the corky periderm and the cortex that are known to contain most of the toxic components. Then hydrogen cyanide is considerably reduced and driven off during, slicing, grating, and subsequent processing stages. Thus, proper processing is indispensable to use cassava safely as a healthy diet for the majority of the population.

To my understanding so far there is no cassava peeler machine in Ethiopia, however; the slicing and grating machine was developed by MARC. Cassava peeling is the first and most important activity in the overall cassava processing line and failure of adequate peeling of cassava tuber will result in health problems on the human being as the major percentages of hydrogen cyanide which is responsible for the toxicity of cassava is found in corky periderm and cortex (Sheriff *et al*., 1995). Most of these operations are still being done manually especially peeling, and they are generally labor-intensive, arduous in nature, time-consuming, and unsuitable for large-scale processing because of their low output (Adetan *et al*., 2003 and Davies *et al*., 2008). Mechanization of cassava peeling process will significantly increase the rate of processing, quality, and quantity of products and their availability for users in the market (Aniedi *et al*., 2012). In this work to mechanize cassava peeling processes mechanical cassava peeling machine was constructed from locally available materials, while it is performance was tested by means of peeling efficiency, percentage mass of flesh loss and throughput capacity.

1.2. Statement of the Problem

Peeling involves the removal of a tiny layer usually called the peels from a stock. It is essential to remove the peels of cassava tuber as it has been known that the concentration of hydrogen cyanide responsible for cassava toxicity is highest in cassava peels than other portion of tuber (Oyedele et al., 2019). In addition failure to adequately and timely peeling of cassava tubers will result in overall deterioration of the tubers due to high concentration of water usually about 60% (Tewe and Olumide, 2004). So far in the history of cassava-peeling several machines were designed and developed. There were different types of cassava peeling machine that was designed in the world, however, some are not economical to be used at a village level rather for high industries. The others have limited peeling efficiency and throughput capacity. As the world is emerging with various type of technology for better quality of life, easy of processing and efficient production of food; automated and mechanized technology for agricultural fields was of great importance. The optimized electrical motor-operated cassava peer was those; solve the problems concerned with electric power consumption, and cost of initial investment. There by increase cassava tuber production and consumption by one step.

1.3. Objectives

1.3.1. General objective

To design, develop, and evaluate performance of cassava peeler

1.3.2. Specific objectives

- To design shaft, pulley and drum.
- To construct a cassava peeling machine.
- To select belt and electrical motor.
- To evaluate the performance of the cassava peeling machine.

1.4. Significance of the Study

In Ethiopia, cassava tuber was peeled manually this requires intensive human labor through exhaustive activity. In line with this, the quality and quantity of the produce cannot satisfy the current needs. Therefore, it has been found very important to manufacture the electrically operated cassava peeler. The machine can be utilized in rural areas of SNNPR where small scale farming of cassava is their primary commodity. The main benefit of a 1hp electrical motor-operated cassava peeler is reducing human power requirements and easing the peeling operation. Mechanical cassava peeler technology has a significant contribution to the development of cassava tuber processing, at the same time; it plays a great role in food insecurity by providing high quality and quantity products at a balanced cost of production. This study will also help future researchers engaged in cassava tuber peeling machines.

1.5. Scope of the Study

The scope of this research study was limited to the design, development, and performance evaluation of electrical motor-operated cassava peelers. The machine was applicable to small scale operation for cassava processing in SNNPR. Parameters used for the design and development of electrical motor operated cassava tuber peeler includes;- the force required to drive the drum, (N), the toque due to load on the drum, (Nm), and the power required to drive the drum with angular velocity, (ω). Whereas performance analysis of the machine was guided by parameters like mass of peeled cassava, (Kg), the mass of peels of cassava, (Kg), the mass of flesh loss, (Kg), peeling efficiency and mechanical damage.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Cassava Tuber

Cassava *(Manihot esculenta)* is a woody shrub perennial plant that belongs to the spurge family (*Euphorbiaceous*). It is extensively cultivated as an annual crop in the tropical and subtropical regions for its edible starchy tuberous root. Cassava is a primary staple food in the developing world, providing a basic diet for over half a billion people. In Ethiopia, cassava is locally known as Mita Boye, Yenchet Boye, Furno tree, and Mogo (Chanie and Walelign, 2020).

Cassava is mostly cultivated and grown around fences and homesteads. Farmers use cassava for food as a composite flour for baking with other cereals like maize, *tef*, and wheat in the southern and southwestern of Ethiopia. It is one of the most drought-tolerant crops, capable of growing on marginal soils. The mature tubers can be 5-10 cm in diameter and 15-30 cm long when harvested 9-12 months after planting (Egbeocha, 2016).

Figure 1. Cassava tuber plant

The tuber is usually cylindrically tapered which differs in weight, size, and shape. They are sometimes white, brown, or reddish depending on the variety. It is surrounded by a thin cambium layer covered by peel, which consists of a corky periderm on the outside and cortex on the inside (Adetan *et al*., 2003). The outside periderm may be thick, rough, or thin, and smooth with surfaces varying considerably in color from pink to grey (Igbeka, 1985). The three layers of cassava tuber as described by (Hassan, 2012) are (i) the periderm-the tuber's uttermost layer, the peel, (ii) the cortex-usually about 1.5 to 2.5 mm thick and white and lies below the periderm, and (iii) the central portion of the tuber-mostly composed of stored starch, which is white; which makes up the more significant portion of the cassava tuber.

2.2. Cassava Tuber Processing

2.2.1. The purpose of processing

Chemically cassava is composed of water 60% and starch with minor amounts of protein, fiber, minerals, vitamins, and toxic component hydrogen cyanide containing glycoside (Tewe and Olumide, 2004). The presence of these toxic components demands special processing procedures to reduce the toxic glycosides to a safer level and make the product safe for human consumption. Toxicity is initially considerably reduced during peeling. Grating breaks down the internal cells and so releases the enzyme that breaks down the cyanogenic glycoside complex and releases hydrogen cyanide (Hassan, 2012). During subsequent fermentation stages, almost a total breakdown of glycoside occurs and the final frying or roasting step drives off the hydrogen cyanide (Hassan, 2012). Sun drying, soaking, fermenting and other activities are old proven technics used to reduce cyanide levels. Thus, proper processing is indispensable to use cassava safely as a healthy diet. The other major reason why the processing of cassava is indispensable is that fresh cassava does not store well because of its high moisture content. After harvesting, cassava roots are susceptible to spoilage and without any preservative; measures can only be stored for about 48hr before they begin to deteriorate (Oyesola, 1981). Therefore, the tubers must be processed as soon as possible after harvesting to stop the deterioration process and thereby change it to storable food staff.

2.2.2. Cassava processing unit operations

Cassava is usually processed traditionally to obtain different relatively shelf-stable, intermediate, and final products for various food applications. Machines for cassava processing are made to replace the hand-operated method and to increase output to attain the required demand for food, feed, and industrial materials. Suitable mechanization and automation are vitally needed to achieve the desired product. For industrial use, cassava is processed to obtain starch. The processing of cassava tubers for industrial or human use involves different unit operations. According to Hassan (2012), unit operations undertaken for cassava processing comprises peeling, slicing, grating, drying, and sieving.

2.3.Cassava Peeling

2.3.1. Concept of peeling

After harvesting the tubers and cleaning from debris, peeling was the first operation to be performed. Cassava peeling has been practiced as far back as when cassava came into existence in South America. However; the tools used for peeling have developed from stones and wooden flight into a simple household knife the desired quantity and quality of peeling were not attended. Cassava must be peeled to remove the inedible outer part of the root consisting of the corky periderm and the cortex (Adetan et al., 2003). These are known to contain most of the toxic components called HCN. According to Bencini (1991), about 83% of the total cyanide was removed by peeling operation.

The cross-sectional image of cassava tuber (Fig 2) consists of a central core called parenchyma or the pith; this is surrounded by the starchy flesh that forms the bulk of the tuber and the primary storage region. The tuber peel which consists of a corky periderm on the outside and cortex on the inside covers the cambium layer. The cortical area is usually white and varies in thickness between 1.5 and 2.5 mm (Hassan, 2012). According to Alhassan *et al*. (2018), the cassava peels constitute 18.2% out of the whole tuber without flesh loss. Unlike the other root crops, the peel of fresh cassava tubers can easily be removed from tubers because of the thin cambium layer separating them. Thus, during peeling unit operation the intentions are to remove the corky periderm and cortex that are responsible for cassava toxicity as seen in Fig 2 below Adetan *et al*. (2003)

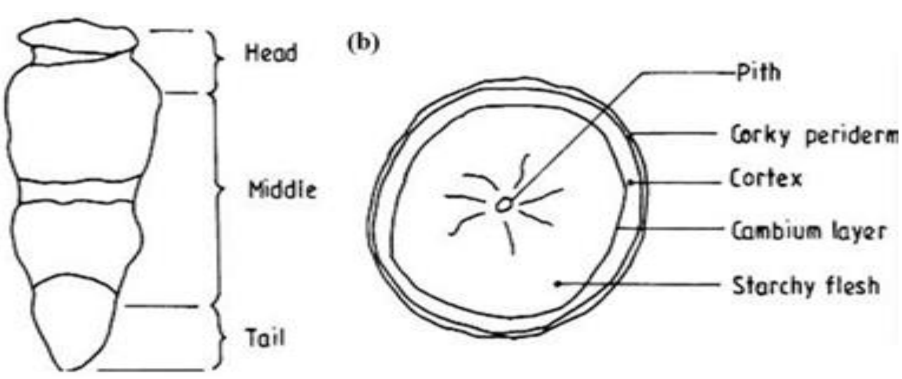


Figure 2. Morphology of cassava tubers

2.3.2. Peeling Methods

In the peeling operation of cassava, both periderm and cortex need to be removed as a waste whereas the central portion of the tuber was left as the only desired output. Since the production and conception of cassava tubers, several methods of peeling cassava tubers have been practiced and adopted. They include Manual, Chemical, Steaming, Flame, And Mechanical methods. Each has its advantages and disadvantages (Hassan, 2012).

2.3.2.1. Chemical peeling

The chemical method is often adopted in industries, factories, and food processing companies. It involves chemical actions and thermal shock, which leads to softening and loosening of the skin using caustic soda (NaOH). Peeling is achieved by making a hot solution of sodium, hydrogen, and oxygen to form sodium hydroxide that helps to loosen the skin of the root when the solution is applied to it. Chemical peeling that is the common method for manufacturing industries and food processing companies to peel potatoes can also be used to peel cassava (Adetan *et al*., 2006). However; the chemical peeling method has the following disadvantages; - Cost of acquiring caustic soda, difficulty in controlling the penetration of chemical into the cassava tuber, and the difficulty in the removal of chemicals, as it may be poisonous.

According to Igbeka (1985) chemical cassava peeling method will not be suitable for cassava tuber peeling due to higher operating pressure, higher NaOH concentration, higher temperature requirement as cassava peels were thick and rough compared to that of potatoes peels and more time needed for immersion required for cassava tubers with tougher peels than the peels of potatoes; food poisoning because when the concentration of sodium hydroxide is high, the sodium hydroxide in the cassava root will need to be neutralized and the only way the base can be neutralized is by immersing the root inside an acid to form a salt. This also can lead to more additional running costs; formation of dark color heat rings which usually appear in patches on the surface of peeled cassava tubers. Therefore, this will hinder the cassava to be processed into foods since it will affect the appearance. For food or industrial starch production, the method may result in the formation of an objectionable heat ring (dark color) on the surface of the tuber and the gelatinization of starch (Igbeka, 1985; Oluwole and Adio, 2013; Jimoh *et al*., 2014).

2.3.2.2. Steam pealing

According to Floros (1988), steam peeling is widely used in the processing industries and this is because of its high level of automation, accurate time, temperature, and pressure control by electronic devices to reduce loss of useful flesh during peeling. Steam peeling is either batch or continuous operation and it involves putting some amount of the cassava root inside a pressure vessel and then subjecting them to pressurized steam for about a minute or two. The hot pressurized skin ruptures on the sudden release of the high-pressure water (Simplot, 2006). Limitations of steam peeling include the unpleasant appearance of the resulting root especially the color. According to Garcia and Diane (2005), the basic conditions in steam peeling treatment were peeling condition pressure, exposure time, and vacuum size, which is considered for the interpretation of peeling efficiency. By thermal softening the firmness, adhesiveness, and springiness of the tuber are affected (Sajeev *et al*., 2009). Despite the above demerits, the steaming method has a favorable peeling effect without causing any appreciable loss in the mass of the cassava tubers (Abdullahi *et al*., 2010).

2.3.2.3. Flame Peeling

Flame peeling has been used to remove the outer skin of various fruits, vegetables, tuber, and root crops. It has been applied only to materials of extremely high moisture content. In such applications, the moisture content of the fruit or vegetable material has the right amount of heat capacity that will make it burn easily or remove the outer covering of the vegetable material. Inflame peeling, a direct flame that goes as high as 1000 degrees Celsius, or gases that are hot inside a rotating flame peeler act on the crop introduced inside the peeler (Oyedel *et al*., 2019). Heat causes the steam to have increased energy and this energy makes the skins swell up. When the skin swells up, it can easily be washed away with water. This flame peeling is immediately followed by adding cold water to bring down the temperature quickly. The limitation encountered in this type of peeling is that when vegetable skin or coat is in direct contact with gases at extremely high temperatures, the temperature of the main body of the vegetable material elevates to a point at which undesirable change occurs.

2.3.2.4. Manual peeling

Manual peeling using a knife is the most common method since the history of cassava production and consumption until today. In varieties that are easy to peel, the peel is slit along the length of one side of the root, and the knife-blade and fingers are used to roll back the skins from the fleshy portion of the root. With varieties that are difficult to peel, the two layers of peels are whittled with a knife in a motion indicative of sharpening a pencil. A manual cassava root tuber-peeling rate of about 21.8kghr^{-1} was reported by (Oluwole and Adio, 2013). NCAM (National Centre for Agricultural Mechanization) has developed a manual peeling tool with an output capacity of 35-40 kghr^{-1}, peeling efficiency of 99 %, and tuber loss of less than 0.4 %. IITA (International Institute of Tropical Agriculture) has also produced a knife-like manual tool with a capacity of less than 30kghr^{-1} with minimum tuber flesh loss mostly used by women and children. However, manual peeling of cassava is less effective, tedious, labor-consuming, and expose for mold development on skins. In addition, it is not suitable for commercial purposes (Ohwovoriole *et al*., 1988).

Though the manual method has peeling speed limitations, high injury rates, is very exhaustive and exposes for mold growth yet, it yields the best results for local processors or small-scale farmers still. However; compared with manual peeling mechanical peeling of cassava can peel the cassava in batches; improve the speed of cassava processing, save labor input, avoid direct contact so save for the operator. Mechanical peeling of cassava is very essential for the large-capacity cassava processing plant.

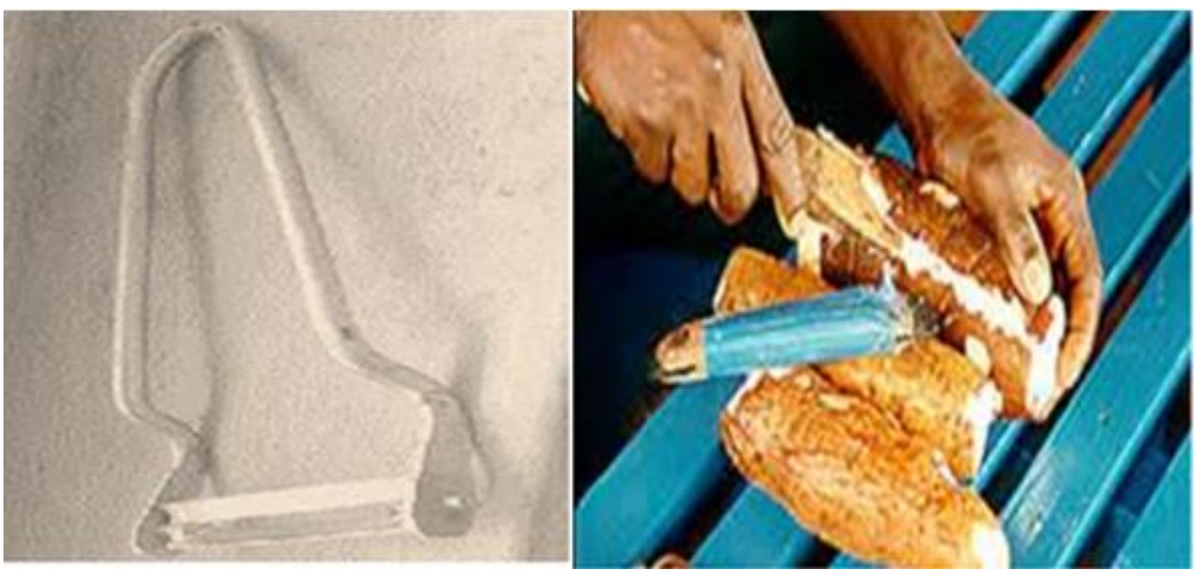
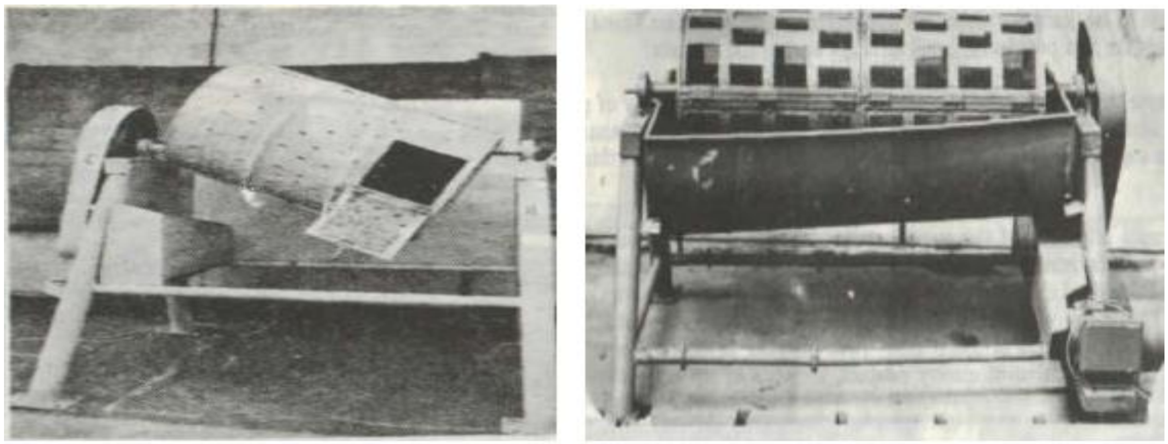


Figure 3. NCAM and IITA knife-like cassava peeling tool

2.3.2.5. Mechanical Peeling

. Mechanical peelers have different types of machine parts that interact directly with cassava skin and then remove it, thereby providing high quality fresh final products. Products from mechanical peelers are environmentally friendly and non-toxic (shirmohammadi, 2012). In addition, mechanical peeling methods complete the peeling process in one step and any further washing or removing skin would not be required. Common prototype peelers have functional systems such as abrasive devices, brushes, drums, rollers, knives, blades, and milling cutters which remove the outer cortex using mechanical means to reduce drudgery and eliminate hazards encountered in manual peeling. This method mainly aims at a larger number or batch of tubers at a time. It includes mechanized means of peeling and washing at the same time that incorporates the use of conveyors, abrasive objects, and water splash (Hassan, 2012). This method seems to be the most effective and convenient to use for cassava peeling on a commercial basis, but its major challenges are the irregular shapes, sizes, and lengths of the tubers. In addition, tuber flesh loss and mechanical damages are very high during its operation, which increases food loss and food insecurity (Egbeocha *et al*., 2016; Jimoh *et al*., 2014) mechanical means of cassava peeling was recognized better than those discussed above. The abrasive type-peeling machine works on the principle of abrasion. Peeling is achieved when the cassava tubers encounter an abrasive material. The abrasive material rubs off the peel from the cassava tuber.

