DEVELOPMENT AND PERFORMANCE EVALUATION OF DIESEL ENGINE OPERATED CASSAVA GRATING MACHINE

Amanuel Erchafo Ertebo

A Thesis Submitted to the Department of Mechanical Engineering, School of Mechanical, Chemical and Materials Engineering Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Agricultural Machinery Engineering

Office of Graduate Studies
Adama Science and Technology University

November, 2023
Adama, Ethiopia

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DECLARATION

I hereby declare that this Master thesis entitled "Development and Performance Evaluation of Diesel Engine Operated Cassava Grating Machine" 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 through citation.

Amanuel Erchafo Ertebo	______________________	_____________________
Name of student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Development and Performance Evaluation of Diesel Engine Operated Cassava Grating Machine" prepared under my guidance by Amanuel Erchafo Ertebo submitted in partial fulfillment of the requirements for the degree of Masters of Science in Agricultural Machinery Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. Amana Wako Koroso (Ph.D.)	____________________	____________________
Name of Advisor	Signature	Date

APPROVAL PAGE FOR THESIS

I, the advisors of the thesis entitled "Development and Performance Evaluation of Diesel Engine Operated Cassava Grating Machine" and developed by Amanuel Erchafo Ertebo, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Amana Wako Koroso (Ph.D.)	____________________	____________________
Name of Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Amanuel Erchafo Ertebo have read and evaluated the thesis entitled "Development and Performance Evaluation of Diesel Engine Operated Cassava Grating Machine" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfilment of the requirement of the degree of Master of Science in Agricultural Machinery Engineering.

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ACKNOWLEDGMENT

First of all, I would like to thank my God for his guidance and for giving me strength throughout the process of completing this thesis work. I am grateful to my advisor, Dr. Amana Wako for his invaluable advice and assistance throughout the thesis work.

Thankful to both the Agricultural Engineering Research Directorate and Process for providing all the necessary logistics for the completion of this thesis. I am also thankful to Melkassa Agricultural Research Center Agricultural Engineering Research process staff for their vital advice and assistance during the research work, especially to Mr. Tilahun Teka who assisted me technically during the manufacturing of the prototype, and Mr. Eyob Hailu, Mr. Manaye Ayalew and Mr. Alemayehu Girma for their co-advisor role throughout my thesis work. Mr. Besufikad Getachew, Mr. Yigerm Tadesse and Mr. Frezer Abebe who assisted me in conducting the performance evaluation of the fabricated prototype deserve special thanks. Grateful to Mrs. Afomia girma who assisted me in the laboratory for the determination of cassava physical properties.

The last, but not the least, gratitude goes to my loving wife and family who supported me throughout my studies.

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ACRONYMS

AMD	Arithmetic Mean Diameter
ANOVA	Analysis of Variances
AOAC	Association of Official Agricultural Chemist
ARCADEM	Africa Regional Centre for Engineering Designs and Manufacturing
ASABE	American Society of Agricultural and Biological Engineers
CV	Coefficient of Variation
DF	Degrees of Freedom
ETB	Ethiopian Birr
FAO	Food and Agriculture Organization
GME	Geometric Mean Diameter
HCN	Hydrogen Cyanide
HP	Horsepower
IITA	International Institute of Tropical Agriculture
ISO	International Organization for Standardization
LSD	Least Significance Difference
MARC	Melkassa Agricultural Research Center
MS	Mean Squares
NASENI	National Agency for Science and Engineering Infrastructure
NCAM	National Centre for Agricultural Mechanization
NGO	Non-Governmental Organization
PAES	Philippines Agricultural Engineering Standards
RPM	Revolution per Minutes
SD	Standard Deviation
SNNPR	Southern Nation, Nationality and Peoples Region
SS	Sum of Squares
SSA	Sub-Saharan Africa
USDA	United States Department of Agriculture
WHO	World Health Organization

ABSTRACT

Cassava is one of the most crucial tuber crops with an edible root, which grows mostly in tropical and subtropical areas of the world. It is the fourth most important crop for farmers in the tropics and sub-tropics after rice, wheat, and maize. In Ethiopia, cassava generally grows in almost all parts of the country but the bulk of its production is in south, south western and western parts of the country. As the world is emerging with various types of technology for ease of processing, and efficient production of cassava; automated and mechanized technology was of great importance.