Adetan *et al*., (2005) critically and carefully designed spring-loaded cassava peeling machine with five spring-loading points equally spaced at 140mm intervals located along the length of the knife assembly with a spring rate of 2.193N/mm. The cassava was then introduced in various sizes and the average height of the bed respectively to suit various tuber sizes. However, the result indicates that there were 15% of broken tubers with a peeling efficiency of 98.8%. Odigbo (1983), designed three models of cassava peeling machine models I, II, and III. In model I, an oil drum was punched about two-third millimeter diameter holes per square cm of its surface and eccentrically mounted on a drum with 200mm by 150mm opening to load cassava inside the drum. Cassava tubers and a predetermined quantity of some inert materials or pieces of 3.2-4.8 mm hard quarry stone are loaded into the drum that is then rotated at 40rpm. The rubbing action removed the peels from the cassava tubers, leading eventually to the complete and uniform peeling. Water is sprayed to wash away the finely abraded peels to prevent polluting and dulling the abrasive surface. In model II, balls of expanded metals were used to replace pebbles. Model III had four abrasive cylinders of expanded metal mounted inside the main peeling drum driven by a planetary gear arrangement to rotate about their axes at four times the rpm of the main drum, in addition, balls of expanded metals also loaded into the drum which is then rotated at 40rpm.



(a) Model I **(b) Model II**

Figure 4.Cassava peeling machine

The design of cassava peeling machine using an abrasive mechanism has been carried out by Alhassan et.al, (2018). It was practically observed that a slow speed favors the machine operation and this was achieved using a reduction gear (Alhassan et.al, 2018).

2.4. Possible power source for cassava peeling machine

Human, engine and electrical motors are among well-known power source for cassava peeling machine. However, to mechanize cassava peeling operation either engine or electrical motor was used as power source because human lobar has been used for longer period of time and no appreciable results were obtained. While engine power is also have a problems with food contamination using of electrical motor was the recommended one so that is why a single phase 1hp electrical motor was used in these work.

2.5. Research Gap

Of all the unit operations involved in cassava processing, several processes have been mechanized successfully. However, cassava peeling has remained a serious global challenge to engineers involved in cassava processing operations and systems design, this is due to the irregular shapes, weight, and sizes (Egbeocha et al., 2016). Several cassava-peeling machines have been developed because of the efforts put in to research field, yet, relatively low-quality performance, including peeling efficiency, has been the outcome, and this is due to the irregular shapes, weight, and sizes of the tubers (Hassan, 2012).

Thus, considering all the above research gaps encountered in cassava peeling with chemical peeling, steam peeling, flame peeling, and manual peeling mechanism the researcher was able to design, develop and evaluate mechanical cassava peeling machine by supporting the principle of abrasive drum used by (Odigbo, 1983) while reducing the complexity by replacing the hard quarry stone, balls of expanded metals and eccentric cylinders with abrasive drum made of a set of perforated stainless steel sheet metal plates which is then rotated at 30 and 60rpm achieved by speed reducer gear and changing pulley size.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Study Site Description

The study, design, development, and performance evaluation of cassava peeling machine was conducted at Melkassa Agricultural Research Center (MARC), which is located 117 km southeast of Addis Ababa, Ethiopia, and 17 km South of Adama city. It is found at an altitude of 1466m above sea level and lies on the geographical coordinates of 8° 24' 0" N, 39° 20' 0" E Latitude, and Longitude, respectively.

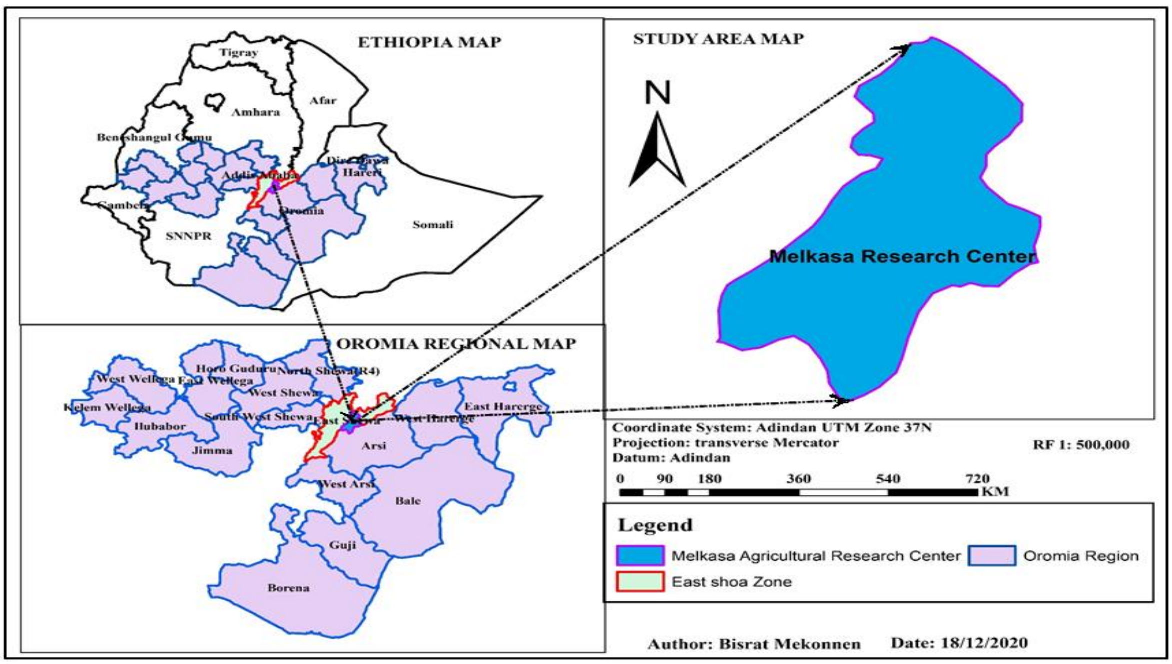


Figure 5. MARC Map

3.2. Materials

During the development of the machine, the strength of materials, and the theory of machine, and mechanism were considered. According to Adetan *et al*., (2003), a good knowledge of the physical properties of the tuber is important to mechanize the cassava peeling process. In the construction of the cassava-peeling machine, the quality of the food as well as the durability of the material for the construction was put into consideration (Alhassan *et al*., 2018). To preserve the quality of food, fabrication materials should not contaminate it but should possess the ability to withstand corrosion, wear and tear. In addition, affordability, availability, the strength of the materials for construction as well as physical properties of the materials to be peeled were given due consideration (Alhassan *et al*., 2018). The materials selected for the constructions were based on ease of fabrication, toughness, machinability, availability, and cost.

During the construction of parts of the machine that has direct contact with the cassava tubers like a drum, a great concern was given to food contamination. Accordingly, the drum was constructed with a stainless steel sheet metal plate. Whereas, other parts like frame, drum cover, and protective hood were constructed from the high thickness and strength materials by considering the durability of the developed machine to meet the expected working lifetime.

All the machines and materials used for the construction of the cassava peeler were listed in table 1 along with their necessity.

Table 1. Machine, tools, and materials used for the development of peeler machine

No	Machine /tool/ materials.	Necessity
1	Lath	Turning, facing, and boring
2	Hydraulic machine	Marking perforated holes
3	Power hacksaw	Cutting
4	Rolling machine	Rolling sheet metal
5	Arc welding	Welding
6	Portable grinder	Grinding and cutting
7	Digital Varner caliper	Measuring
8	Tape	Measuring
9	Center punch	Pointing
10	Hammer	Kicking
11	Measuring balance	Weighting
12	Milling machine	For key way cutting
13	Spanner	Tighten and loosen the nut
14	Screwdriver	Tighten or loosen the screw
15	Drilling machine	Making holes
16	Square pipe	Frame

17	Milled still road	Shaft
18	Bering	For smooth rotation shaft
19	Antirust	Corrosion control
20	Pulley	Power transmission
21	Belt	Power transmission
22	Electric motor (1hp)	Power source
23	Stainless sheet metal plat	Making drum
24	Paint	Coloring
25	Labeled cylinder	Volume determination
26	Bolt and nut	Connecting
27	Oven	To determine moisture content
28	Tachometer	To check revolution per meters of drum
29	Knife	To remove the peels of partially peeled tuber
30	Hinge	For opening and closing of drum cover
31	Graduated cylinder	For volume measurement
32	Plastic container	To collect displaced water
33	Sheet metal	For drum cover and protective
34	Stainless steel sheet metal	For drum construction
35	Angle iron	For engine setup construction
36	Drill bit	For making hole
37	End mill	For cutting keyway
38	Vice clip	To tightly holding

3.3. Source of Experimental Materials

For physical properties determination, preliminary test, as well as performance evaluation of developed cassava peeling machine the sample of cassava tuber, was collected from MARC (Melkassa Agricultural Research Center), fruit and vegetable department, and farmers of Wolayta zone, Wolayta zuria woreda.

3.4. Measuring Tools and Instruments

Different tools and instruments were used to carry out different measurements on the cassava root tubers. A measuring tape was used to measure the length of cassava tubers while the diameter of the cassava tubers was measured by using a digital Varner caliper. The weight of cassava tubers before and after peeling, the weight of cassava peels removed by machine and manually hand, and the weight of flesh loss were measured with an electronic weighing balance. The time of operation was recorded using a mobile stopwatch application while partially peeled cassava peels were removed by a knife manually.

3.5. Determination of Physical Properties

3.5.1. Geometric mean diameter

The diameters of peeled and unpeeled cassava tubers were measured using a digital venire caliper with an accuracy of 0.01 mm and a measuring range of 0.00 –150.00 mm. This was done at the major diameter (head) taken as "a", intermediate diameter (middle) as "b", and minor diameter (tail) "c" as shown in figure 2 above the morphology of cassava tubers. The main concern to determine the diameter of cassava tubers was to specify the clearance between the plates made the drum. The mean values of GMD of cassava tubers were calculated to be 12.91mm using equation 3.1 (Simonyan and Ehiem, 2012).

$$GMD = \sqrt[3]{a\ b\ c} \quad \text{………………………………………………………………..……………} \quad 3.1$$

Where; GMD = Geometric mean diameter (mm),

a = Major diameter (mm),

b = Intermediate diameter (mm),

c = Minor diameter (mm),

3.5.2. Mass and volume

A digital weighting balance of accuracy of 0.1g and a capacity of 15kg weighted the mass of cassava tubers. The volume of cassava tubers was determined by water displacement methods in such a way that the container was filled with water up to the top and placed in another container. The cassava tubers were then immersed totally into the water-filled container then the amount of water displaced was used to determine the volume of cassava tubers (Hughes, 2005). Therefor the determination of volume of cassava tuber is to know the volume of peeling unit.

3.5.3. Bulk density

The bulk density of tubers was determined by weighing the tubers packed in a container of known weight and volume. The container having a volume of 18 liters and a mass of 0.5kg was filled by cassava tuber in a way that it was at the top level of the containers. Then the container together with samples of cassava tuber was weighted by weighting balance of accuracy 0.1g and capacity of 15 kg to be 12.5kg. The bulk densities of cassava tubers were calculated to be 666.67 kgm^{-3} using equation 3.2 (Rahman, 2014).

$$\rho b = \frac{Mb}{Vc} \qquad \text{…3.2}$$

Where: ρ_b = Bulk density of the tubers (gcm^{-3}),

M_b = Bulk mass of the tubers (g),

V_c = Volume of the container (cm^3).

3.6. Parts and Description of Cassava Peeling Machine

As showed on figure 6 below the parts of the developed cassava tubers peeling machine include peeling drum, drum cover, protective hood, bearings, belt and pulleys, motor setup for power source, and mounting frame. The peeling unit is a cylindrical drum having an outside diameter of 506cm and a length of 600cm. It was constructed from 20 pieces of perforated stainless steel sheet metal plates that are equally spaced. The space between each plate made the drum was wide enough to let out the cassava peels removed from the tuber while, narrows enough to retain the smallest peeled cassava tuber interims of thickness or diameter. The peeler has a prime mover 1hp single phased electrical motor rotating at speed of 1450 rpm and speed reducer gear having a speed reduction capacity of 50 to 1rpm assembly that is aligned with the shaft of the peeling drums and mounted on the frame and motor setup. The developed machine was constructed in such a way that the frame and motor setup was easily connected by bolt and nut that making it easy for transportation and moving place to place. The protective hood and drum cover was used to guide the peels to the delivery opening and prevent the splash of dust and peels to the operator and motor.

The available construction material in the work shop was used to develop the cassava peeling machine. Square hollow section was used for frame and engine setup construction, round bar for shaft construction, angle iron used to strengthen drum cover and construction of engine setup, flat iron, cylindrical hinges, iron pipe, mild steel sheet metal, stainless steel sheet metal, bolts and nuts, pulleys and belts for power transmitting, and bearings for smooth rotation of drum as shown in figure 6 below. Every component of the cassava peeler would be fabricated in such a way that as to give strength and stability to the system during operation for efficient output.

Figure *6*. Developed cassava peeling machine

1. Drum cover, 2. Belt, 3. Speed reducer gear, 4. Pulley, 5. Prime mover (1hp electric motor), 7. Drum, 8. Bearing, 9. Shaft, 10. Peels protective hood and 11. Frame.

3.7. Design and selection of Cassava Peeling Machine Component

The major design analyses were done on the drum, shaft, and pulley. Another part of the machine that was included in the design was the frame, drums cover, and protective hood that guides peels to the outlet. The rest part of the machine that was not designed like the belt, bearing, and speed reducer gear was selected based on the standard.

3.7.1. Drum design

The peeling unit as shown in Figure 6 is a cylindrical drum and its diameter and length can be determined based on the available power source, desired capacity, and compactness of the machine. The drum was made of a set of perforated stainless steel sheet metals plates of 3mm thickness arranged in a cylindrical manner. According to Khurmi and Gupta (2005), the volume cylinder was determined using equation 3.3. The volume of the peeling drum can be determined based on the capacity of 120 $kghr^{-1}$ that is corresponding to a 20% percentage drum fill. The volume of $1.11\times 10^{-2}m^3$, $1.7\times 10^{-2}m^{3,}$ and $2.22\times 10^{-2}m^3$ corresponding to the machine capacity of 60 $kghr^{-1}$, 90 $kghr^{-1,}$ and 120 $kghr^{-1}$ respectively, the detail of calculation was shown in appendix A. For the Drum having an outer diameter of 0.506 m, the inner diameter of 0.5 m, outer height 0.6m, and inner height 0.58m the total volume was calculated to be $1.11\times 10^{-1}m^3$.

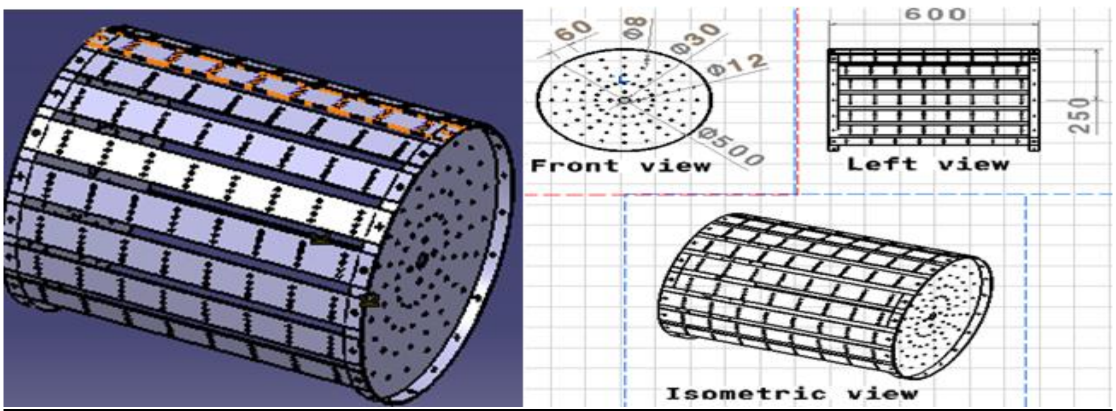


Figure 7. Cylindrical peeling drum

The volume of a peeling drum was designed for the maximum capacity of about 600$kghr^{-1}$ that was equivalent to 100% peeling drum filed by cassava tuber by volume. Nevertheless, for properly peeling the tubers and to avoid clogging, the volume of unpeeled cassava tuber within the peeling drum was 10-50% of the total volume of the drum (Alhassan *et al.,* 2018). To know the number of stainless steel sheet metal plates that made the drum use circumference of a circle and dived by the width of the plate by considering the clearance between the plates made drum as equation 3.4 and 3.5 respectively. Accordingly, the circumference of the drum and the number of plates used to make the drum were calculated to be 1.571m and 20 pc respectively.

$$V = \pi r^2 h \qquad \text{3.3}$$

Where: V = Volume of the peeling drum (m3),

r = radius of peeling drum (m) and

h = height of peeling drum (m)

$C = 2\pi r$……………………………..……………...…………………….……………..3.4

$No = \frac{C}{w}$…………………………..…………………...………………………………..3.5

Where: C= Circumference of peeling drum (m),

r = Radius of drum (0.25m),

w = Width of plates made drum (0.06m) and

No = Number of plates.

3.7.1.1. Design of plates

The plate was constructed in the shape of a rectangle from 3mm thickness stainless steel sheet metal plats so that, a rectangular structural formula as equation 3.6 was used to calculate the volume of a single plate that was $10.8\times10^{-5}m^3$.

$Vp = L \times w \times t$……………………………...…………………………………………….3.6

Where: L= Length of plate (0.6m),

w = Width of plate (0.06m),

t = Thicknes of plate (0.003m) and

Vp= Volume of plate (m^3).

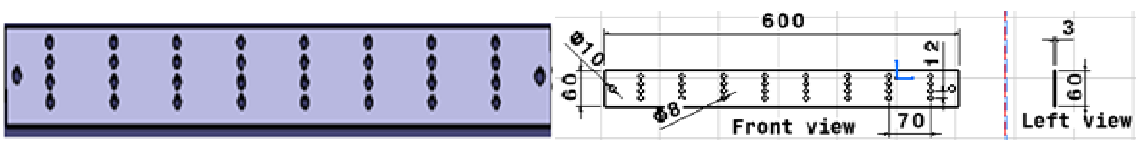


Figure 8. Design of plate

3.7.1.2. Design of circular plates

For the two ends closing the drum circular stainless steel sheet metal was used and its volume was determined to be $5.89\times10^{-4}m^3$ for a single plate using equation 3.7.

$Vcp=\pi r^2 t$……………………………………..……...……………………………….3.7

Where: r = Reduce of the circle (m),

t = Thickness of plate (m) and

V_{cp} = Volume of the circular plate (m^3).

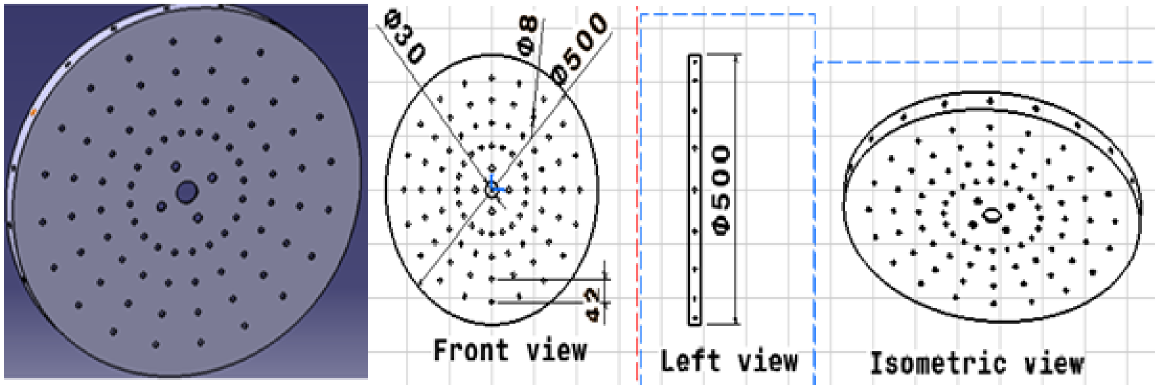


Figure 9. Design of circular plate

From Equations 3.8 and 3.9, the mass of the plate made the drum can be calculated by using the volume and density, for stainless steel the density was 7,700kgm^{-3}. Therefore; for 20 rectangular stainless steel sheet metal plates and 2 circular plates mass was calculated to be 15.24kg and 9.06kg respectively.

$M_p = \rho \times V_p$……………………………………………………..…………………3.8

$M_{cp} = \rho \times V_{cp}$……………………………………………...……...………………..…3.9

Where: Mp = Mass of plate (kg),

Mcp = Mass of circular plate (kg),

ρ = Density of stainless steel (7,700kgm^{-3}),

Vp = Volume of plate (m^3) and

Vcp = volume of circular plates.

The total mass, therefore, was the sum of the mass drum (26.8kg), and the maximum mass of cassava tuber to be peeled at a time (15kg), which was equal to 41.8kg. The force "F" required to peel cassava by the drum of mass "m" having a tangential acceleration "a" is given by Newton's second law as equation 3.10.

$F = m \times a$ ………………………………………………………………………..……...3.10

Where: F = Force required to peel cassava tubers (N),

m = Mass of drum together with cassava tubers (kg) and

a = Tangential acceleration of drum (m/sec).

From the equation of motion v = u + at, since the drum is turning at average constant speed by the time the peeling begins, the initial speed "u" is zero. Then equation 3.10 is re-written as equation (3.11).

$$F=\frac{v}{t}\times m \text{ ……………………………………………………………………………}3.11$$

The angular speed "v" was given by equation 3.12.

$$v=\frac{2\pi rN}{60}\text{………………………………………………………………………………}3.12$$

Substituting equation 3.12 to equation 3.11 the force required to peel cassava tubers was given by equation 3.13. Note the calculation was based on optimum revolution per minute of the peeling drum (60rpm).

$$F=\frac{2\pi rN}{60t}\times m\text{……………………………………………………………………………}3.13$$

$$F=\frac{2\times3.142\times0.25m\times60}{60(7\times60)sec}\times41.8kg$$

$$F=\frac{1.57m}{420sec}\times41.8kg$$

F = 0.16N

Where: F = Force required to peel cassava tubers (N),

m = Mass of drum together with cassava tubers (41.8kg),

t = Time (7× 60sec),

N = Speed of drum (optimum 60rpm) and

r = Reduce of peeling drum (0.25m).

The normal force, the torque, angular velocity, and power required to peel cassava tubers were determined to be 0.16N, 0.04Nm, 6.284rads^{-1}, and 0.25watt using equations 3.13, 3.14, 3.15, and 3.16 respectively (Khurmi and Gupta, 2005).

$$T = Fr\text{…………………………………………………………………………………}3.14$$

T = 0.16N × 0.25m

T = 0.04Nm

$$\omega=\frac{2\pi n}{60}\text{…………………………………………………………………………… }3.15$$

$$\omega=\frac{2\times3.142\times60}{60}rpm$$

ω = 6.284rpm

$$P = T\omega\text{…………………………………………………………………………………}3.16$$

P = 0.04 × 6.284watt

P = 0.25watt

Where: P = Power required (watts),

T = Torque required to drive peeling drum (N m),

ω = Angular velocity (rad.s-1),

n = Speed of peeling drum (rpm) and

r = Radius of peeling drum (m).

3.7.2. Shaft design

The design of shafts of ductile material was based on strength and makes use of the maximum shear stress theory or Guest's theory. Shafts must be designed so that deflections are within acceptable levels. The diameter of the shaft subjected to fluctuated load can be estimated using 3.17 (Khurmi and Gupta, 2005). According to the ASMBE code for rotating shafts, when the load was applied with minor shock, the values of Kb = 1.2 to 2.0 and Kt = 1.0 to 1.50. Furthermore, it was noted that for a shaft without a keyway, the allowable stress τ must be 55 MN/m^2 and for the shaft with the keyway, the allowable stress τ should not exceed 40 MN/m^2 (Khurmi and Gupta, 2005).

$$d^3 = \frac{16}{\pi\tau all}\sqrt{(KbMb)^2+(KtT)^2} \quad \ldots\ldots 3.17$$

Where: d = Diameter of the shaft (mm),

τall = Allowable stress (N m^{-2}),

kb = Combine shock and fatigue factor applied to bending moment,

Mb = Bending moment (N m),

kt = Combine shock and fatigue factor applied to torsional moment,

T = Torsional moment (N m),

The amount of torque exerted on the speed reducer pulley by an electrical motor of 1hp and speed of 1450rpm was determined to be 4.91N m by using equation 3.18 (Khurmi and Gupta, 2005). However, according to Khurmi and Gupta (2005), the maximum torque was 25% greater than the calculated torque and can be equal to 6.14N m.

$$T = \frac{60\ P}{2\Pi N} \quad \ldots\ldots 3.18$$

$$T = \frac{60 \times 746W}{2 \times 3.142 \times 1450rpm}$$

$$T=\frac{44,760}{9,111.8}Nm$$

$T = 4.91Nm$

Where: P = Electrical motor power (W)

N = Electrical motor speed (rpm) and

T = Torque (N m)

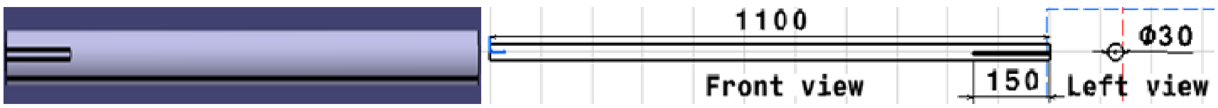


Figure 10. Design of shaft

The torque and tension both in the motor side and drum side were calculated because of the presence of a speed reducer gear in between motor and drum. Therefore, the drum side torque and tension were used in the determination of shaft diameter. The torque exerted on the driven pulley or speed reducer inlet pulley was given by equation 3.19 (Khurmi and Gupta, 2005).

$$T = (T_1 - T_2)\, r_2 \quad \text{……3.19}$$

Where: T_1 = Tight side tension of the belt in a motor side (N),

T_2= Slack side tension of the belt in a motor side (N) and

r_2 = Radius of pulley of speed reducer gear at the inlet (m).

According to Khurmi and Gupta (2005), the wrap angle and angle of the lap for an open belt can be calculated using equations 3.20 and 3.21 respectively.

$$\sin\alpha = \frac{r_1 - r_2}{x} \quad \text{……3.20}$$

Where: r_1= Radius of drive pulley (mm),

r_2= Radius of driven pulley (mm) and

x= Center distance between two pulleys (mm) and

α = Warp angle (̊).

$$\theta=(180-2\alpha)\frac{\pi}{180}\,rad \quad \text{……3.21}$$

According to Khurmi and Gupta (2005), the belt tension equation can be determined using equation 3.22.

$$2.3\log\left(\frac{T_1}{T_2}\right) = \mu\,\theta \qquad \text{.......} 3.22$$

Where: θ = Lap angle (°),

T_1 = Tension in the tight side of the belt in motor side (N),

T_2 = Tension in the tight side of the belt in motor side (N) and

μ = Coefficient of static friction between belt and pulley.

From equation 3.21 the torque exerted on the speed reducer pulley was,

$T_{sr} = (T_1 - T_2)\, r_2$

$6.14 \text{ N m} = (T_1 - T_2)\, 0.032\text{m}$

$T_1 - T_2 = 191.88\text{N}$ .... (a)

The minimum center distance between the motor pulley and speed reducer can be calculated using equation 3.23 (Khurmi and Gupta, 2005).

$$X = \frac{(D_1+D_2)^2}{2} + D_1 \qquad \text{.......} 3.23$$

$$X = \frac{(0.1+0.064)^2}{2} + 0.1\text{m}$$

$$X = \frac{0.03}{2} + 0.1\text{m}$$

$$X = 0.11\text{m}$$

From equation 3.20 warp angle was given by the relation.

$$\sin\alpha = \frac{r_1 - r_2}{x}$$

$$\sin\alpha = \frac{0.05-0.032}{0.11}$$

$$\sin\alpha = 0.16$$

$$\sin^{-1} 0.16 = \alpha$$

$$\alpha = 9.42^0$$

From equation 3.21 lap angles were given by the relation

$$\theta = (180° - 2\alpha)\frac{\pi}{180}\text{rad}$$

$$\theta = (180° - 18.82°)\frac{\pi}{180}\text{rad}$$

$$\theta = 161.16 \times \frac{3.142}{180}\text{rad}$$

θ = 2.82 rad

From belt tension equation 3.22

$$2.3 \log\left(\frac{T_1}{T_2}\right) = \mu\, \theta$$

Take coefficient of static friction between the aluminum pulley and rubber belt was 0.3 (Khurmi and Gupta, 2005).

$$2.3 \log\left(\frac{T_1}{T_2}\right) = 0.3 \times 2.82$$

$$2.3 \log\left(\frac{T_1}{T_2}\right) = 0.85$$

$\log\frac{T_1}{T_2}$ = 0.37 Take anti log.

$$\frac{T_1}{T_2} = 2.33 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(b)}$$

From a and b that is

T_1-T_2 = 191.88N and T_1 = 2.33T_2

$2.33T_2 - T_2 = 191.88$

$1.33T_2 = 191.88$

$$T_2 = \frac{191.88}{1.33}$$

T_2 = 144.27N

T_1=2.33T2

T_1=336.15N

For drum side, toque and tension calculations use the relation between speed and torque as equation 3.24 (Khurmi and Gupta, 2005).

$$\frac{T_{sr}}{T_{dr}} = \frac{N_4}{N_3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.24$$

$$T_{dr} = \frac{N_3}{N_4} \times T_{sr}$$

$$T_{dr} = \frac{45\text{rpm}}{60\text{rpm}} \times 6.14\text{N m}$$

T_{dr} = 0.75 × 6.14Nm

T_{dr} = 4.61N m

T_{dr} = (T_3-T_4) r_4

$4.61N\ m = (T_3\text{-}T_4)N\times 0.05m$

$T_3\text{-}T_4 = 92.2N$……………………………………………………………….……..a’

Where: T_{sr} = toque on speed reducer pulley (N m),

T_{dr} = toque on drum pulley (N m),

N_3 = speed reducer outlet speed (rpm) and

N_4= drum speed (rpm)

From equations 3.20, 3.21, and 3.23 warp angle, lap angel and center distance for drum side belt and pulley can be calculated as showed below.

$$\sin\alpha = \frac{r_3\text{-}r_4}{x}$$

$$X = \frac{(D_3+D_4)^2}{2} + D_3$$

$$X = \frac{(0.13+0.1)^2}{2} + 0.13m$$

$$X = \frac{0.05}{2} + 0.13m$$

$$X = 0.16m$$

$$\sin\alpha = \frac{0.07\text{-}0.05}{0.16}$$

$$\sin\alpha = 0.09$$

$$\alpha = 5.38^{\circ}$$

$$\theta = (180^{\circ}\text{-}2\alpha)\frac{\pi}{180}\text{rad}$$

$$\theta = (180^{\circ}\text{-}2\times 5.38^{\circ})\frac{3.142}{180}\text{rad}$$

$$\theta = (180^{\circ}\text{-}10.76^{\circ})\times 0.02\text{rad}$$

$$\theta = 2.95\text{rad}$$

From belt tension equation 3.24

$$2.3\log\left(\frac{T_3}{T_4}\right) = \mu\,\theta$$

$$\log\left(\frac{T_3}{T_4}\right) = \frac{0.3\times 2.95}{2.3}$$

$$\log\left(\frac{T_3}{T_4}\right) = 0.39$$

$\frac{T_3}{T_4} = 2.43$…………………………………………………………………………b’

From a’ and b’

T_3 - T_4 = 92.2and T_3 = 2.43T4

$2.43T_4 – T_4 = 92.2$

$1.43T_4 = 92.2$

$T_4 = 64.48N$

$T_3 = 156.68N$

Therefore, the load on the shaft due to the pulley and belt was the sum of tension on both sides and that of the pulley load. That is 1.5kg pulley weight 1.5×9.81= 14.71N + 156.68N + 64.48N= 235.87N was weight exerted by belt and pulley on the shaft. The other weight exerted on the shaft was the weight of the drum and the maximum weight of cassava tuber loaded to the machine. From section 3.7.1.2 the total mass of the drum was 26.8 kg and the machine is designed to be loaded a maximum of 15kg. Therefore, the weight due to drum and cassava tubers was 41.8×9.81 = 410N. In the shear force and bending moment diagram, the reaction force at point R1 and R2 correspond to bearing support and can be determined as follow.

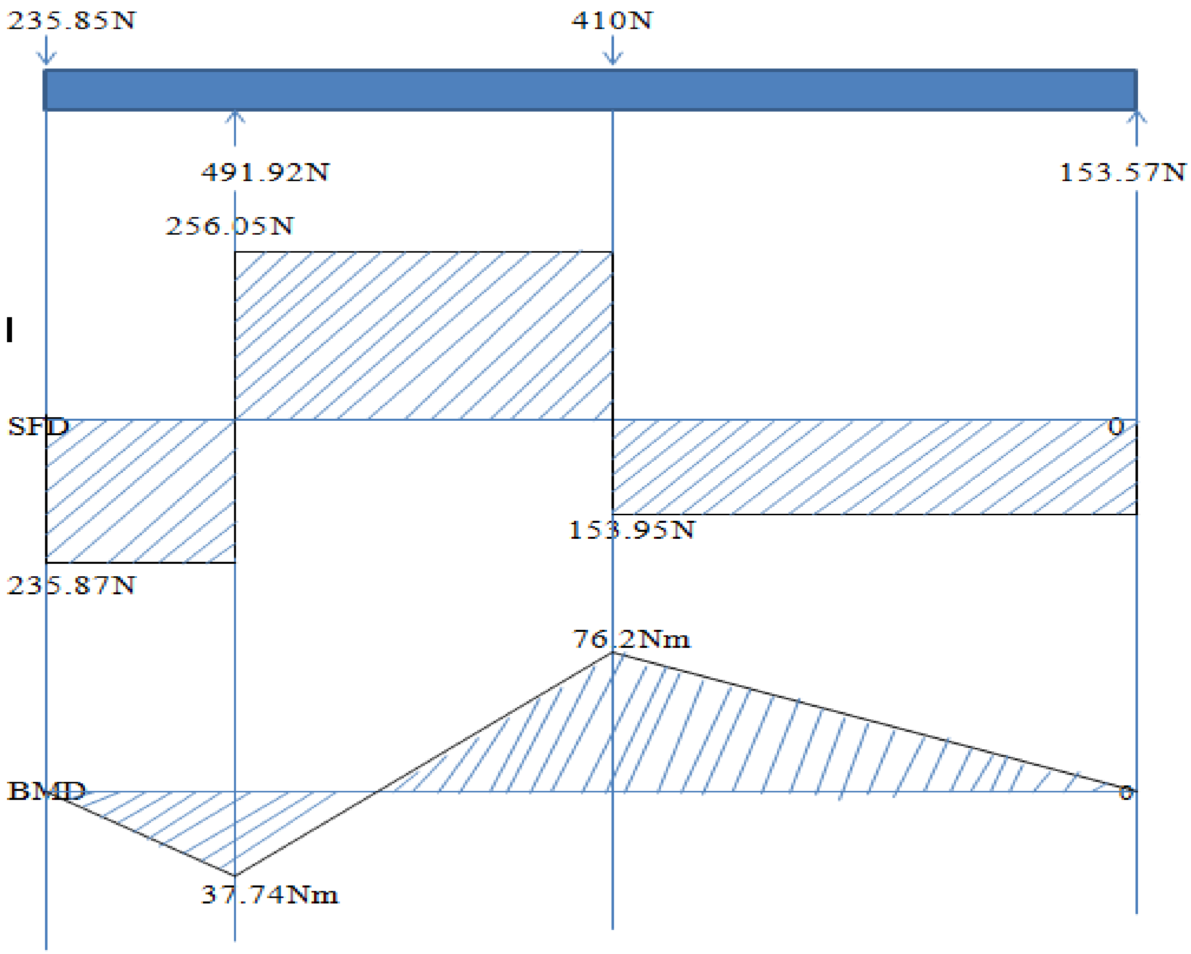


Figure 11. Shaft loading diagram for shear force and bending moment

$\sum MR_1=0$ assumes clockwise direction as positive.

410N × 0.445m –R2 (0.495+0.445) m -235.87N× 0.16m

182.45N m-37.74N m = 0.94R_2m

147.17N m = 0.94R2m

$R_2 = \dfrac{144.71\text{N m}}{0.94\text{m}}$

R_2 = 153.95N

$\sum FY = 0$

-235.87N + R_1N – 410N + 153.95N = 0

R_1 = 235.87N + 410N – 153.95N

R_1 = 491.92N

From the bending moment diagram, the maximum bending moment was Mb $=76.2\times10^3$N mm, from the torque applied on the shaft Mt =40N mm and from equation 3.17 diameter of shaft can be calculated as.

$$d^3=\frac{16}{\pi\tau all}\sqrt{(kb\ Mb)^2+(kt\ Mt)^2}$$

$$d^3=\frac{16}{3.142\times40}\sqrt{(2\times76{,}200mm)^2+(1.5\times40mm)^2}$$

$$d^3=\frac{16}{125.68}\sqrt{2.32x10^{10}mm^2+3.6x10^4mm^2}$$

$$d^3=0.13\sqrt{2.40282\times10^{10}}\ mm$$

$$d^3=0.13\times152{,}315.47mm$$

$$d=\sqrt[3]{19{,}801mm}$$

$$d = 27.05mm \approx 30mm$$

For the shaft with the keyway, the allowable stress τ should not exceed 40 MN/m^2 (Khurmi and Gupta, 2005).