The major limitation of cassava is its rapid postharvest physiological deterioration and it should be processed immediately after harvest because it is highly perishable. The objective of this study was to develop and evaluate the performance of a diesel engine operated cassava grating machine. In this research work, a cassava grating machine was fabricated from stainless steel sheet metal. The experiment was carried out by randomized block factorial design and the collected data were analyzed using Statistix 8 software. Analysis of variance revealed that the main effects of drum speed, feed rate, and their interaction effect were significant at the 5% level. The highest throughput capacity of 471.4 $kghr^{-1}$ was observed at a drum speed of 1400rpm and feed rate of 5kg/min, while the lowest throughput capacity was 272.5 $kghr^{-1}$ observed at a drum speed of 1100rpm and feed rate of 5kg/min. The highest grating efficiency of 97.33% was observed at a drum speed of 1400rpm and feed rate of 15kg/min, while the lowest grating efficiency was 81.6% observed at a drum speed of 1100rpm and feed rate of 5kg/min. The lowest percentage of mechanical loss of 2.45% was observed at a drum speed of 1400rpm and feed rate of 15kg/min, while the highest percentage of mechanical loss was 18.4% observed at a drum speed of 1100rpm and feed rate of 5kg/min. The fuel consumption of the machine was measured as 1.82L/hr. Finally, the regression analysis result for throughput capacity showed that 95% of throughput capacity was accounted for by two independent factors collectively, $F(2, 33) = 311.17$, $R = 0.974$, $p = 0.000$. and the predicted throughput capacity was equal to $249.05 + 53.29V - 11.86F$. This machine was recommended for cassava grating at operating a drum speed of 1400rpm.

Keywords: Cassava, Cassava Processing, Grating Machine, and Performance Evaluation.

CHAPTER ONE

1. INTRODUCTION

1.1. Background and Justification

Cassava (*Manihot esculenta Krantz*) is a perennial woody plant with a delicious root, which grows in tropical and subtropical regions of the world. Cassava is one of the most popular foods in Africa and the foundation of food security in Africa because of its significance and adaptability. Cassava has emerged as one of the most crucial tuber crops in many tropical economies that are now in development. After rice, wheat, and maize, cassava is the fourth most significant crop for farmers in the tropics and subtropics. Approximately one billion people worldwide consume cassava (Musa et al., 2022). More than 26 million hectares of cassava were planted globally in 2017, with 76% of those being in Africa (Adiele et al., 2021). About 278 million tons of cassava root were produced worldwide in 2018, with Nigeria accounting for 21% of this amount and being the leading producer. The other main cassava producers were Thailand, the Democratic Republic of the Congo, Brazil, and Indonesia (Musa et al., 2022).

As the world is emerging with various types of technology for a better quality of life, ease of processing, and efficient production of food; automated and mechanized technology for agricultural fields was of great importance. The optimized engine operated cassava grater was solving the problems concerned with manual grating. Efficient mechanized graters that use grating drums are needed to produce a sufficient quantity of cassava mash to meet market demand. For large-scale cassava processing, mechanical cassava grating is absolutely necessary. The mechanical grater has many machine components that contact directly with the cassava tuber and subsequently grate it, producing high-quality, fresh end products. The method primarily targets a bigger batch or quantity of tubers at once. Environmentally safe and non-toxic goods are produced by mechanical graters (Bello et al., 2020). Additionally, mechanical grating techniques finish the grating process in a single step, therefore additional steps are not necessary. Common prototype graters have functional systems including abrasive tools, drums, rollers, teeth, disks, and milling cutters that grate tubers mechanically to avoid risks and lessen labor-intensive manual grating.