The power required to rotate the shaft was determined to be 5.55watt as equation 3.25 (Gupta Khurmi and Gupta, 2005). The mass of the shaft was fined to be 6kg in section 3.8.2.

$$P = m_{sh}gr_{sh}\omega \qquad \text{……………………………………………………………………3.25}$$

$$P = 6kg\times9.81m/se\times0.25m\times6.284rad/sec$$

$$P= 5.55\ watt$$

Where: P = Power required to rotate peeling drum and shaft (watts),

g = Gravitational acceleration force (m.s^{-2}),

m_{sh}= Mass of shaft (kg),

r_{sh} = Reduce of shaft (m) and

ω = Angular velocity (rad.s-1)

3.7.3. Pulley design

Among well-known power transmission elements, Pulleys were one of the most common menaces of power transmission, indeed they require careful design. The design of the pulley according to classical v-belt was shown here. Some of the advantages of V-belts are compactness due to smaller distance between pulleys, positive drive because the slip between belt and pulley grooves are negligible, smooth drive because it was made endless, provides longer operation time up to 3 to 5 years, easy to install, and remove quiet operation of pulley and belt, and high velocity ration.

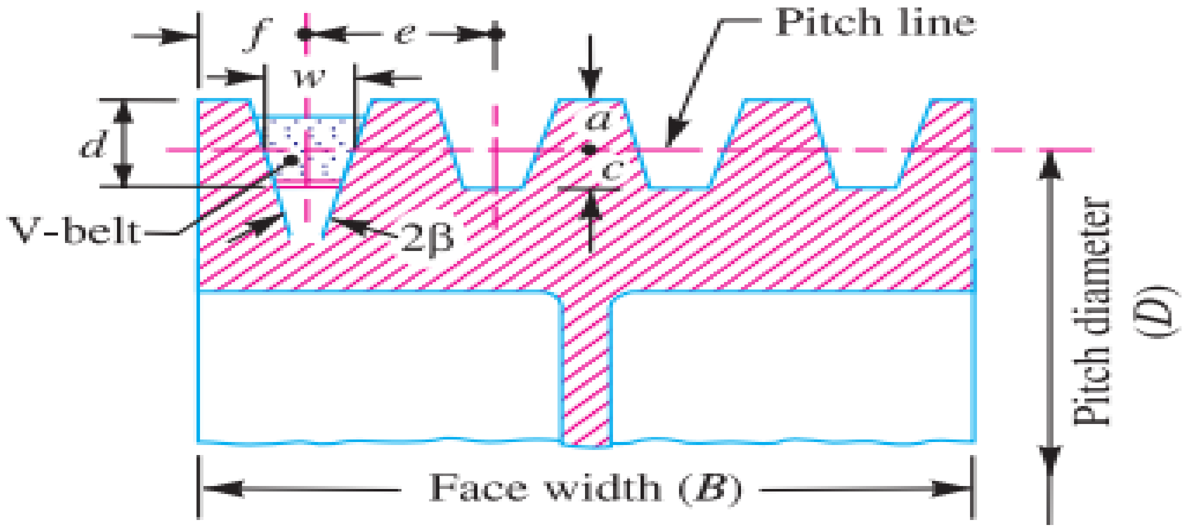


Figure 12. Cross-section of a v-groove pulley

Table 2. Dimension of standard v-grooved pulley (all dimension in mm)

Types of belt	W	D	A	C	F	E	Groove angel (2β) degree
A	11	12	3.3	8.7	10	15	32, 34, 38

Source: Khurmi and Gupta (2005).

The drive pulley gives the horsepower rating at a maximum pitch diameter of pulleys and the corresponding speeds. The horsepower rating of the motor was therefore determining the diameter of the driver pulley. The shaft speed of the speed reducer inlet pulley and the speed of the prime mover pulley was related by using equation 3.26 (Khurmi and Gupta, 2005).

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \qquad \text{3.26}$$

Where: N_1 = Angular speed of the motor (rpm),

N_2 = Angular speed of speed reducer gear driven pulley (rpm),

D_1= Maximum pitch diameter of driving or motor pulley (mm) and

D_2 = Maximum pitch diameter of driven or speed reducer gear pulley (mm).

The width of the pulley (B) was usually considered to be 25% greater than the width of belt (b) and equation 3.27 as suggested by (Richard and Nisbett, 2011) can be used to estimate the width of the pulley for the design of intended cassava tubers peeling machine.

$$B = b + 0.25b = 1.25b \qquad 3.27$$

Where: B = Width of pulley (mm) and

b = Width of belt (mm)

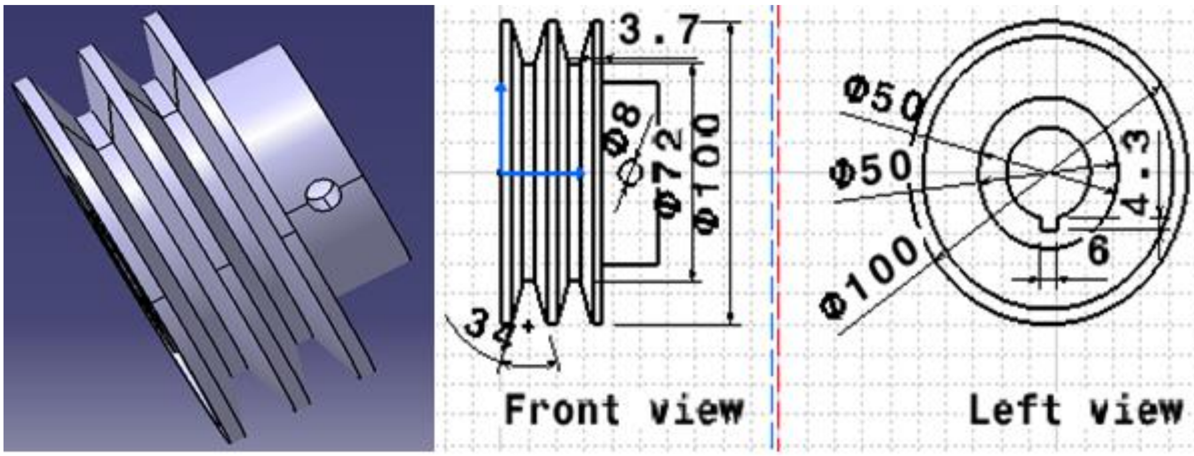


Figure 13. Pulley of the shaft

3.7.4. Drum cover design

The drum cover was made from sheet metal of 1.5mm thickness and 25mm angle iron. It has the shape of a half-cylinder and is used to protect the splash of peels and specks of dust to operator, motor and to make the area clean from peels and debris.

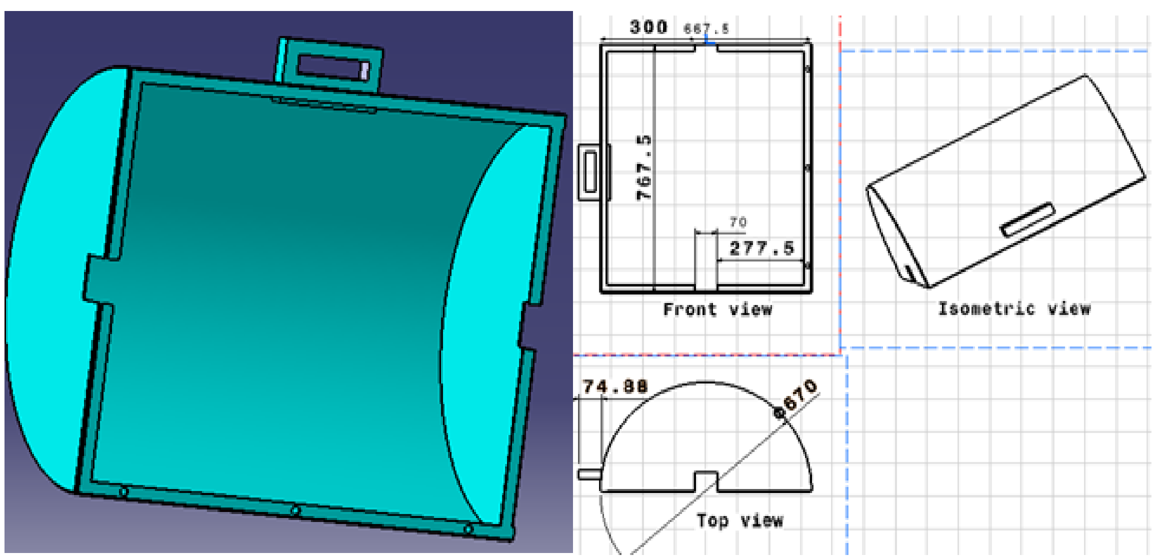


Figure 14. Drum cover

3.7.5. Protective hood design

The protective hood in figure 14 was made from 1.5mm sheet metals. It is used to protect the splashing of dust and peels to the operator and motor. The angle of inclination of the protective hood was related to the repose angle of cassava peels but it is dependent moisture content of the tubers.

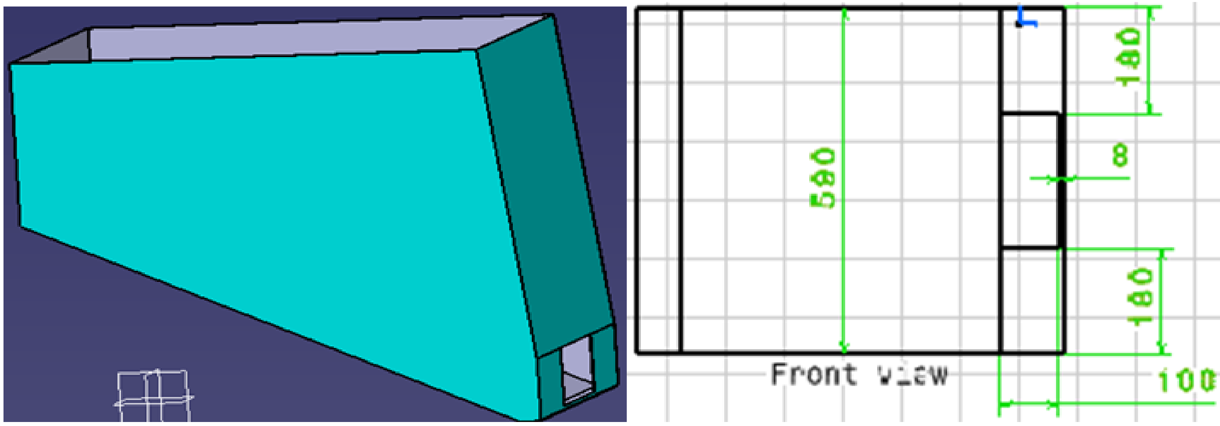


Figure 15. Protective hood

3.7.6. Frame design

The frame supports the entire weight of the peeling machine. The total weights carried by the frame include; the weight of the peeling drum, the weight of cassava tuber, the weight of drum cover, the weight of the shaft, the weight of bearings, the weight of pulleys, and belt, and the weight of the protective hood. As shown below the frame was rectangular, 770mm by 670mm, and made from hollow square section which can support the entire weight of the machine. The frame must be rigid that it can sustain static and dynamic loading (direct axial loading or torque).

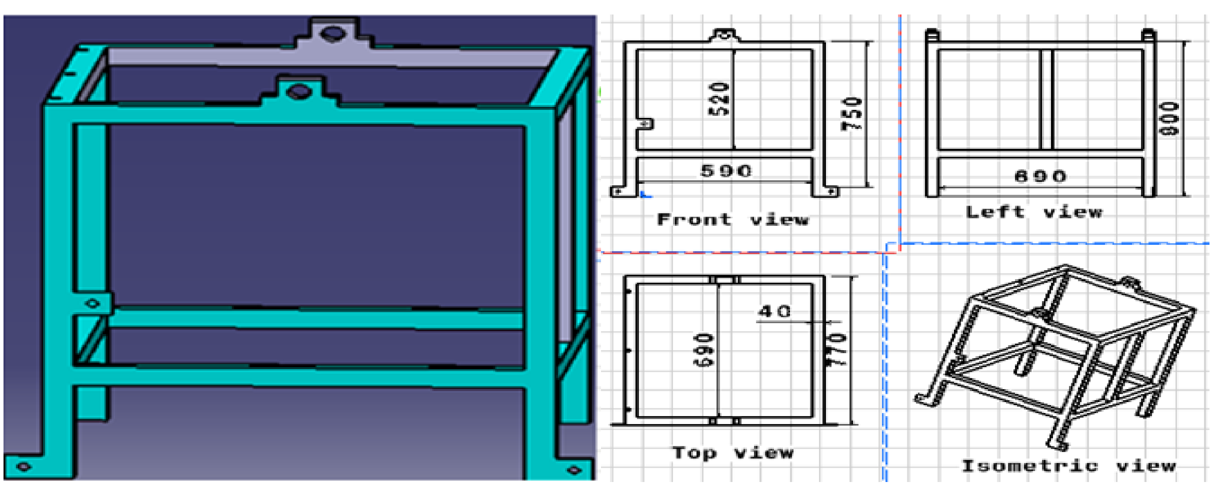


Figure 16. Frame

3.7.7. Belt selection

Selection of belt needs due integrated consideration about types, deamination of standard v-belt according to ISO 4184. Classical V-Belts are mostly used as a power transmission element in terms of economy and ease of replacement. Based on equation 3.30 and 3.31 A-section belt having the belt code 50, inner length 1270 and outer length 1300 for both motor side and drum side was chosen for the development of machine. From section 3.7.2 center distance between each pulley was calculated.

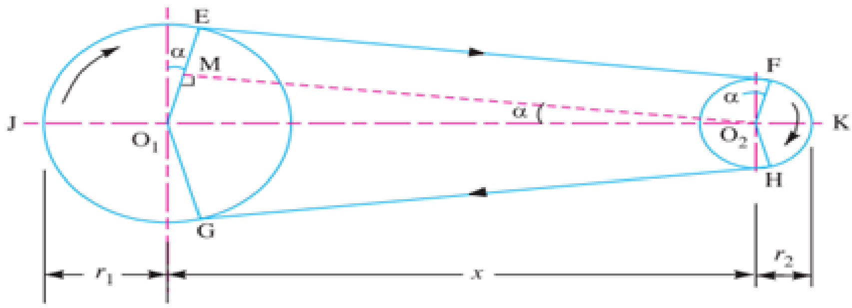


Figure 17. Belt expiration

Table 3. Dimension of standard v-belt

Types of belt	Power ranges KW	The minimum pitch diameter of pulley (D) mm	Top width (b) mm	Thickness (t) mm	Weight per meter length in newton
A	0.7-3.5	75	13	8	1.06

Source: Khurmi and Gupta (2005).

The nominal pitch length of the belt from an electric motor shaft to the speed reducer shaft and from the speed reducer shaft to the peeling drum shaft must be determined to know the actual belt size needed to transmit power from an electric motor to the peeling drum. Therefore, according to Khurmi and Gupta (2005), the nominal pitch length "L" can be determined using equation 3.28 for the motor side and equation 3.29 for drum side belt length respectively.

$$L = 2X+\frac{\pi}{2}(D_1+D_2)+\frac{(D_2-D_1)^2}{4X} \quad \text{..3.28}$$

$$L=2X+\frac{\pi}{2}(D_3+D_4) + \frac{(D_4-D_3)^2}{4X} \quad \text{..3.29}$$

Where: D_1 = Diameter of the motor pulley (mm),

D_2 = Diameter of speed reducer pulley (mm),

D_3 = Diameter of speed reducer pulley (mm),

D_4 = Diameter of shaft pulley (mm) and

X = Distance between the motor shaft pulley and speed reducer shaft pulley for motor side and distance between speed reducer shaft pulley and drum shaft pulley for drum side (mm).

Power transmitted by the V-belt and velocity of the belt can be calculated using equations 3.30 and 3.31 (Srivastava *et al*., 2006).

$$P = \frac{(T_1 - T_2)V}{1000} \qquad 3.30$$

$$V = \frac{\pi \times D \times N}{60} \qquad 3.31$$

Where: T_1 and T_2= Tight-side and slack-side tension respectively (N)

P = Power transmitted (kW)

V = Belt speed (ms^{-1})

D = Diameter of the pulley (m) and

N =Speed of pulley (rpm).

But, the power required to operate the peeling machine is the total sum of the power required to drive the peeling drum, shaft, cassava tuber inside the drum, and the power required to overcome the frictional force and can be determined using equation 3.32 (Nduka *et al*, 2012).

$$P_t = P + 0.1P \qquad 3.32$$

Where: P_t = Total power (kW).

The number of belts required to transmit the power of the motor to the drum can be determined using equation 3.33 (Khurmi and Gupta, 2005).

$$\text{number of belts required} = \frac{\text{total power transmitted}}{\text{power transmitted per belt}} \qquad 3.33$$

As the result of continuous runs of the belt over the pulleys, there was, a centrifugal force developed whose effect is to increase the tension of the belt in both tight and slack sides. However, according to Khurmi and Gupta (2005), if the speed of the belt was small (less than

10m/sec) the effect of centrifugal tension was not considered. Equation 3.34 was used to determine centrifugal tension (Khurmi and Gupta, 2005).

$$T_c = mV^2 \qquad \text{……………} 3.34$$

Where: T_c= Centrifugal tension (N)

m = Mass of belt (kg m^{-1}) and

V = Velocity of belt m (sec^{-1}).

The tight side tension can be determined using equation 3.35 (Khurmi and Gupta, 2005) suggested.

$$T_1 = T_{max} - T_c \qquad \text{……………} 3.35$$

Where: T_1 = Tight side belt tension (N)

T_{max} = Maximum tension of the belt (N) and

T_c = Centrifugal tension (N).

The maximum tension of the belt, mass of belt, and area of the belt can be estimated using equations 3.36, 3.37, and 3.48 respectively (Khurmi and Gupta, 2005).

$$T_{max} = A\sigma \qquad \text{……………} 3.36$$

$$m = \rho \times A \qquad \text{……………} 3.37$$

$$A = \frac{(b-x)}{2} t + xt \qquad \text{……………} 3.38$$

Where: T_{max} = Maximum tension of the belt (N),

A = Cross sectional area of belt (mm^2),

σ = Maximum allowable stress of belt (MPa),

m = Mass per unit length of belt (kgm^{-1}),

b = Top width of belt (mm),

x = Bottom width of belt (mm),

t = Thickness of belt (mm) and

ρ = Density of belt (kgm^{-3}).

$$L = 2X+\frac{\pi}{2}(D_1+D_2)+\frac{(D_2-D_1)^2}{4X}$$

$$L=2(0.5)+\frac{3.142}{2}(0.1+0.064)+\frac{(0.064-0.1)^2}{4(0.5)}$$

$L = 1+1.57(0.164) + 0$ m

$L = 1.26$m or

$L = 1{,}260$mm to standard $1{,}270$mm

For drum side by the same way

$$L=2X+\frac{\pi}{2}(D_3+D_4) + \frac{(D_4-D_3)^2}{4X}$$

$$L=2(0.5)+\frac{3.142}{2}\ (0.064+0.1)+\frac{(0.1-0.064)^2}{4(0.5)}$$

$L = 1+ 1.57(0.164) + 0$m

$L = 1.26$m or

$L = 1{,}260$mm make standard $1{,}270$mm

Power transmitted by V-belt was determined using equation 3.30 but the tension used to calculate the power was drum side tension that is T3 and T4. The drum side speed of the belt was, therefore, given by equation 3.31 which was corresponding to the optimum speed of drum 60rpm.

$$V=\frac{\pi\times D_4\times N_4}{60}\frac{m}{sec}$$

$$V=\frac{3.142X0.1\times 60}{60}\ m/sec$$

$V = 0.31$m/sec

$$P=\frac{(T_3-T_4)V}{1000}$$

$$P=\frac{(156.68-64.48)N\times 0.31m/sec}{1000}kw$$

$$P=\frac{(92.20)N\times 0.31m/sec}{1000}kw$$

$$P= \frac{28.58}{1000}kw$$

$P= 0.03$KW

But, from equation 3.34 total powers were given by the relation

Pt = P + 0.1P

Pt = 0.03kw + 0.1x0.03kw

Pt = 0.033kw

3.7.8. Bearing selection

A bearing can be selected based on its load-carrying capacity, life expectancy, and reliability. For selection and determination of bearing for any installation, the following are considered; radial load, thrust load, speed and diameter of the shaft, and desired life. In addition, a bearing must have a high enough load rating to provide an acceptable combination of life and reliability (Khurmi and Gupta, 2005 and Richard *et al.*, 2011). Bearing size can be determined using the maximum resultant force acting on a bearing and the desired maximum lifespan. Equation (3.39 and 3.40) can be used for analysis and selection of bearing.

$$R=\left(\sqrt{R_{BX}^{2}+R_{BY}^{2}}\right) \qquad \text{3.39}$$

And dynamic load rating can be determined using equation (3.42), (Khurmi and Gupta, 2005, Richard *et al.*, 2011).

$$C=\left((L\alpha f R\frac{N\times Hm}{10^{6}})^{\frac{1}{k}}\right) \qquad \text{3.40}$$

Where: C= basic dynamic load rating,

RBX = maximum resultant force acting on a bearing on the horizontal plane (KN),

RBY = maximum resultant force acting on a bearing at point B on the vertical plane (KN),

R = maximum resultant reaction force on the bearings at point B (KN),

N = revolution of the shaft (rpm),

Lαf = Load application factor or service factor

Hm = desired maximum lifespan of the bearings (hr),

K= 3 for ball bearing and 10/3 for roller bearings.