In this research work to mechanize cassava processing, a mechanical cassava grating machine was fabricated from locally available materials. During the development of the existing grating machine, the strength of materials, and the mechanism were considered. Cassava is thought to have first been domesticated in South America, and cultivation of it has since expanded across the wet tropics and subtropics (Adebayo & Silberberger, 2020). Additionally, the Portuguese initially introduced it to Africa in the Congo Basin in around 1558. (Eshbel et al., 2022). Cassava requires less labor than other basic crops, but more labor after harvest because the roots need to be processed into a storable form right away after harvest (Oyejide et al., 2021). Cassava is primarily a subsistence crop farmed by small-scale farmers in sub-Saharan Africa (SSA) who sell the extra. It requires little labor and thrives in poor soils.

When compared to other agricultural goods, cassava is the staple crop with the best potential for new market growth. One of the best-marketed crops for supplying staple foods (Nyamekye, 2021a). Learning about the nutritional qualities and health advantages of cassava in relation to agricultural methods, environmental challenges, and plant variations is a necessary component of developing sustainable cassava crops (Mombo et al., 2017). Due to its low cash input cost, cassava has a lower cash income than the other broad staples. According to studies by Okwuonu et al. (2021), cassava has evolved in Africa from a famine reserve crop and a staple crop to a cash crop since the turn of the century. Due to its great nutritional value, year-round availability, and capacity to thrive under extremely stressful conditions, cassava helps to alleviate food shortages in Africa (Andrade et al., 2022).

In Africa, cassava is a crucial crop that serves as a reserve for food, raw materials for industry, and animal feed (Amelework et al., 2021). For marginal farmers and the domesticated animals, they keep in tropical areas, cassava is regarded as a key food source. The majority of the cassava farmed in Africa is utilized for food consumption, with 50% being processed and 38% being used fresh or boiled; the remaining 12% being used as animal feed. Many industrialized methods are utilized to prepare various food varieties using cassava (Nyamekye, 2021b). It is raised for both human and animal consumption as well as a raw resource for industry (Wellens et al., 2022). It is the third-largest source of carbohydrates in the world, with Africa being its primary production region (Andrade et al., 2022).

Cassava is one of the significant roots and tuber crops supporting a sizeable section of the Ethiopian population. Cassava is an important staple food in the south, southwest, eastern, and northwest regions of the country, where it is farmed by small-scale subsistence farmers in resource constrained settings (Sarka et al., 2017). Cassava produce a lot more than cereal crops, are environmentally beneficial, and add cheap, nutrient-dense energy to the human diet (Okigbo, 1980). Cassava is mostly grown in the southern part of Ethiopia. It was believed that certain non-governmental organizations (NGOs) brought cassava to the country's drought-prone southern regions, including Amaro, Gamogoffa, Sidama, Wolayta, and Gedeo, mostly to fill the gap created by the failure of other crops due to drought for subsistence farmers (Amsalu, 2006).

In the Southern area of Ethiopia, cassava was grown on 195,055 hectares with a yield of 501,278.5 tons annually on average in 2013 (Feyisa, 2021). Since the famine of 1984, Ethiopia has appreciated its usage as a viable food crop (Amsalu, 2006). Cassavas make major contributions to assuring year-round access to sustainable food, revenue generation, resource conservation, and food security. It is also one of the most significant starchy crops, and its tuberous roots are an excellent source of calories, particularly in underdeveloped nations like Ethiopia where malnutrition and calorie deficiency are common (Amsalu, 2006). Cassava root's ability to grow entirely well in bad soil and its innate capacity to stay for a long time in the soil even after maturity are both highly significant qualities that have made it an important food security crop, especially among low-income countries (Tobiloba et al., 2019). Injera, Dabo, Anebabero, and Porridge are four different traditional Ethiopian dishes with two percentages of cassava blending with grains at the proportions of 50% and 70%, according to Sarka et al. (2017)

Cassava has historically been the most perishable of all root tubers. When the tubers are cut off from the main plant, they become unpleasant two to three days after harvest, resulting in post-harvest physiological decline (Okonkwo et al., 2019). After harvesting cassava roots, are processed by various methods into different products. The various unit operations involved include grating, peeling, slicing, fermenting, drying, and other final processes. So, the above-listed cassava processing unit operations, are very difficult tasks 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. Cassava is a crop that may be left in the ground for up to two years before being harvested, earning it the moniker "food security crop" (Ferguson et al., 2021).

According to the study results, when farmers were surveyed in 2015 in the south western region of Ethiopia, 98.4% were aware that cassava contains hydrogen cyanide. Farmers employed a variety of eradication techniques to address this issue. By boiling fresh root vegetables or frying them, 65% of the farmers remove hydrogen cyanide. 12.7% of farmers remove the hydrogen cyanide from the cassava product by grating and sun drying it, while some (22.2%) farmers remove it before boiling or frying (Gezahegn & Bazie, 2021). The fermentation of grated cassava tuber is efficient at removing cyanogenic glucosides (Lambri & Fumi, 2014).

Since hydrogen cyanide (HCN) is poisonous to people, a significant portion of the processing of cassava tubers is required to encourage the release and removal of HCN before to consumption (Omojokun et al., 2021). In order to make the product safe for human consumption given the presence of this hazardous component, specific processing is required. These sections are the inedible outer parts of the root. Then, during the slicing, grating, and following processing steps, hydrogen cyanide is significantly decreased and driven off. To utilize cassava safely as part of a nutritious diet for the vast majority of people, adequate processing is, therefore, essential.

1.2. Statement of the Problem

The cassava grating machine was developed by Temam (2020), which had the following drawbacks or limitations: The grating capacity of this machine was too low, the efficiency and percentage loss of machine was not evaluated, the outlet of the grating machine was not placed in the proper inclination, the hopper of the grating machine did not have proper length, the inclined part of hopper was not positioned in the proper inclination this forced the users to use wood to push cassava and the length and diameter of drum was too small.

Grating cassava tubers using manual graters makes the process tedious, labor-intensive, time-consuming, less effective, low quality and quantity of product, and exposes mold development on skins. In addition, it is not suitable for commercial purposes (Krishnakumar et al., 2022). Though the manual method has grating speed limitations, high injuries to the fingers of the operator, and is very exhaustive yet, it yields bitter results for local processors or small-scale farmers still. To hand grate, one tonne of freshly peeled cassava roots generally requires 10 to 15 man days of effort (Moreno et al., 2021). However, a mechanical grater of cassava can grate the cassava on a large scale; improve the speed of cassava processing, save labor input, avoid direct contact, and save time. Mechanical grating of cassava is very essential for the minimizing above-mentioned problem and large-scale cassava processing.

A major drawback of cassava is its fast-postharvest physiological deterioration. It must be processed immediately after harvest because it is extremely perishable. Deterioration usually starts within 48 to 72 hours after it is taken from the ground (Musa et al., 2022). The cyanide (cyanogenic glucosides) that the cassava plant generates is dangerous and when taken can cause nausea, vomiting, headaches, dizziness, and exhaustion (Nyamekye, 2021b). Hence, it is critical that the tubers are processed as initially as possible (Fadeyibi & Ajao, 2020). The presence of hydrogen cyanide in cassava is the primary worry of the consumer during use. Therefore, processing the cassava decreases its cyanide content which is poisonous. So, this extends the product's shelf life, reduces post-harvest losses, and prevents contamination of the products which will convert the crop into safer and more marketable (Doydora et al., 2017a). Also, upon harvest, cassava is massive and holds a high amount of moisture, estimated as 70%, and both the roots and leaves contain changeable amounts of cyanide, which is toxic to human health (Nyamekye, 2021b).

1.3. Objectives

1.3.1. General objective

To develop and evaluate the performance of the diesel engine operated cassava grating machine.