According to Khurmi and Gupta (2005) while selecting bearing one has to be familiar with bearing codes table 4. Therefore, for the construction of the above discussed machine a bearing coded as 206 with outer diameter of 62mm and width of 16mm was selected.

Table 4. Radial bearing numbers and their implication

Bearing code No.	Bore (mm)	Outside diameter	Width (mm)
206		62	16
306	30	72	19
406		90	23

Since the axial reaction force was not applied on the shaft $F_a = 0$ and $F_a/F_R < 0.7$, that is the type of bearing selected was SRDGBB. According to ABMA and ISO defines bearing dynamic capacity can be calculated using equation 3.41 (Edinger, 2003).

$$C=P_D\left(\frac{L}{10^6}\right)^{\frac{1}{K}} \quad \text{……………………………………}3.41$$

Where: Where, L = Rating life,

C = Basic dynamic load rating,

P_D = Design basic dynamic equivalent radial load, and

K= 3 for ball bearing.

Basic dynamic equivalent radial load (P_D) was determined using equation 3.42 (NTN, 2011).

$$P_D= PK_S \quad \text{……………………………………..}3.42$$

Where, K_s= service factor 1.5 and

P = equivalent dynamic load

The Equivalent dynamic load was estimated using equation 3.43 (Ashahi, 2016).

$$P= X\times V\times F_R+Y\times F_a \quad \text{……………………………………..}3.43$$

Where Y= axial load factor

X = radial load factor

V = rotation factor = 1, for all types of bearings, when the inner race is rotating, 1, for self-aligning bearings, when the inner race is stationary, and = 1.2, for all types of bearings except self-aligning, when the inner race is stationary.

Since the shaft rotates the inner race, the rotation factor was assumed as 1 that is v=1. The values of radial load factor (X) and axial load factor (Y) for the dynamically loaded bearings taken as $F_a/F_R = 0$, X = 1 and Y = 0 Khurmi and Gupta (2005). Thus, the equivalent dynamic load for shafts was calculated as follows.

Rating life in revolution also calculated using equation 3.44 and the estimation of life in working hours obtained as 12,000 because the life of bearing in hours (L_H) for stationary machineries is 12, 000 to 20,000 (Bsen-ds, 2018).

$$L = 60N \times L_H \qquad \text{...3.44}$$

Where, L =Rating life in revolution,

L_H=the life in working hours estimated, and

N = the shaft speed in r.p.m.

Since the optimum drum speed was 60rpm the rating life in revolution are

$$L = 60 \times 60 \times 12,000 \text{ Hr}$$

$$L = 4.32 \times 10^7 \text{ Hr}$$

3.7.9. Speed reducer gear selection

The speed reducer gear having the speed reduction ratio of 50 to 1 rpm was used to bring about the intended revolution per minute of the peeling drum. According to Egbeocha *et al.*, (2016) and (Seth, 2020) reviewed a cassava peeling machine was operated over a wide range of speed 40rpm to 700rpm and 40rpm to 1400rpm respectively.

3.7.10. Electrical motor selection

The selected electrical motor has a model number YL-802, power of 0.75KW, speed of 1450-rpm single phase motor Chinas product.

3.8. Weight of Machine Component

3.8.1. Weight of shaft

The shaft was made from a carbon steel bar with a diameter of 30 mm and length of 1.1m to determine the mass it was necessary to know about the area and volume of the shaft. The area of the metallic shaft was determined using equation 3.46 (ITSI-SU, 2011).

$$A_{Sh} = \frac{\pi D_{Sh}^2}{4} \qquad \text{...3.46}$$

$$A_{Sh} = \frac{3.142 \times 30^2}{4}$$

A_{Sh} = 706.86mm^2

Ash = 7.7 × 10^{-4}m^2

Where: A_{Sh} = Area of shaft (mm^2) and

D_{Sh} = Diameter of shaft (mm).

The volume of the shaft was determined using equation 3.47 (ITSI-SU, 2011).

$V_{Sh}=A_{Sh}\times L_{Sh}$……………………………………….…………………………......3.47

V_{Sh} = 706.95mm^2 × 1100mm

V_{Sh} = 7.77 × 10^{5}mm^3

V_{Sh} = 7.8 × 10^{-4}m^3

Where: V_{Sh} = Volume of the shaft (m^3) and

L_{Sh} = Length of the shaft (mm).

The mass of the shaft was determined using equation 3.48 (ITSI-SU, 2011).

$M_{Sh} = V_{Sh}\times \rho$…………………………………………………………………..4.48

M_{Sh} = 7.8× 10^{-4}m^3 × 7,700kgm^{-3}

M_{Sh} = 6kg

Where: M_{Sh} = Mass of the shaft (kg),

V_{Sh} = Volume of shaft (kgm^{-3}) and

ρ = Density of carbon steel (7,700kgm^{-3}).

The weight of the shaft was determined using equation 3.49 (Gat, 1988).

$W_{Sh} = M_{Sh} \times g$……………………..………………………………………………4.49

W_{Sh} = 6kg × 9.81msec^{-2}

W_{Sh} = 58.92N

Where: W_{Sh} =Weight of shaft (N) and

g = Acceleration due to gravity (m/sec^2)

3.8.2. Weight of pulley

The area of the pulley was calculated by considering the shape and dimension during design. The volume of the pulley was calculated using equation 3.50 (ITSI-SU, 2011).

$$V_p = \left(\left(\pi r_1 - \pi r_2\right) \times t\right) - \left(\frac{1}{2} a \times b \times h\right) + (a \times b \times h) \quad \text{.......3.50}$$

Where: V_p = Volume of pulley (mm),

r_1= Reduce of pulley (mm),

r_2 = Reduce of the shaft (mm) and

t = Thickness of pulley (mm).

The mass of the pulley was estimated using equation 3.51 (ITSI-SU, 2011). But in this, the mass of the pulley was directly measured using a weighing balance.

$$M_p = Vp \times \rho \qquad \text{3.51}$$

Where: Mp = Mass of pulley (kg) and

ρ = Density of aluminum (2,710 kgm^{-3}).

The weight of the pulley was calculated using equation 3.52 (Gat, 1988).

$$Wp = Mp \times g \qquad \text{3.52}$$

Where: Wp = Weight of aluminum (N),

Mp = Mass of aluminum (kg) and

g = Acceleration due to gravity (m/sec^2).

3.8.3. Weight of belt

The belt weight in unit meter length by newton was given in section 3.7.7 table 3, and from equations 3.30 and 3.31, the belt length was calculated to be 1,270mm. The weight of the belt was thus, 2.692N.

3.8.4. Weight of drum

The drum was made from a set of perforated stainless sheet metal plates both rectangular and circular. The mass of the drum was determined in section 3.7.1.2; the weight of the drum was thus calculated to be 262.9N by using equation 3.53 (Gat, 1988).

$$Wd = Md \times g \qquad \text{3.53}$$

Where: Wd = Weight of drum (N),

Md = Mass of drum (kg) and

g = Acceleration due to gravity (m/sec^2).

3.9. Experimental Procedure

Before the actual test of the developed machine, a preliminary test was conducted at three levels of drum speed, (30, 60 and, 90rpm) and three-level of a drum fill, (10, 15, and 20%). Accordingly, at drum speed of 30 and 60rpm and corresponding percentage drum fill of 10, 15, and 20% the developed machine would peel cassava tubers at different peeling efficiency, percentage flesh loss, and throughput capacity. Whereas, at drum speed 90rpm the developed machine would not considerably peel cassava tubers at leasted percentage drum fill in specified retention time. From this situation, the researcher examined that at high speed the cassava tuber in the drum can be collected to the center of the drum along the shaft due to the action of centripetal force.

Thus, from the above situation, it was observed that slow speed was performing better. At the same time during the preliminary test, the machine was looked for unwanted sounds, vibration, uneven rotation of the drum, the sleep of the belt, and overall stability of the machine. The test was carried out at the MARC using freshly harvested cassava from farms of Wolayta zone, Wolayta zuria woreda. A total of 195kg of fresh cassava tubers *Hawassa-4* variety free from damage, scratches, deterioration, and abrasion were used for the entire test run. *Hawassa-4* variety was selected because of its availability and well known for its high production characteristics in the Wolayta zone.

The cassava tubers were sorted out based on the length and cut to an average length of 30 cm. Five pulley sizes (two 64 mm, two 100 mm, and one 130mm) were used for speed variation of 30rpm and 60rpm; Stopwatch, digital weighing balance, digital Varner caliper, knife, and meter rule were used in experimenting. The machine was run using a 30 and 60rpm pulley's arrangement for 10, 15, and 20% drum fill and the data was collected from the result obtained. The performance of the machine was then evaluated in terms of peeling efficiency, throughput capacity, and flesh loss. The data collected during the entire test run was found in appendix C.

3.10. Testing and Performance Evaluation of Cassava Peeler

3.10.1. Experimental design

The experiment was carried out by randomized block design (RBD) with drum speed as a blocking factor and percentage of drum fill as a treatment. The experiment was repeated three times to have 18 experimental units (2×3×3=18).

3.10.2. Variables and data collection

3.10.2.1. Independent variables

The independent variables are drum speed (30 rpm and 60rpm) and percentage drum fill (10%, 15%, and 20%).

3.10.2.2. Dependent variables

- Peeling efficiency (%)
- Throughput capacity (kgh^{-1})
- Percentage mass of flesh loss

3.11. Performance Evaluation of Cassava Peeler

During the peeling operation, some parts of the cassava may remain unpeeled due to the irregular nature of cassava tuber shapes, shorter peeling time, and delimitation of the machine. Therefore, it is important to categorize machine operational variables as the dependent variable and independent variable. Variables like peeling efficiency, tuber flesh losses, and throughput capacity were considered as dependent variables and used to evaluate the performance of the developed machine, while machine variables such as peeling drum speed and percentage drum fill were considered as independent variables.

3.11.1. Peeling efficiency

The peeling efficiency of the cassava peeler machine was determined based on how much cassava tuber peels were collected at the outlet of the machine and how much cassava peels were removed by hand. It was estimated based on the proportion of the mass of cassava peels removed by the machine to the sum of cassava peels removed by the machine and by hands. Equation 3.51 was used to determine the peeling efficiency of the designed cassava peeler machine.

$$\text{peeling efficiency}(n) = \frac{M_{pls}}{M_{prh}+M_{pls}} \times 100 \qquad 3.51$$

Where: M_{pls} = Mass of cassava peels collected at the outlet of the machine in (kg) and

M_{prh} = Mass of cassava peels removed by hand after machine peeling in (kg).

3.11.2. Throughput capacity

Throughput capacities of the cassava peeler were determined based on the amount of cassava tuber peeled at the specified period using equation 3.52.

$$\text{Throughput}(Tc) = \frac{M_t}{T} \qquad 3.52$$

Where: M_t = Mass of cassava feed to the machine in (kg) and

T = Time taken for cassava and its peels to completely leave the machine in hours.

3.11.3. Percentage mass of flesh loss

Percentage mass of flesh loss of cassava peeling machine depends on proportion mass of flesh tuber loosest with peels to the sum of the mass of peeled cassava by machine and hand, minus the mass of peels of cassava peeled by hand. Equation 3.53 was used to estimate the percentage mass of flesh loss.

$$\%\text{mass of flesh loss} = \frac{M_f}{M_{tf}} \times 100 \qquad 3.53$$

Where: M_f = Mass of flesh cassava removed along with the peels by the machine in kg and

M_{tf} = Total mass of flesh tubers in kg.

3.11.4. Percentage mass of peeled cassava

The percentage mass of peeled cassava depends on the proportion mass of cassava tubers peeled by the machine to the total mass of cassava tuber feed to the machine. Equation 3.54 was used to estimate the percentage mass of peeled cassava.

$$\%\text{mass of peeled cassava} = \frac{M_p}{M_t} \times 100 \qquad 3.54$$

Where: M_p = Mass of completely peeled cassava (kg) and

M_t = Total mass of cassava feed to machine (kg).

3.11.5. Percentage mass of peels of cassava

The percentage mass of peels of cassava depends on the proportion mass of peels of cassava peeled by the machine and peeled by hand to the total mass of cassava tuber feed to the machine. Equation 3.55 was used to estimate the percentage mass of peels of cassava.

$$\%\text{mass of peels of cassava} = \frac{M_{pls}+M_{prh}}{M_t} \text{x}100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.55$$

Where: M_{pls} = Mass of cassava peels collected at the outlet of the machine (kg),

M_{prh} = Mass of cassava peels removed by hand after machine peeling (kg) and

M_t = total mass of cassava feed to machine (kg).

3.11.6 Percentage mass of unpeeled cassava

The percentage mass of unpeeled cassava depends on the proportion mass of unpeeled cassava to the total mass of cassava tuber feed to the machine. Equation 3.56 was used to estimate the percentage mass of unpeeled cassava.

$$\%\text{mass of unpeeled cassava} = \frac{M_u}{M_t} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.56$$

Where: Mu = Mass of unpeeled cassava in (kg) and

M_t = Mass of cassava fed into the machine in (kg)

3.12. Economic Analysis

The economic analysis of the developed cassava tuber peeler was analyzed in terms of the cost of the machine and the cost-benefit relationship as in appendix B.

3.13. Statistical Data Analysis

The collected data were analyzed using SPSS (statistical packages for social sciences) statistical software version 25. Alternative hypotheses were used to answer the research equation. The research equation used in the analyses of the data shows whether there was a relationship between independent and dependent variables. Confidence intervals of 95% were used to show the significance of the relationship between variables; $p < 0.05$ indicated that the relationship was significant.

CHAPTER FOUR

4. RESULT AND DISCUSSION

In this section, the effect of selected variables on peeling efficiency, percentage flesh loss, and throughput capacity was discussed. The result obtained from the developed cassava peeling machine and the result from related cassava peeling machines were discussed in this section. The data normality and linearity also emphasized.

4.1. Details of Electrical Motor Operated Cassava Peeling Machine

The developed cassava-peeling machine works on the principles of abrasion and consists of a drum, speed-reducing gear, a set of pulley arrangements that were used to rotate the drum by predetermined revolution per meter, and others. The drum was made from internally perforated stainless steel sheet metal to have a volume of $1.11\times10^{-1}m^3$. The speed reducer gear with a gear reduction ratio of 50:1 was assembled in the middle of the electrical motor and drum to reduce the speed of the electrical motor. There are five pulleys used to vary the revolution per meter of the drum to 30 and 60rpm. The optimum flesh loss of about 4% and throughput capacity of $120kgh^{-1}$ of the developed machine was better than that of Alhassan *et al*, (2018) with flesh loss of about 5% and throughput capacity of $31kgh^{-1}$ being powered 3hp electrical motor.

4.2. Performance Test of Cassava Peeler

4.2.1. Peeling efficiency (n)

This study was conducted to test if peeling drum speed (PDS) and percentage of drum fill (PDF) affect peeling efficiency (n) of the machine. It was hypothesized that peeling drum speed and percentage of drum fill has a significant impact on peeling efficiency. To test these hypotheses, multiple regression analysis was used. The result showed that 69.4% of peeling efficiency was accounted for by two factors collectively, F (2, 15) = 17.025, p = 0.00. Looking at individual contribution of the predictors, the result showed that peeling drum speed (β = 0.747, t = 5.228, p = 0.00) positively affect the peeling efficiency and the percentage of drum fill (β = -0.37, t = -2.591, p = 0.02) negatively affect the peeling efficiency of the developed cassava peeler machine; both peeling drum speed and percentage drum fill significantly affect the peeling efficiency of the machine, ($p < 0.05$). The predicted peeling efficiency is equals to 75.481 + 8.772 (PDS) + -2.633 (PDF).

As is shown, the regression equation increasing peeling drum speed by a unit would increase the peeling efficiency by 8.772, whereas increasing the percentage drum fill by a unit will result in decreasing peeling efficiency by 2.633. This is because increasing drum speed means that increasing the chance of cassava tubers in the drum to physically contact the perforated edge of the drum while increasing percentage drum fill means that reducing the chance of cassava tubers to physically contact with the perforated edge of the drum.   Table 7 shows the summary of the finding. The effect of peeling drum speed at varying percentage drum fill was discussed using a graph as shown in figure 17. As shown on the graph both minimum peeling efficiency (77.97%) and maximum peeling efficiency (94.87%) were recorded at 10% drum fill but at 30rpm and 60rpm drum speed respectively. However, at 15% and 20% drum fill the corresponding values of peeling efficiency of the machine were not influenced by drum speed like that of 10% drum fill.

Table 5. Integrated effect of peeling drum speed and percentage drum fill on peeling efficiency

Hypothesis	Regression weight	Beta Coefficient	t-value	p-value	Hypothesis supported
H_1	PDS $\rightarrow$ n	0.747	5.228	0.00	YES
H_2	PDF $\rightarrow$ n	-0.37	-2.591	0.02	YES

H_1 and H_2 = hypothesis 1 and hypothesis 2 respectively, PDS = peeling drum speed, n = peeling efficiency, PDF = percentage drum, fill.