1.3.2. Specific objectives

- To study engineering properties of cassava tuber.
- To develop cassava grating machine.
- To evaluate the performance of the cassava grating machine.
- To analyze economic costs of the cassava grating machine.

1.4. Significance of the Study

In Ethiopia, cassava tuber was grating manually which requires intensive human labor through exhaustive activity. Therefore, it was very important to manufacture the engine-operated cassava grater. The main benefit of an engine-operated cassava grater was reducing human power requirements and easy grating operation. Mechanical cassava grater technology had a significant contribution to the development of cassava tuber primary processing at the same time; it played a great role in food security by providing high quality and quantity products at a balanced cost of production. Mechanized grating of fresh cassava into mash contributes to reducing postharvest losses of cassava, increasing its shelf life and improving food security. This study also will help many researchers engaged in cassava tuber grating machines in the future.

1.5. Scope of the Study

The scope of this research study was limited to the development and performance evaluation of a diesel engine-operated cassava grating machine. The machine was applicable to small-scale operations for cassava primary processing in the south, southwestern and western parts of the country. Parameters used for the development of engine operated cassava grater includes: the force required to drive the drum (N), the torque due to load on the drum (Nm), and the power required to drive the drum with speed. The machine could be utilized in rural areas of SNNPR where small-scale farming of cassava was their primary commodity.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Cassava Tuber

Cassava (*Manihot esculenta Crantz*) is a starchy tuberous root crop that is a member of the Euphorbiaceae family (Huang et al., 2020). The edible starchy tuberous root is the primary reason it is grown extensively as an annual crop in tropical and subtropical areas. Over 500 million people get their fundamental nutrition from cassava, which is a major staple food in poor countries (Bayata, 2019). Local names for cassava in Ethiopia include Mogo, Furno tree, Mita Boye, and Yenchet Boye (Misganaw & Bayou, 2020). The majority of cassava farms and homesteads are enclosed by fences. In the southern and southwestern regions of Ethiopia, farmers blend cassava flour with other grains including maize, tef, and wheat to create a composite flour for baking.

The root is relatively high in vitamin C and has considerable levels of calcium, phosphorus, and iron (Enidiok et al., 2008). In terms of its chemical makeup, cassava is mostly made up of water (60%) and starch, with traces of protein, fiber, minerals, and vitamins as well as the poisonous substance HCN (Mosobalaje et al., 2019). In addition to food, cassava is exceedingly adaptable, and its derivatives and starch can be used to make a wide range of goods, including monosodium glutamate, medicines, sweeteners, glues, plywood, textiles, and paper. Cassava peels and leaves are used to make alcohol and as animal feed (Okoli, 2020). The nutritional value of cassava roots varies considerably. When harvested nine to twelve months after planting, the mature tubers can measure 5 to 10 cm in diameter and 15 to 30 cm in length (Egbeocha et al., 2016).

Figure 1. Cassava tuber plant. Source: Adgidzi (2019)

According to (Hassan, 2012), the cassava tuber has three layers: the periderm, which is the tuber's outermost layer, the peel; the cortex, which is typically 1.5 to 2.5 mm thick and white and sits below the periderm; and the central portion, which is mostly made of stored starch and is white and makes up the bulkier part of the tuber. The corky periderm and cortex that cause cassava toxicity are therefore intended to be removed during the unit operation, as seen in fig. 2 below (Adetan et al., 2003).

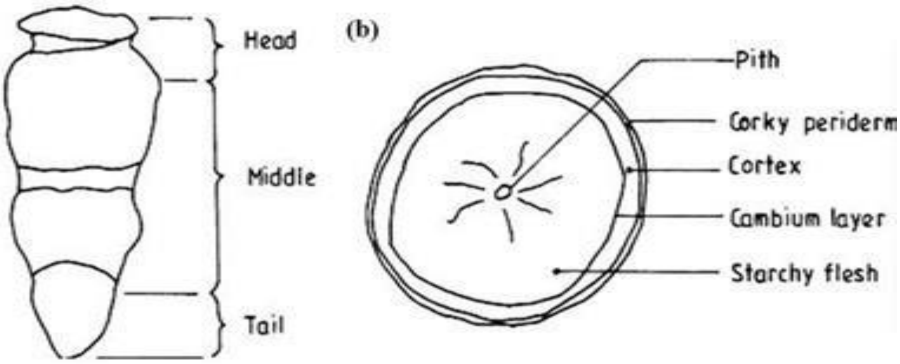


Figure 2. Morphology of cassava tuber. Source: Adetan et al. (2003)