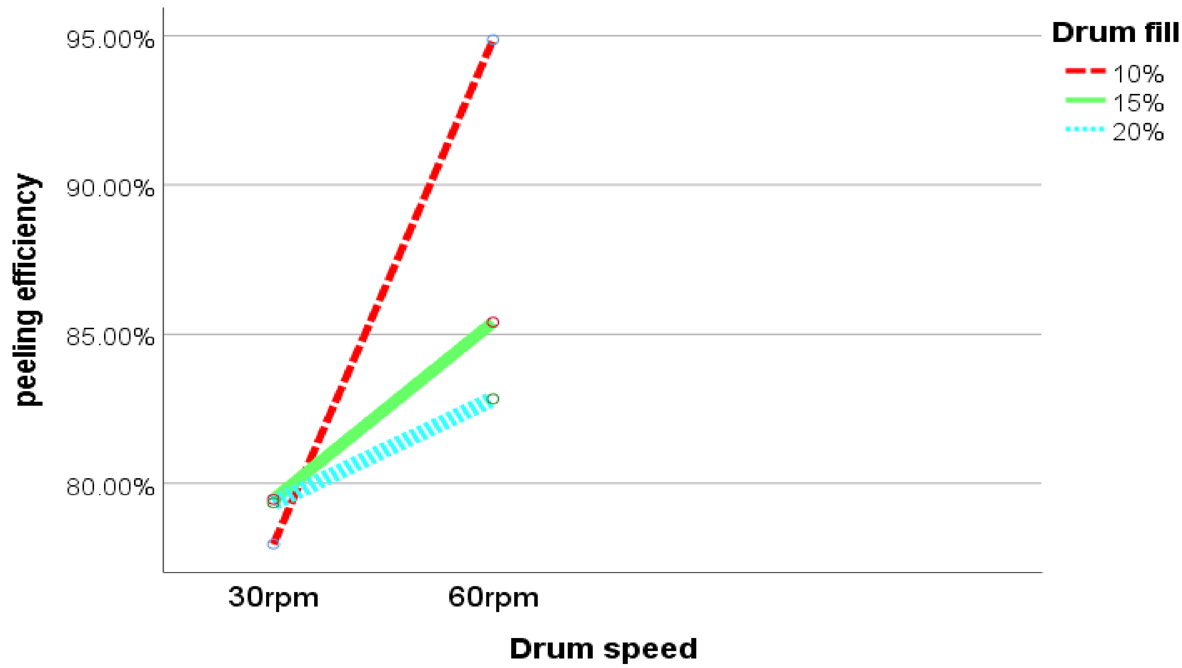


Figure 18. Effect of drum speed and drum fill on peeling efficiency

The normality and linearity of the data were shown on standardized residual histograms figure 18. Accordingly, the bell-shaped symmetrical curve is observed having a maximum score at the middle and minimum score at the edges. Thus, from the graph, it has recognized that there are no normality and linearity-related issues.

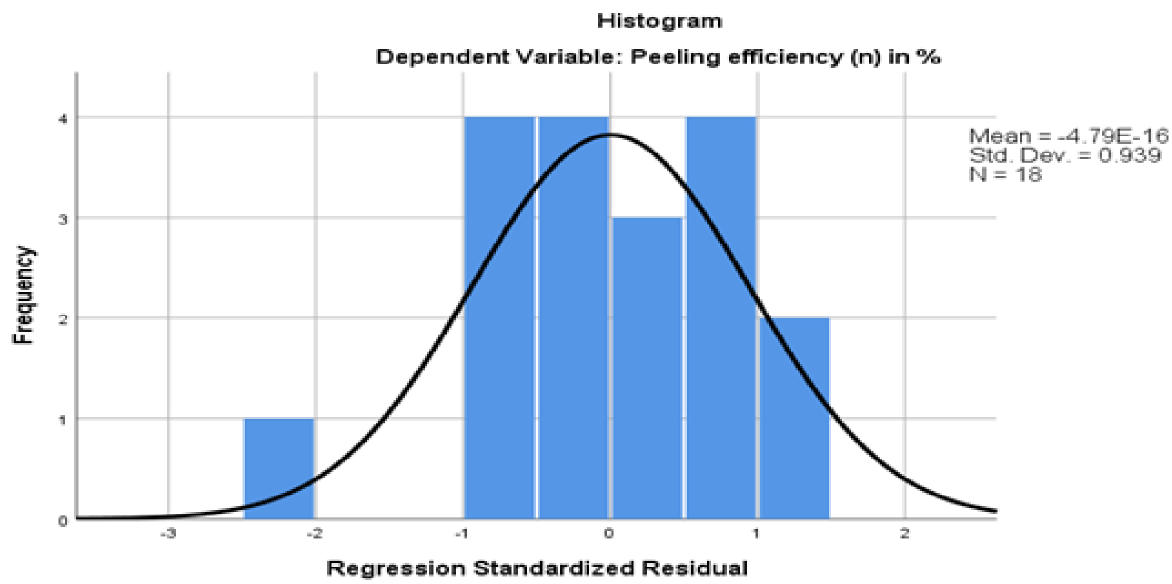


Figure 19. Standardized residual histogram for peeling efficiency

4.2.2. Percentage mass of flesh loss

This study was conducted to test if peeling drum speed (PDS) and percentage of drum fill (PDF) affect the percentage mass of flesh loss of the developed machine. It was hypothesized that peeling drum speed and percentage of drum fill has a significant impact on the percentage mass of flesh loss. To test these hypotheses, multiple regression analysis was used. The result showed that 74.8% of the percentage of flesh loss was accounted for by two factors collectively, F (2, 15) = 22.234, p = 0.00. Looking at individual contribution of the predictors, the result showed that peeling drum speed (β = 0.799, t = 6.165, p = 0.00) negatively affect the percentage flesh loss and the percentage of drum fill (β = -0.33, t = -2.542, p = 0.023) positively affect the percentage mass of flesh loss of cassava peeler machine; both peeling drum speed and percentage drum fill significantly affect percentage mass of flesh loss, ($p < 0.05$). The predicted percentage mass of flesh loss is equals to 1.067 + 3.367 (PDS) + -0.85 (PDF).

As shown on the regression equation per unit increase in peeling drum speed will increase the percentage flesh loss by 3.367, whereas a unit increase in percentage drum fill would result in the reduction of percentage mass of flesh loss by 0.85. This is because increasing drum speed means that increasing the chance of cassava tubers in the drum to physically contact with the perforated edge of the drum which would result in over peeling and meanwhile it would cause the starchy flesh of the tubers to be removed along with the peels while increasing percentage drum fill mean that reducing the chance of cassava tubers to physically contact with the perforated edge of the drum that would result in reduced percentage flesh loss. Table 8 shows the summary of the finding. The effect of peeling drum speed at varying percentage drum was discussed using the graph as shown in figure 19. As shown on the graph both minimum percentage mass of flesh loss 2.2% and the maximum percentage mass of flesh loss 7.8% was recorded at 10% peeling drum fill but 30 and 60rpm peeling drum speed respectively.

Table 6. Integrated effect of peeling drum speed and drum fill on percentage mass of flesh loss

Hypothesis	Regression weight	Beta Coefficient	t-value	p-value	Hypothesis supported
H_3	PDS $\rightarrow$ MF	0.799	6.165	0.00	YES
H_4	PDF $\rightarrow$ MF	-0.33	-2.542	0.023	YES

H_3 and H_4 = hypothesis 3 and hypothesis 4 respectively, PDS = peeling drum speed, MF= percentage mass of flesh loss, PDF = percentage drum fill.

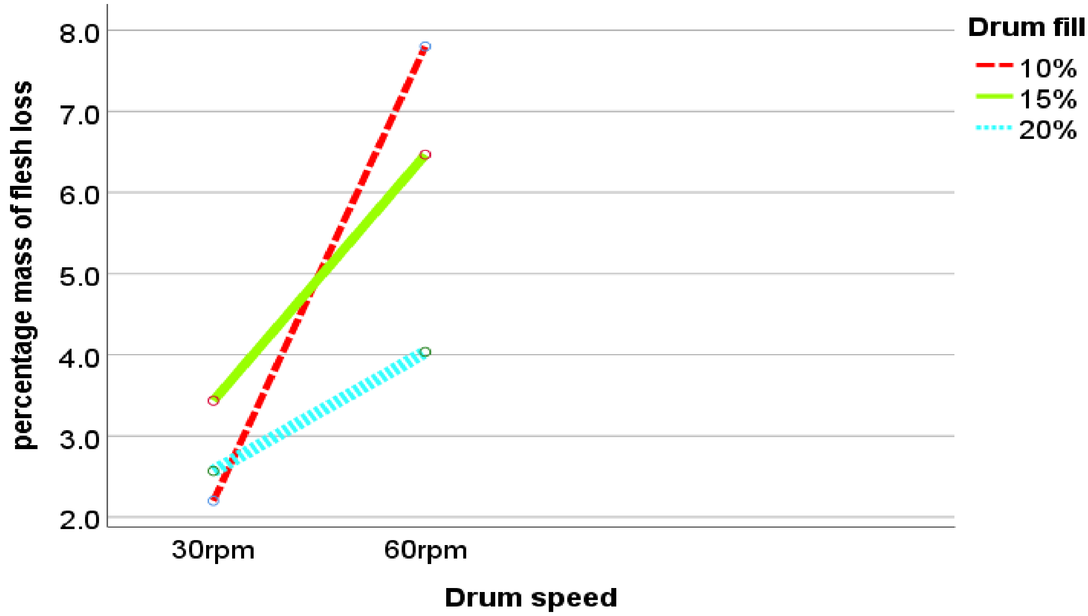


Figure 20. Effect of drum speed and drum fill on percentage flesh loss

The normality and linearity of the data shown from standardized residual histograms figure 20, accordingly, the bell-shaped symmetrical curve is observed having a maximum score at the middle and minimum score at the edges. Thus, from the graph it's recognized that there is no normality and linearity related issues.

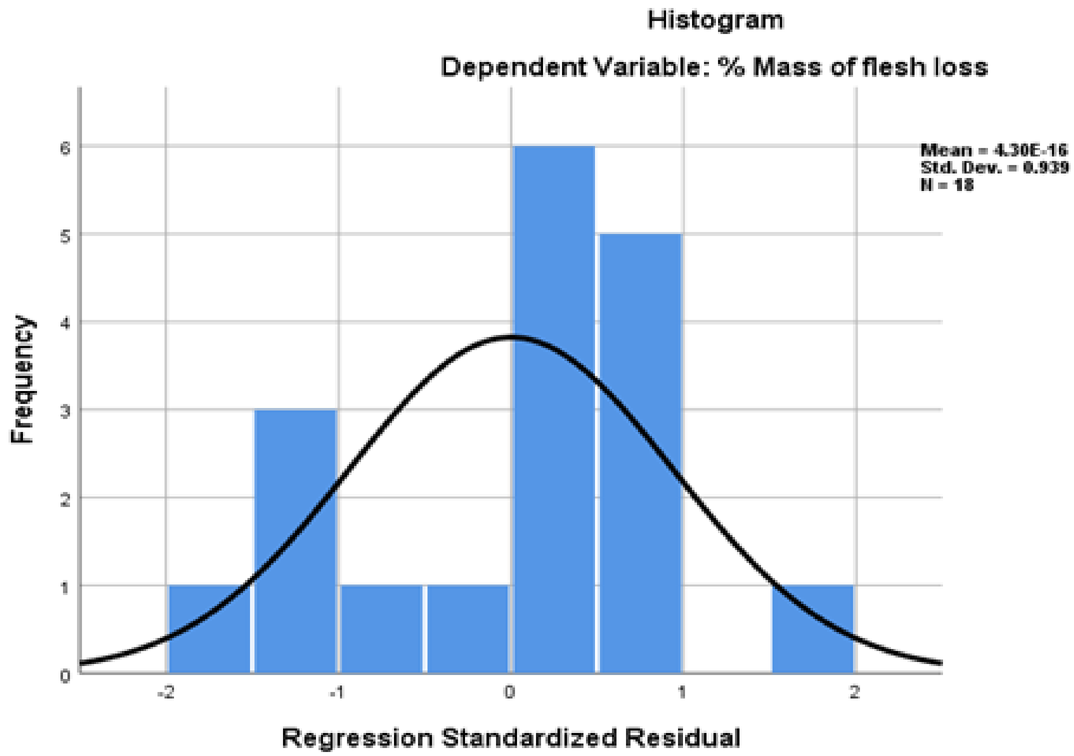


Figure 21 Standardized residual histogram for percentage mass of flesh loss

4.2.3. Throughput capacity

This study was conducted to test if peeling drum speed and percentage mass of drum fill affect the throughput capacity of the developed machine. It was hypothesized that peeling drum speed and percentage of drum fill has a significant impact on throughput capacity. To test these hypotheses, multiple regression analysis was carried out. The result showed that 100% of throughput capacity was accounted for by a single factor that is percentage drum fill. On the other hand, drum speed cannot have any effect on the throughput capacity of the developed cassava peeling machine. The predicted throughput capacity is equals to 30 + 0.00 (PDS) + 30.00 (PDF). As it was shown on the regression equation above peeling drum speed has zero effect on the throughput capacity of the machine, this was because the machine was batch filled and rotated by peer determined revolution per minute for a seated time, whereas per unit increase in percentage drum fill would result in increasing throughput capacity by 30. Table 9 shows the summary of the finding.

Table 7. Integrated effect of peeling drum speed and drum fill on throughput capacity.

Hypothesis	Regression weight	Beta Coefficient	t-value	p-value	Hypothesis supported
H_5	PDS → TC	0.00	0.00	1.00	NO
H_6	PDF → TC	1	-	0.00	YES

H_5 and H_6 = hypothesis 5 and hypothesis 6 respectively, PDS = peeling drum speed, TC= throughput capacity, and PDF = percentage drum fill.

The effect of peeling drum speed at varying percentage drum fill was discussed using a graph as shown in figure 21. As shown on the graph minimum throughput capacity of 60kgh^{-1} was recorded at 10% drum fill independent of peeling drum speed, whereas the maximum throughput capacity 120kgh^{-1} was recorded at 20% drum fill independent of peeling drum speed.

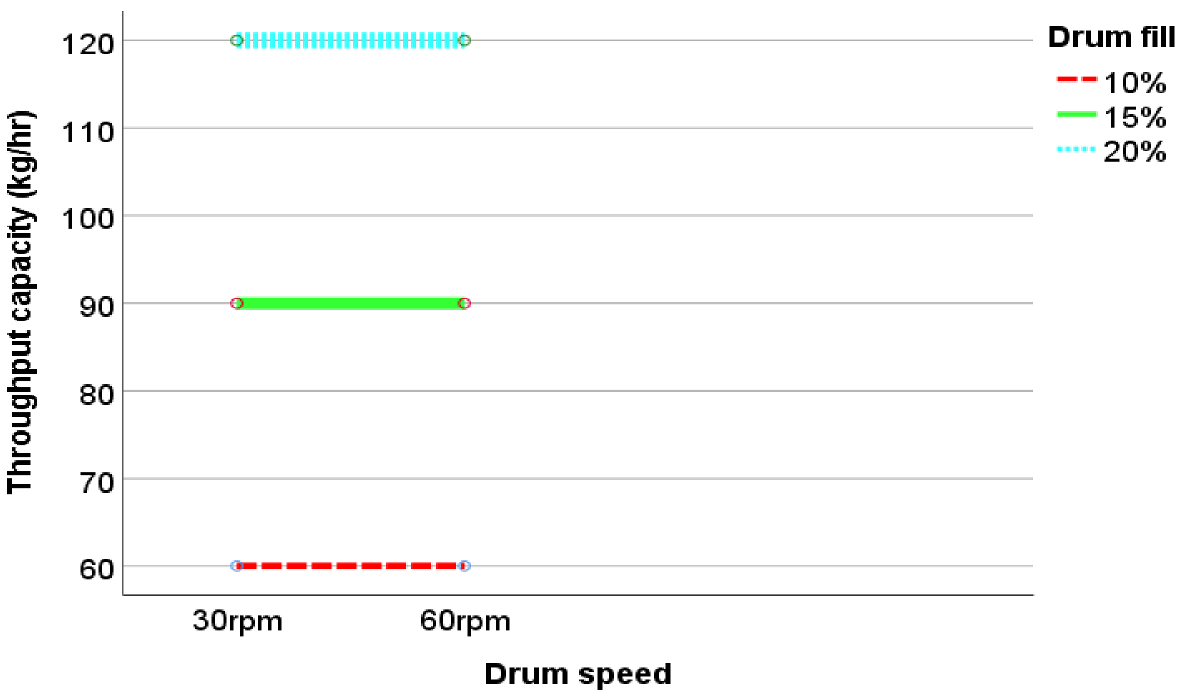


Figure 22. Effect of drum speed and drum fill on throughput capacity

4.3. Summary of Result and Discussion

In sections 4.3.1 to 4.3.3, the researcher discussed the result obtained from multiple regression based on the effect of an independent variable over a dependent variable. In addition, the data normality and linearity were discussed using the graph. Whereas, in this section, the optimum working condition for developed cassava peeling machines was discussed. Accordingly, using the data obtained from descriptive statistics, in table 10 the effect of an independent variable over the dependent variable. The optimum working condition for the developed machine was decided to be peeling efficiency, percentage flesh loss, and throughput capacity corresponding to 60rpm drum speed and 20% peeling drum fill. As we have seen from table 10 the maximum peeling efficiency of 94.867% was recorded at the point corresponding to 60rpm peeling drum speed and 10% peeling drum fill; at the same point, the values of percentage mass of flesh loss were at their maximum of 7.8%, in addition, the values of throughput capacity were at its minimum 60kgh^{-1} so that, the maximum peeling efficiency 94.867% was no way to be the efficiency of the developed machine. In line with this, the second maximum peeling efficiency of 85.4% was recorded at the point corresponding to 60rpm peeling drum speed and 15% peeling drum fill; at the same point the values of percentage mass of flesh loss at its second maximum point 6.467%, in addition, the values of throughput capacity was moderate 90kgh^{-1} but, when compared with 120kgh^{-1} it is still lesser.

Table 8. The effect of independent variables over dependent variables

Descriptive Statistics					
	Drum speed	drum fill	Mean	Std. Deviation	N
peeling efficiency (n) in %	30rpm	10%	77.9667%	3.36204%	3
		15%	79.4667%	0.64291%	3
		20%	79.3500%	0.31225%	3
	60rpm	10%	94.8667%	0.90738%	3
		15%	85.4000%	0.98489%	3
		20%	82.8333%	1.15902%	3
% mass of flesh loss	30rpm	10%	2.200	.3606	3
		15%	3.433	.3786	3
		20%	2.567	.3215	3
	60rpm	10%	7.800	1.0440	3
		15%	6.467	.4726	3
		20%	4.033	.7506	3
Throughput capacity (Tc) in kgh^{-1}	30rpm	10%	60.00	.000	3
		15%	90.00	.000	3
		20%	120.00	.000	3
	60rpm	10%	60.00	.000	3
		15%	90.00	.000	3
		20%	120.00	.000	3

CHAPTER FIFE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

In Ethiopia, cassava tuber production for consumption and income generation was not popular as the rest of the world; yet, the country has a potential for cassava tuber production and the tubes have the potential to tackle food insecurity. Nonetheless, in SNNPR there was better production and consumption of cassava tuber than in the rest regions of the country. In my observation at present time, cassava peeling was undertaken manually through intensive labor input, exhaustive and long day work. Furthermore, manual cassava peeling is costly, time-consuming, inefficient, and exposed human skin for mold growth. Moreover, a major percentage of toxic element hydrogen cyanide which was responsible for cassava toxicity was present in the cassava peels.