2.2. Current Production of Cassava

In 2019, there were 304 million metric tons of cassava produced worldwide, with Africa accounting for around 63.3% of that total (Sengar, 2022). Since 2010, there have been 240 million metric tons more cassava produced globally (Sengar, 2022). According to FAO forecasts, sub-Saharan Africa will produce 62% of the world's cassava by 2025 (Olaoye et al., 2020). Nigeria produces more cassava than any other nation in the world, roughly twice as much as Indonesia, Thailand, and Brazil put together. According to forecasts, domestic consumption of cassava would rise by 1.67 million tons to 47.34 million tons in 2021 from 45.68 million tons in 2020. The initial stock is anticipated to expand by roughly 3.47 million tons to 8.15 million tons in 2021 from 4.68 million tons in 2020.

At present cassava is grown in around 40 different countries throughout Africa, from Madagascar in the southeast to Senegal and Cape Verde in the northwest. This continent accounts for roughly half of the world's cassava production. Nigeria, the Democratic Republic of the Congo, Ghana, Tanzania, and Mozambique produce over 75% of Africa's cassava. Millions of impoverished African farmers, many of whom are women, cultivate cassava, frequently on marginal ground.

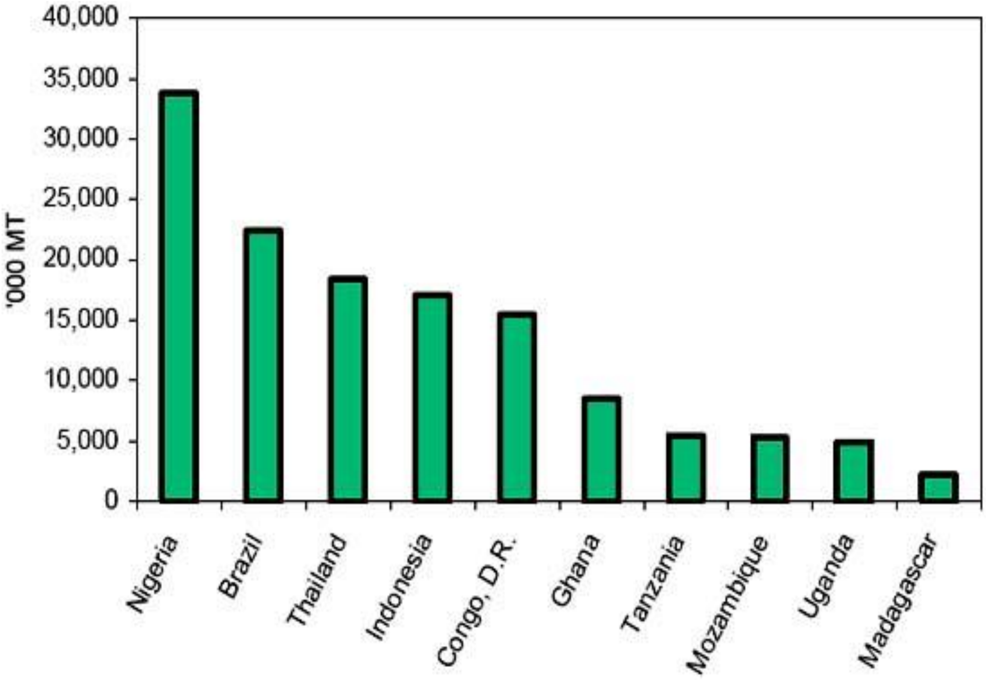


Figure 3. Leading world producers of cassava. Source: FAO

2.3. Cassava Production in Ethiopia

In Ethiopia, cassava typically grows across almost all of the part of country. However, the majority of the nation's production is concentrated in the southwest, west, and south. The average yearly land coverage and productivity in Ethiopia are 195,055 hectares and 501,278.5 tons, respectively. This suggests that the average productivity of cassava in the nation is not more than 25 tons per hectare (Feyisa, 2021), which is excessively low compared to the yield attained by other tropical countries like Nigeria, which is 35 tons per hectare per year (Otekunrin & Sawicka, 2019).

Cassava was introduced to Ethiopia in the 1960s, and the plant is now being planted all throughout the nation as a means of addressing food insecurity (Kebede et al., 2012a). However, the distribution by area is not as noticeable. In the southern region of the nation, it was produced for a longer period of time to cover the key times of household food insecurity. These days, it is being encouraged in Ethiopia's northern regions, where there is a food shortage (Kebede et al., 2012a). Ethiopia, unlike other African nations, does not yet have unique processing techniques, storage capabilities, or consumption patterns (Wellens et al., 2022).

2.4. Cassava Tuber Processing

The rate of processing, the quality, and the quantity of the products, as well as their accessibility to customers in the market, will all be considerably improved by mechanizing the cassava grating process (Adiele et al., 2021). However, mechanization is necessary for the commercialization of cassava production in Nigeria in order to successfully perform unit activities such as grating, drying, milling, pressing, screening, frying, and extrusion (Oyejide et al., 2018).

The most crucial step in the entire cassava processing chain is cassava grating. If this step is not done correctly, health issues will arise for people since the cortex and corky periderm of the cassava tuber contain the majority of the hydrogen cyanide that causes the tuber to be toxic (Nyamekye, 2021b). Most of these tasks are still carried out manually, particularly grating, and because of their laborious nature, length of time, and low output, they are not appropriate for processing on a wide scale (Adetan et al., 2003) ; (Davies et al., 2008).

2.4.1. The purpose of processing

Cassava roots can only be stored for around 48 hours without preservatives after harvest since they are prone to deterioration (Oduor et al., 2017). The fact that raw cassava does not store well due to its high moisture content is another key factor in why processing it is essential. To stop the degradation process and turn the tubers into storable food stock, it is necessary to process them as quickly as possible after harvest. When cassava is harvested, it first experiences physiological deterioration that lasts for two to three days. Then, microbial deterioration begins since the earlier stage of deterioration would have created ideal conditions for microbial infestation. It is essential to process the product as soon as possible after harvest because of how quickly it deteriorates after that. Peeling, grating, dehydrating, milling, and sieving are steps in the processing of cassava that reduces its size (Ndaliman, 2006)

Processing is required for different reasons. First, it eliminates or reduces the cyanogenic glucosides, which are present in raw cassava and may be hazardous. Second, it acts as a tool of preservation. Third, processing produces goods with various properties, adding variety to the diets of people who eat cassava. When fresh cassava roots are processed properly, they become safer and more marketable goods by lowering the amount of cyanide in the finished goods, extending their shelf lives, minimizing fresh cassava root losses after harvest, and preventing product contamination (Tarawali et al., 2017). While cyanide, a toxin, is present in cassava roots, they are nonetheless edible. Once the roots are treated, this decrease.

Grating destroys internal cells, which releases an enzyme that degrades the cyanogenic glycoside complex and produces hydrogen cyanide (Hassan, 2012). During grating, toxicity is initially markedly reduced. Nearly all of the glycoside is broken down during later fermentation stages, and the final step of roasting or frying removes the hydrogen cyanide (Hassan, 2012). In terms of its chemical makeup, cassava is mostly made up of water (60%) and starch, with trace amounts of protein, fiber, minerals, and vitamins as well as the poisonous glycoside that contains hydrogen cyanide (Kebede et al., 2012b).