In the way to solve the problems encountered in cassava peeling processes, electrical motor-operated cassava peeling machine was designed, developed, tested, and evaluated. The cassava peeler machine has a rotating drum with an opening inlet and outlet door, a protective hood (drum cover and means to guide peels out), and a motor setup and supporting frame.

The physical properties of cassava tuber important for designing cassava peeler were studied. The study showed that the mean major, intermediate and minor diameters for smaller *Hawassa-4* variety cassava tuber were 8, 15, and 18mm. The mean geometric diameter, sphericity, and bulk density of the same variety cassava tuber were 12.91mm, 0.86, and 667kgm^{-3} respectively.

The performance of the developed cassava peeling machine was evaluated in terms of peeling efficiency (%), the mass of flesh loss (%), and throughput capacity (kghr^{-1}). The test was carried out at 30 and 60 rpm peeling drum speed and 10, 15, and 20% drum fill by holding the operation at 7 minutes. 7-minute retention time was selected during the result obtained at the preliminary test of the machine. The maximum peeling efficiency of 94.87% of developed cassava peeling machines was recorded when the machine was operated at 60rpm drum speed, 10% drum fill, and 7 minutes retention time. At this operating condition percentage mass of flesh loss and throughput capacity was found to be 7.8% and 60kgh^{-1} respective, (Table 10).

The maximum throughput capacity of 120kghr^{-1} was recorded at 20% drum fill independent of drum speed. The maximum tuber flesh loss of 7.8% on the other hand was recorded when drum speed was 60rpm and the drum is filled at 10%.

There was a direct relationship between percentage drum fill and throughput capacity. However, the relationship between peeling drum speed and peeling efficiency, percentage drum fill and peeling efficiency, peeling drum speed and percentage mass of flesh loss, and percentage drum fill and percentage mass of flesh loss were not directly interrelated. Testing and performance evaluation of developed cassava peeler machine was conducted to determine the effect of peeling drum speed and percentage drum fill on peeling efficiency, percentage mass of flesh loss, and throughput capacity of the machine by keeping retention time constant.

The optimum operating conditions were determined by considering measurement made and analysis carried out. Accordingly, the following conclusions were made.

- The drum speed has a significant effect on the peeling efficiency of the cassava-peeling machine.
- Percentage drum fill has the least effect on the peeling efficiency of a cassava-peeling machine.
- The drum speed does not affect the throughput capacity of a cassava-peeling machine.
- Drum speed has a significant effect on the percentage mass of flesh loss of a cassava-peeling machine.
- Percentage drum fill has the least effect on percentage mass of flesh loss
- Percentage drum fill has a direct effect on the throughput capacity of a cassava-peeling machine.

5.2. Recommendations

The developed cassava tuber peeler was able to be more efficient at peeling drum speed of 60rpm and 20% drum fill holding retention time for 7 minutes. Nonetheless, it is recommended that:

- The machine should be re-evaluated at more peeling drum speed, percentage drum fill, and retention time.
- The machine should be tested by a different variety of cassava tubers.
- The peeling drum should be incorporated with sharp blades.
- The clearance between the plates forming the drum should be re-adjusted.
- The machine should be washing supported.

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APPENDICES A

A) Physical properties of cassava sample calculation.

1) Moisture content

$$M_C = \frac{Ww\text{-}Wd}{Ww} \times 100$$

1.1) $M_C = \frac{60.4-27.2}{60.4} \times 100$

$M_c = 54.97\%$

1.2) $M_C = \frac{75.7-33.6}{75.7} \times 100$

Mc = 55.61%

1.3) $M_C = \frac{73.3-32.8}{73.3} \times 100$

Mc = 55.25%

The mean value of moisture content was

$$M_C = \frac{54.97+55.61+55.25}{3}$$

Mc = 55.28%

2) Geometric mean diameter (mm)

To determine GMD the test was conducted three times and the mean values were taken.

$GMD = (a \times b \times c)^{1/3}$

2.1) $GMD = \sqrt[3]{14 \times 16 \times 8}$

GMD = 12.15

2.2) $GMD = \sqrt[3]{16 \times 19 \times 9}$

GMD = 13.99

2.3) $GMD = \sqrt[3]{15 \times 19 \times 7}$

GMD = 12.59

The mean values of GMD = $\frac{12.15+13.99+12.59}{3}$

The mean values of GMD = $\frac{38.73}{3} = 12.91$

3) Sphericity

$$\text{sphericity} = \frac{GMD}{a}$$

$$3.1)\ \text{sphericity} = \frac{12.15\text{mm}}{14\text{mm}} = 0.87$$

$$3.2)\ \text{sphericity} = \frac{13.99\text{mm}}{16\text{mm}} = 0.87$$

$$3.3)\ \text{sphericity} = \frac{12.59\text{mm}}{15\text{mm}} = 0.84$$

$$\text{The mean values of sphericity} = \frac{0.87+0.87+0.84}{3}$$

$$\text{The mean of sphericity} = \frac{2.58}{3} = 0.86$$

4) Bulk density (ρb)

$$\rho b = \frac{Mb}{Vc}$$

$$4.1)\rho b = \frac{12{,}000\text{kg}}{18\text{m}^3} = 667\text{kgm}^{-3}$$

$$4.2)\rho b = \frac{11{,}500\text{kg}}{18\text{m}^3} = 639\text{kgm}^{-3}$$

$$4.3)\ \rho b = \frac{12{,}500\text{kg}}{18\text{m}^3} = 694.4\text{kgm}^{-3}$$

$$\rho b = \frac{(667+639+694.4)\text{g}}{18\text{cm}^3} = 666.8 \approx 667\text{kgm}^{-3}$$

$\rho b = 667\text{kgm}^{-3}$.

B) Peeling machine part calculation

1) Drum volume calculation

$$V = \pi r^2 h$$

$$V = 3.142 \times 0.25^2\text{m}^2 \times 0.58\text{m}$$

$$V = 1.11 \times 10^{-1}\text{m}^3$$

The volume of drum corresponding to (10%, 15%, and 20%) drum fill was calculated as shown below respectively.

$$V10\% = \frac{10 \times 0.111}{100}\text{m}^3$$

$$V = 1.11 \times 10^{-2}\text{m}^3$$

$$V15\% = \frac{15 \times 0.111}{100}$$

$V = 1.66 \times 10^{-2} m^3$

$$V20\% = \frac{20 \times 0.111}{100} m^3$$

$V = 2.22 \times 10^{-2} m^3$

The mass of cassava tuber corresponding to (10%, 15%, and 20%) drum fill was calculated as shown below respectively.

$m = \rho \times v$

Mass (m) at 10% drum fill = $667 kgm^{-3} \times 0.0111 m^3 = 7.404 kg$

Mass (m) at 15% drum fill = $667 kgm^{-3} \times 0.0166 m^3 = 11.2 kg$

Mass (m) at 20% drum fill = $667 kgm^{-3} \times 0.0222 m^3 = 15 kg$

The machine capacity (kgh^{-1}) of the machine was determined based on the time taken to accomplish one batch (7 minutes) and the time taken to fill and collect the peeled tubers from the drum (30 sec). Thus, in one hour the machine performs eight times, using this relation the machine capacity concerning percentage drum fill was determined.

Machine capacity at 10% drum fill $= 7.404 kg \times \frac{8}{h} \approx 60 kgh^{-1}$

Machine capacity at 15% drum fill $= 11.2 kg \times \frac{8}{h} \approx 90 kgh^{-1}$

Machine capacity at 20% drum fill $= 15 kg \times \frac{8}{h} \approx 120 kgh^{-1}$

2) Pulley size calculation.

Initially electrical motor and speed reducer gear have equipped with pulleys; the electrical motor has a 100mm pulley and the speed reducer gear have 64mm on both sides. Thus; using equation 3.28 the rest pulley size was determined as follows. There were three puller arrangements so that the drum was rotated at 30, 60, and 90rpm.

A) For 30rpm

$$\frac{N_1}{N_2} = \frac{D_2}{D_1}$$

$$N_2 = \frac{N1 \times D1}{D2}$$

$$N_2 = \frac{1450 \times 0.1}{0.064}$$

N_2 = 2,266rpm, since the speed reducer has a reduction ratio of 50:1.

$$N_3 = \frac{N_2}{50}$$

$$N_3 = \frac{2{,}266}{50}$$

N_3= 45rpm

$$\frac{N_3}{N_4} = \frac{D_4}{D_3}$$

$$D_4 = \frac{N_3 \times D_3}{N_3}$$

$$D_4 = \frac{45 \times 0.064}{30}$$

D_4 = 0.1m

B) For 60rpm

$$\frac{N_3}{N_4} = \frac{D_4}{D_3}$$

$$D_3 = \frac{N_4 \times D_4}{N_3}$$

$$D_3 = \frac{60 \times 0.1}{45}$$

D_3 = 0.13m

C) For 90rpm

$$\frac{N_3}{N_4} = \frac{D_4}{D_3}$$

$$N_3 = \frac{N_4 \times D_4}{D_3}$$

$$N_3 = \frac{90 \times 0.1}{0.13}$$

N_3 = 69rpm, so N_2 can be $N_3 \times 50$ that is

$N_2 = N_3 \times 50$

$N_2 = 69 \times 50$

N_2 = 3,450rpm, know

$$\frac{N_1}{N_2} = \frac{D_2}{D_1}$$

$$D_1 = \frac{N_2 \times D_2}{N_1}$$

$$D_1 = \frac{3{,}450 \times 0.064}{1450}$$

$D_1 = 0.15m$

Where: N_1 = electrical motor speed (rpm),

N_2= speed reducer inlet pulley speed (rpm),

N_3 = speed reducer outlet pulley speed (rpm),

N_4 = peeling drum speed (rpm),

D_1 = electrical motor pulley diameter (m),

D_2 = speed reducer inlet pulley diameter (m),

D_3 = speed reducer outlet pulley diameter (m) and

D_4 = peeling drum shaft pulley diameter (m).

APPENDICES B

Cost of cassava peeler machine.

Table 9. (B.1). Materials cost

No	Types of materials	Standard size	Unit price (EB)	Used	Total price (EB)
1	Hollow square pipe 3mm	40×40×3000 mm	430	15,000 mm	2,150.00
2	Stainless sheet metal 3mm	3×1000×2000 mm	5000	725,000mm^2	1,812.50
3	Sheet metal 1.5 mm	1.5×1000×2000 mm	700	753,750mm^2	263.81
4	Angel iron 2 mm	2×25×6000mm	300	2,840mm	142.00
5	Angel iron 4 mm	4×40×6000mm	800	1,500mm	200.00
6	Circular hollow pipe	Φ30×6000mm	850	1000mm	141.67
7	Round bar	Φ30×6000mm	1670	800mm	122.67
8	Hinge 1		25	2 pcs	50.00
9	Hinge 2		13	2 pcs	26.00
10	Bolt and nut	M8×40	10	50 pcs	500.00
11	Bolt and nut	M6×25	6	6 pcs	36.00
12	Bolt and nut	M12×70	25	4 pcs	100.00
13	Pulley	Φ86 mm	250	1 pcs	250.00
14	Pulley	Φ64 mm	200	2 pcs	400.00
15	Pulley	Φ100 mm	300	1 pcs	300.00
16	V-Belt	B-49 (1095.15)	500	1 pcs	500
17	V-Belt	B-53 ()	600	1pcs	600
18	Bearing	P206	600	2 pcs	1,200.00
19	Electrode	2.5	300	1 packet	300.00
20	1 HP Electric motor	1450 rpm	6000	-	6000
21	Speed reducer	50 to 1 %	2000	-	2000

22	Paint		150	2 liter	300.00
23	Antirust		200	1 liter	200.00
Sub total					17,594.65

Table 10. (B.2). Machine and labor cost.

No.	Types of machine	Machine cost/hr.	Working hour	Cost (EB)	Labor cost/hr.	Working hour	Cost (EB)	Total price (EB)
1	Universal metal cutting	11	16	176	6.25	16	100	276
2	Power hack saw	4	16	64	6.25	16	100	164
3	Arc welding	6	36	216	6.25	36	225	441
4	Lath	15	16	240	6.25	16	100	340
5	Milling	15	8	120	6.25	8	50	170
6	Drill	3	16	48	6.25	16	100	148
7	Portable cutting and grinding	1	18	18	6.25	18	112.5	130.5
8	Hydraulic pressing	5	16	80	6.25	16	100	180
9	Roller	3.5	6	21	6.25	6	37.5	58.5
10	Bending	3.5	3	10.5	6.25	3	18.25	28.75
				993.50			943.25	1,936.75

Table 11. (B.3). Cost summery.

No	Cost variables	Cost (EB)
A	Raw materials cost	17,594.65
B	Materials wastage (2.5%)	439.87
C	Machine cost	993.5
D	Labor cost	943.25
E	Overhead cost 5% (C+D)	96.84
F	Profit 10% (A+B+C+D+E)	2,006.81
G	Selling tax 15%	3,010.22
Selling price (EB)		23,078.32

COST ANALYSIS

The cost of operation for the developed cassava peeling machine was calculated by the following procedure. The operating cost includes the fixed and variable costs.

Assumption Made

Some assumption was made based on the quality and durability of the materials used for the development of the cassava peeling machine.

- The expected life of the machine = 10 years
- Expected operational hour per year (annual use) = 1200 hr.
- Salvage value =10% of total cost of the machine
- Interest rate 15%

Operational cost of machine

Fixed cost of peeler

a) Depreciation (Dp),

$$Dp = \frac{SP\text{-}SV}{EL}$$

$$Dp = \frac{23{,}078.32EB\text{-}2{,}307.832EB}{10 \times 1200hr}$$

$Dp = 1.73EBhr^{-1}$

Where: Dp = depreciation cost

SP = selling price of peeler

SV = salvage values (10% of selling price) and

EL = economic life

b) Interest on capital (IC),

$$IC = \frac{SP+SV}{2U} \times I\%$$

$$IC = \frac{23,078.32EB+2,307.832EB}{2\times1200hr} \times \frac{15}{100}$$

$IC = 1.59EBhr^{-1}$

Where: IC = interest on capital

SP = selling price

SV = salvage value

U = annual use

I = interest

The total cost is the sum of depreciation cost and interest on capital

Total fixed cost = Dp + IC

Total fixed cost = $1.73\ EBhr^{-1} + 1.59EBhr^{-1}$

Total fixed cost = $3.32EBhr^{-1}$

Variable cost

a) Labor cost or wages

Labor wages of 150EB per day, 8hr in a day.

$$LW = \frac{DLW}{DWH}$$

$$LW = \frac{150EB}{8hr}$$

$LW = 18.75\ EBhr^{-1}$

Where: LW = labor wages

DLW = daily labor wages

DWH = daily working hour

b) Electric power consumption cost

The total power consumption $E_{(kWh)}$ is equal to 0.746 times of multiplication of total operating hours $t_{(h)}$ in an hour, the rated power $P_{(HP)}$ in HP, and the X percentage of the load. Assume full loads.

$E_{(KWh)} = 0.746 \times P_{(HP)} \times X \times t_{(h)}$

$E_{(KWh)}=0.746\times 1hp \times 1 \times 1200hr$

E = 895.2 KWh

To calculate the electricity bill just multiply the total power consumed by the motor with the per kWh price.

The electricity cost = Total power consumption × per kWh price

Electric cost = 895.2KWh × 0.35birr

Electric cost = 313.32birr

Electric cost per hour = electric cost/1200hr

Electric cost per hour = 0.261EB

Total variable cost = electric cost + labor cost=0.261+ 18.75EBhr^{-1}

Total variable cost = 19.011EBhr^{-1}

Total cost = Total fixed cost + Total variable cost

Total cost = 3.32EBhr^{-1}+19.011EBhr^{-1}

Total cost = 22.331EBhr^{-1}

Taking the peeling capacity of 120Kghr^{-1}, the cost to Peele 1kg can be calculated as

$$\text{Cost of peeling 1 kg of cassava tubers by machine} = \frac{\text{total cost per hour}}{\text{peeling capacity of the machine per hour}} EB$$

$$\text{Cost of peeling 1 kg of cassava tubers} = \frac{22.331}{120}\text{EB}$$

Cost of peeling 1 kg of cassava tubers =0.19EB

Benefit from one kg of cassava tuber.

The average manual peeling capacity was also determined for two people; the average manual peeling capacity of cassava tubers was recorded to be 42 Kghr^{-1}. Taking for a single person performing at a maximum peeling capacity, the average throughput of labor was 21kghr^{-1} and the labor cost of 150EB in the day (8 hours) per person was 18.75EBhr^{-1}

- Cost of manual peeling = 0.893EBKg^{-1}
- Cost of peeling by machine = 0.19EBkg^{-1}

Peeling 1kg of cassava tuber manually is estimated to be 0.893EBkg^{-1} while an estimated cost to peel the same amount of tuber was 0.184EBkg^{-1} using a developed cassava peeling machine. **Cost-Benefit Ratio = 1:4.85**

APPENDICES C

Collected during the entire test run.

Table 12. (C1). Data collected at drum speed 30 rpm, 10% drum fill (7.5kg), and at 7min retention time.

Data gathered during a test run 1	
Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	7.5
Mass of peeled cassava (MP)	4.25
Mass of cassava peels (MPls)	1.065
Mass of unpeeled cassava (Mu)	1.75
Mass of cassava peels removed by hand (Mprh)	0.235
Mass of flesh loss (Mf)	0.2
%mass of peeled cassava = $\frac{M_p}{M_t} \times 100 = 4.25/7.5 \times 100$	56.7%
%mass of peels of cassava = $\frac{M_{pls} + M_{prh}}{M_t} \times 100 = 1.065{+}0.235/7.5$	17.3%
%mass of flesh loss = $\frac{M_f}{M_{tf}} \times 100 = \frac{0.2}{(4.25 + 1.75 - 0.235)} x100$	3.5%
%mass of unpeeled cassava = $\frac{M_u}{M_t} \times 100 = \frac{1.75}{7.5} x100$	23.3
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh}+M_{pls}} \times 100 = \frac{1.065}{0.235 + 1.065} x100$	81.9%
Throughput(Tc) = $\frac{M_t}{T} = \frac{7.5}{0.117}$	60kghr^{-1}

Table 13. (C2). Data collected at drum speed 30 rpm, 10% drum fill (7.5kg) and at 7min retention time.

Data gathered during a test run 2	
Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	7.5
Mass of peeled cassava (MP)	4.1
Mass of cassava peels (MPls)	1.15
Mass of unpeeled cassava (Mu)	1.88
Mass of cassava peels removed by hand (Mprh)	0.24
Mass of flesh loss (Mf)	0.13
%mass of peeled cassava = $\frac{M_p}{M_t}\times 100 = \frac{4.1}{7.5}X100$	54.7%
%mass of peels of cassava = $\frac{M_{pls}+M_{prh}}{M_t}\times 100 = \frac{1.15+0.24}{7.5}X100$	18.5%
%mass of flesh loss = $\frac{M_f}{M_{tf}}\times 100 = \frac{0.13}{4.1+1.88-0.24}X100$	2.3%
%mass of unpeeled cassava = $\frac{M_u}{M_t}\times 100 = \frac{1.88}{7.5}X100$	25.1%
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh}+M_{pls}}\times 100 = \frac{1.15}{0.24+1.15}$	82.7%
Throughput(Tc) = $\frac{M_t}{T}$	60kghr^{-1}

Table 14. (C3). Data collected at drum speed 30 rpm, 10% drum fill (7.5kg), and at 7min retention time.

Data gathered during a test run 3	
Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	7.5
Mass of peeled cassava (MP)	4.04
Mass of cassava peels (MPls)	1
Mass of unpeeled cassava (Mu)	2.02
Mass of cassava peels removed by hand (Mprh)	0.35
Mass of flesh loss (Mf)	0.1

%mass of peeled cassava = $\frac{M_p}{M_t} \times 100 = \frac{4.04}{7.5} X100$	53.9%
%mass of peels of cassava = $\frac{M_{pls} + M_{prh}}{M_t} \times 100 = \frac{1 + 0.35}{7.5} X100$	18%
%mass of flesh loss = $\frac{M_f}{M_{tf}} \times 100 = \frac{0.1}{4.04 + 2.02 - 0.35} X100$	1.8%
%mass of unpeeled cassava = $\frac{M_u}{M_t} \times 100 = \frac{2.02}{7.5} X100$	26.9%
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh}+M_{pls}} \times 100 = \frac{1}{0.35 + 1}$	74.1%
Throughput(Tc) = $\frac{M_t}{T}$	60kghr^{-1}

Table 15. (C4). Data collected at drum speed 30 rpm, 15% drum fill (10kg), and at 7min retention time.

Data gathered during a test run 1	
Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	7.5
Mass of peeled cassava (MP)	4.04
Mass of cassava peels (MPls)	1
Mass of unpeeled cassava (Mu)	2.02
Mass of cassava peels removed by hand (Mprh)	0.35
Mass of flesh loss (Mf)	0.1
%mass of peeled cassava = $\frac{M_p}{M_t} \times 100 = \frac{5.5}{10} X100$	55%
%mass of peels of cassava = $\frac{M_{pls} + M_{prh}}{M_t} \times 100 = \frac{1.35 + 0.37}{10} X100$	17.2%
%mass of flesh loss = $\frac{M_f}{M_{tf}} \times 100 = \frac{0.3}{5.55 + 2.43 - .37} X100$	3.9%
%mass of unpeeled cassava = $\frac{M_u}{M_t} \times 100 = \frac{2.43}{10} X100$	24.3%
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh}+M_{pls}} \times 100 = \frac{1.35}{0.37 + 1.35}$	78.5%

Throughput(Tc) = $\frac{M_t}{T}$	90kghr^{-1}

Table 16. (C5). Data collected at drum speed 30 rpm, 15% drum fill (10kg), and at 7min retention time.

Data gathered during test 2	
Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	10
Mass of peeled cassava (MP)	5.65
Mass of cassava peels (MPls)	1.42
Mass of unpeeled cassava (Mu)	2.3
Mass of cassava peels removed by hand (Mprh)	0.35
Mass of flesh loss (Mf)	0.28
%mass of peeled cassava = $\frac{M_p}{M_t}\times 100 = \frac{5.65}{10} X100$	56.5%
%mass of peels of cassava = $\frac{M_{pls} + M_{prh}}{M_t}\times 100 = \frac{1.42 + 0.35}{10} X100$	17.7%
%mass of flesh loss = $\frac{M_f}{M_{tf}}\times 100 = \frac{0.28}{5.65 + 2.3 - .35} X100$	3.7%
%mass of unpeeled cassava = $\frac{M_u}{M_t}\times 100 = \frac{2.3}{10} X100$	23%
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh}+M_{pls}}\times 100 = \frac{1.42}{0.35 + 1.42}$	80.2%
Throughput(Tc) = $\frac{M_t}{T}$	90kghr^{-1}

Table 17.(C6). Data collected at drum speed 30 rpm, 15% drum fill (7.5kg), and at 7min retention time.

Data gathered during test 3	
Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	10
Mass of peeled cassava (MP)	5.52
Mass of cassava peels (MPls)	1.43

Mass of unpeeled cassava (Mu)	2.44
Mass of cassava peels removed by hand (Mprh)	0.38
Mass of flesh loss (Mf)	0.23
%mass of peeled cassava = $\frac{M_p}{M_t}\times 100 = \frac{5.52}{10} X100$	55.2%
%mass of peels of cassava = $\frac{M_{pls} + M_{prh}}{M_t}\times 100 = \frac{1.43 + 0.38}{10} X100$	18.1%
%mass of flesh loss = $\frac{M_f}{M_{tf}}\times 100 = \frac{0.23}{5.52 + 2.44 - .38} X100$	3%
%mass of unpeeled cassava = $\frac{M_u}{M_t}\times 100 = \frac{2.44}{10} X100$	24.4%
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh}+M_{pls}}\times 100 = \frac{1.35}{0.37 + 1.35}$	79%
Throughput(Tc) = $\frac{M_t}{T}$	90kghr^{-1}

Table 18.(C7). Data collected at drum speed 30 rpm, 20% drum fill (15kg) and at 7min retention time.

Data gathered during test 1	
Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	15
Mass of peeled cassava (MP)	8.89
Mass of cassava peels (MPls)	2.02
Mass of unpeeled cassava (Mu)	3.2
Mass of cassava peels removed by hand (Mprh)	0.52
Mass of flesh loss (Mf)	0.37
%mass of peeled cassava = $\frac{M_p}{M_t}\times 100 = 8.89/15 \times 100$	59.3%
%mass of peels of cassava = $\frac{M_{pls} + M_{prh}}{M_t}\times 100 = 2.02 + 0.52/15 \times 100$	16.9%
%mass of flesh loss = $\frac{M_f}{M_{tf}}\times 100 = \frac{0.37}{(8.89 + 3.2 - 0.52)} x100$	3.2%

%mass of unpeeled cassava = $\frac{M_u}{M_t}$ ×100= $\frac{3.2}{15}x100$	21.3%
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh}+M_{pls}}\times 100 = \frac{2.02}{0.52+2.02}x100$	79.5%
Throughput(Tc) = $\frac{M_t}{T} = \frac{15}{0.117}$	120kghr^{-1}

Table 19. (C8). Data collected at drum speed 30 rpm, 20% drum fill (15kg), and at 7min retention time.

Data gathered during test 2	
Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	15
Mass of peeled cassava (MP)	8.65
Mass of cassava peels (MPls)	2.15
Mass of unpeeled cassava (Mu)	3.33
Mass of cassava peels removed by hand (Mprh)	0.55
Mass of flesh loss (Mf)	0.32
%mass of peeled cassava = $\frac{M_p}{M_t}\times 100 = 8.65/15 \times 100$	57.7%
%mass of peels of cassava = $\frac{M_{pls}+M_{prh}}{M_t}$ ×100=2.15+0.55/15 × 100	18%
%mass of flesh loss = $\frac{M_f}{M_{tf}}\times 100 = \frac{0.32}{(8.65+3.33-0.55)}x100$	2.8%
%mass of unpeeled cassava = $\frac{M_u}{M_t}$ ×100= $\frac{3.33}{15}x100$	22.2%
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh}+M_{pls}}\times 100 = \frac{2.02}{0.52+2.02}x100$	79.6%
Throughput(Tc) = $\frac{M_t}{T}$	120kghr^{-1}

Table 20.(C9). Data collected at drum speed 30 rpm, 20% drum fill (15kg), and at 7min retention time.

Data gathered during test 3	
Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	15
Mass of peeled cassava (MP)	8.56
Mass of cassava peels (MPls)	2.11
Mass of unpeeled cassava (Mu)	3.52
Mass of cassava peels removed by hand (Mprh)	0.56
Mass of flesh loss (Mf)	0.25
%mass of peeled cassava = $\frac{M_p}{M_t} \times 100 = 8.56/15 \times 100$	57.1%
%mass of peels of cassava = $\frac{M_{pls} + M_{prh}}{M_t} \times 100 = 2.11 + 0.56/15 \times 100$	17.8%
%mass of flesh loss = $\frac{M_f}{M_{tf}} \times 100 = \frac{0.25}{(8.56 + 3.52 - 0.56)} x100$	2.2%
%mass of unpeeled cassava = $\frac{M_u}{M_t} \times 100 = \frac{3.52}{15} x100$	23.5%
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh} + M_{pls}} \times 100 = \frac{2.02}{0.52 + 2.02} x100$	79%
Throughput(Tc) = $\frac{M_t}{T}$	120kghr^{-1}

Table 21. (C10). Data collected at drum speed 60 rpm, 10% drum fill (7.5kg), and at 7min retention time.

Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	7.5
Mass of peeled cassava (MP)	4.61
Mass of cassava peels (MPls)	1.35
Mass of unpeeled cassava (Mu)	1.1
Mass of cassava peels removed by hand (Mprh)	0.12
Mass of flesh loss (Mf)	0.32
%mass of peeled cassava = $\frac{M_p}{M_t} \times 100 = 4.61/7.5 \times 100$	61.5%

%mass of peels of cassava = $\frac{M_{pls} + M_{prh}}{M_t}\times 100 = 1.35 + 0.12/7.5 \times 100$	19.6%
%mass of flesh loss = $\frac{M_f}{M_{tf}}\times 100 = \frac{0.32}{(4.61 + 1.1 - 0.12)} x100$	5.7%
%mass of unpeeled cassava = $\frac{M_u}{M_t}\times 100 = \frac{1.1}{7.5} x100$	14.7%
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh}+M_{pls}}\times 100 = \frac{1.335}{0.047 + 1.335} x100$	91.8%
Throughput(Tc) = $\frac{M_t}{T}$	60kghr^{-1}

Table 22. (C11). Data collected at drum speed 60 rpm, 10% drum fill (7.5kg), and at 7min retention time.

Data gathered during a test run 2	
Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	7.5
Mass of peeled cassava (MP)	4.64
Mass of cassava peels (MPls)	1.34
Mass of unpeeled cassava (Mu)	1.05
Mass of cassava peels removed by hand (Mprh)	0.07
Mass of flesh loss (Mf)	0.4
%mass of peeled cassava = $\frac{M_p}{M_t}\times 100 = 4.64/7.5 \times 100$	61.9%
%mass of peels of cassava = $\frac{M_{pls} + M_{prh}}{M_t}\times 100 = 1.34 + 0.07/7.5 \times 100$	18.8%
%mass of flesh loss = $\frac{M_f}{M_{tf}}\times 100 = \frac{0.4}{(4.64 + 1.05 - 0.07)} x100$	7.1%
%mass of unpeeled cassava = $\frac{M_u}{M_t}\times 100 = \frac{1.05}{7.5} x100$	14%
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh}+M_{pls}}\times 100 = \frac{1.34}{0.07 + 1.34} x100$	95%
Throughput(Tc) = $\frac{M_t}{T}$	60kghr^{-1}

Table 23. (C12). Data collected at drum speed 60 rpm, 10% drum fill (7.5kg), and at 7min retention time.

Data gathered during a test run 3	
Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	7.5
Mass of peeled cassava (MP)	4.58
Mass of cassava peels (MPls)	1.32
Mass of unpeeled cassava (Mu)	1.04
Mass of cassava peels removed by hand (Mprh)	0.06
Mass of flesh loss (Mf)	0.5
%mass of peeled cassava = $\frac{M_p}{M_t} \times 100 = 4.58/7.5 \times 100$	61.1%
%mass of peels of cassava = $\frac{M_{pls} + M_{prh}}{M_t} \times 100 = 1.32 + 0.06/7.5 \times 100$	18.4%
%mass of flesh loss = $\frac{M_f}{M_{tf}} \times 100 = \frac{0.5}{(4.58 + 1.04 - 0.06)} x100$	9%
%mass of unpeeled cassava = $\frac{M_u}{M_t} \times 100 = \frac{1.04}{7.5} x100$	13.9%
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh} + M_{pls}} \times 100 = \frac{1.32}{0.06 + 1.32} x100$	95.7%
Throughput(Tc) = $\frac{M_t}{T}$	60kghr^{-1}

Table 24. (C13). Data collected at drum speed 60 rpm, 15% drum fill (10kg), and at 7min retention time.

Data gathered during a test run 1	
Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	10
Mass of peeled cassava (MP)	5.65
Mass of cassava peels (MPls)	1.52
Mass of unpeeled cassava (Mu)	2.07

Mass of cassava peels removed by hand (Mprh)	0.34
Mass of flesh loss (Mf)	0.42
%mass of peeled cassava = $\frac{M_p}{M_t} \times 100 = 5.65/10 \times 100$	56.6%
%mass of peels of cassava = $\frac{M_{pls} + M_{prh}}{M_t} \times 100 = 1.52 + 0.34/10 \times 100$	18.6%
%mass of flesh loss = $\frac{M_f}{M_{tf}} \times 100 = \frac{0.42}{(5.65 + 2.07 - 0.34)} x100$	5.7%
%mass of unpeeled cassava = $\frac{M_u}{M_t} \times 100 = \frac{2.07}{10} x100$	20.7%
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh} + M_{pls}} \times 100 = \frac{1.573}{0.17 + 1.573} x100$	81.7%
Throughput(Tc) = $\frac{M_t}{T}$	90kghr^{-1}

Table 25. (C14). Data collected at drum speed 60 rpm, 15% drum fill (10kg), and at 7min retention time.

Data gathered during a test run 2	
Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	10
Mass of peeled cassava (MP)	5.6
Mass of cassava peels (MPls)	1.66
Mass of unpeeled cassava (Mu)	2
Mass of cassava peels removed by hand (Mprh)	0.29
Mass of flesh loss (Mf)	0.45
%mass of peeled cassava = $\frac{M_p}{M_t} \times 100 = 5.6/10 \times 100$	56%
%mass of peels of cassava = $\frac{M_{pls} + M_{prh}}{M_t} \times 100 = 1.66 + 0.29/10 \times 100$	19.5%
%mass of flesh loss = $\frac{M_f}{M_{tf}} \times 100 = \frac{0.45}{(5.6 + 2 - 0.29)} x100$	6.2%
%mass of unpeeled cassava = $\frac{M_u}{M_t} \times 100 = \frac{2}{10} x100$	20%

peeling efficiency(n) = $\frac{M_{pls}}{M_{prh}+M_{pls}}\times 100 = \frac{1.66}{0.29+1.66}x100$	85.1%
Throughput(Tc) = $\frac{M_t}{T}$	90kghr^{-1}

Table 26. (C15). Data collected at drum speed 60 rpm, 15% drum fill (10kg), and at 7min retention time.

Data gathered during a test run 3	
Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	10
Mass of peeled cassava (MP)	5.4
Mass of cassava peels (MPls)	1.8
Mass of unpeeled cassava (Mu)	2.02
Mass of cassava peels removed by hand (Mprh)	0.28
Mass of flesh loss (Mf)	0.5
%mass of peeled cassava = $\frac{M_p}{M_t}\times 100 = 5.4/10 \times 100$	54%
%mass of peels of cassava = $\frac{M_{pls}+M_{prh}}{M_t}\times 100 = 1.8+0.28/10 \times 100$	20.8%
%mass of flesh loss = $\frac{M_f}{M_{tf}}\times 100 = \frac{0.5}{(5.4+2.02-0.28)}x100$	7%
%mass of unpeeled cassava = $\frac{M_u}{M_t}\times 100 = \frac{2.02}{10}x100$	20.2%
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh}+M_{pls}}\times 100 = \frac{1.8}{0.28+1.8}x100$	86.5%
Throughput(Tc) = $\frac{M_t}{T}$	90kghr^{-1}

Table 27. (C16). Data collected at drum speed 60 rpm, 20% drum fill (15kg), and at 7min retention time.

Data gathered during a test run 1

Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	15
Mass of peeled cassava (MP)	8.77
Mass of cassava peels (MPls)	2.3
Mass of unpeeled cassava (Mu)	2.85
Mass of cassava peels removed by hand (Mprh)	0.43
Mass of flesh loss (Mf)	0.65
%mass of peeled cassava = $\frac{M_p}{M_t} \times 100 = 8.77/15 \times 100$	58.5%
%mass of peels of cassava = $\frac{M_{pls} + M_{prh}}{M_t} \times 100 = 2.3 + 0.43/15 \times 100$	18.2%
%mass of flesh loss = $\frac{M_f}{M_{tf}} \times 100 = \frac{0.65}{(8.77 + 2.85 - 0.43)} x100$	5.8%
%mass of unpeeled cassava = $\frac{M_u}{M_t} \times 100 = \frac{2.85}{15} x100$	19%
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh} + M_{pls}} \times 100 = \frac{2.497}{0.247 + 2.497} x100$	84.2%
Throughput(Tc) = $\frac{M_t}{T}$	120kghr^{-1}

Table 28. (C17). Data collected at drum speed 60 rpm, 20% drum fill (15kg), and at 7min retention time.

Data gathered during a test run 2	
Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	15
Mass of peeled cassava (MP)	8.81
Mass of cassava peels (MPls)	2.35
Mass of unpeeled cassava (Mu)	2.97
Mass of cassava peels removed by hand (Mprh)	0.46
Mass of flesh loss (Mf)	0.41
%mass of peeled cassava = $\frac{M_p}{M_t} \times 100 = 8.81/15 \times 100$	58.7%

%mass of peels of cassava = $\frac{M_{pls} + M_{prh}}{M_t}$ ×100=2.35+0.46/15 × 100	18.7%
%mass of flesh loss = $\frac{M_f}{M_{tf}}$ ×100= $\frac{0.41}{(8.81 + 2.97 - 0.46)} x100$	3.6%
%mass of unpeeled cassava = $\frac{M_u}{M_t}$ ×100 = $\frac{2.97}{15} x100$	19.8%
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh}+M_{pls}}$ ×100 = $\frac{2.35}{0.46 + 2.35} x100$	83.6%
Throughput(Tc) = $\frac{M_t}{T}$	120kghr^{-1}

Table 29. (C18). Data collected at drum speed 60 rpm, 20% drum fill (15kg), and at 7min retention time.

Data gathered during a test run 3	
Operation or activity	Unit (kg)
Mass of cassava feed into the machine (Mt)	15
Mass of peeled cassava (MP)	8.92
Mass of cassava peels (MPls)	2.43
Mass of unpeeled cassava (Mu)	2.7
Mass of cassava peels removed by hand (Mprh)	0.55
Mass of flesh loss (Mf)	0.4
%mass of peeled cassava = $\frac{M_p}{M_t}$ ×100 = 8.92/15 × 100	59.5%
%mass of peels of cassava = $\frac{M_{pls} + M_{prh}}{M_t}$ ×100=2.43+0.55/15 × 100	19.9%
%mass of flesh loss = $\frac{M_f}{M_{tf}}$ ×100= $\frac{0.4}{(8.92 + 2.7 - 0.55)} x100$	3.6%
%mass of unpeeled cassava = $\frac{M_u}{M_t}$ ×100 = $\frac{2.7}{15} x100$	18%
peeling efficiency(n) = $\frac{M_{pls}}{M_{prh}+M_{pls}}$ ×100 = $\frac{2.43}{0.55 + 2.43} x100$	81.5%
Throughput(Tc) = $\frac{M_t}{T}$	120kghr^{-1}

APPENDICES D

Picture showing shaft manufacturing at ARIC Work shop using lathe machine.

picture showing rolling ring on roller Machine at ARIC work shop

picture showing pulley manufacturing at ARIC Work shop using lathe machine

Samples ready for oven drying to determine moisture content.

Digital weighting balance after oven drying.

digital vernire caliper to determine diameter.

Preliminary test photography

Manual peeling of cassava tubers with knife

tachometer for determine rpm of drum