2.4.2. Cassava processing steps

For cassava processing, cassava grating is a necessary step (Obeng et al., 2018). But the required cassava grating machines are different for different finished product requirements. Cassava is processed for food using a combination of fermentation, drying, and cooking. Out of the three processing methods, the fermentation of grated cassava roots for 72 hours sufficiently decreased HCN levels to a safe level (10 ppm, WHO) for human consumption. Peeling, grating, dewatering or fermenting, sifting, and roasting or frying are a few of the significant processes used to turn cassava into the mash (Onu et al., 2016). as shown below in figure 4.

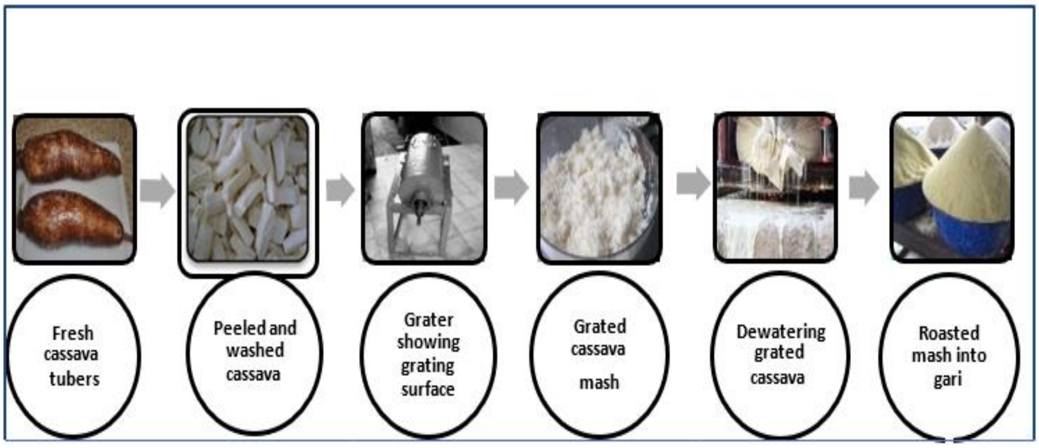


Figure 4. Major steps involved in processing cassava. Source: Obeng et al. (2018)

Post-processing frequently uses the crucial mechanism of fermentation. The cassava fermentation process is a tactic to increase the nutritional value by enriching protein and detoxifying toxic and anti-nutritional chemicals, in particular by lowering harmful cyanogenic glycosides to a level that is safe for eating in cassava products and lowering postharvest losses. Cassava can be fermented using a variety of methods, but the two most common types are submerged fermentation and solid-state fermentation. To eliminate cyanide and generate the desired flavor, fermentation is the primary method of processing and preserving cassava. The substance is next burned to remove any remaining cyanide gas and to kill any enzymes and microbes. In order to detoxify the roots, cassava is fermented for 4 to 6 days (Polytechnic, 2012).

Figure 5. Cassava tuber. Source: Jinrui food engineering

Figure 6. Grated cassava mash. Source: Jinrui food engineering

2.5. Cassava Primary Processing Unit Operations

Processing techniques include grating, peeling, boiling, slicing, drying, fermenting, steaming, soaking or soaking, pounding, roasting, pressing, and grinding (Onu et al., 2016). According to Hassan (2012), the unit activities used to prepare cassava to include grating, slicing, peeling, drying, and sieving. Cassava farmers used fermentation, sun-drying, and boiling techniques to remove antinutritional elements. Cassava is often processed conventionally to produce numerous generally shelf-stable, intermediate, and final products for a variety of food applications.

The right automation and mechanization are essential for producing the desired output. Starch is extracted from cassava for industrial application (Ademakinwa et al., 2021). Different unit processes are used in the initial processing of cassava tubers for use in industry or human consumption. Processing cassava into any of its useable end products, in this example, cassava, entails a number of unit processes, grating being one of them. Figure 7 is a flowchart of these unit operation.

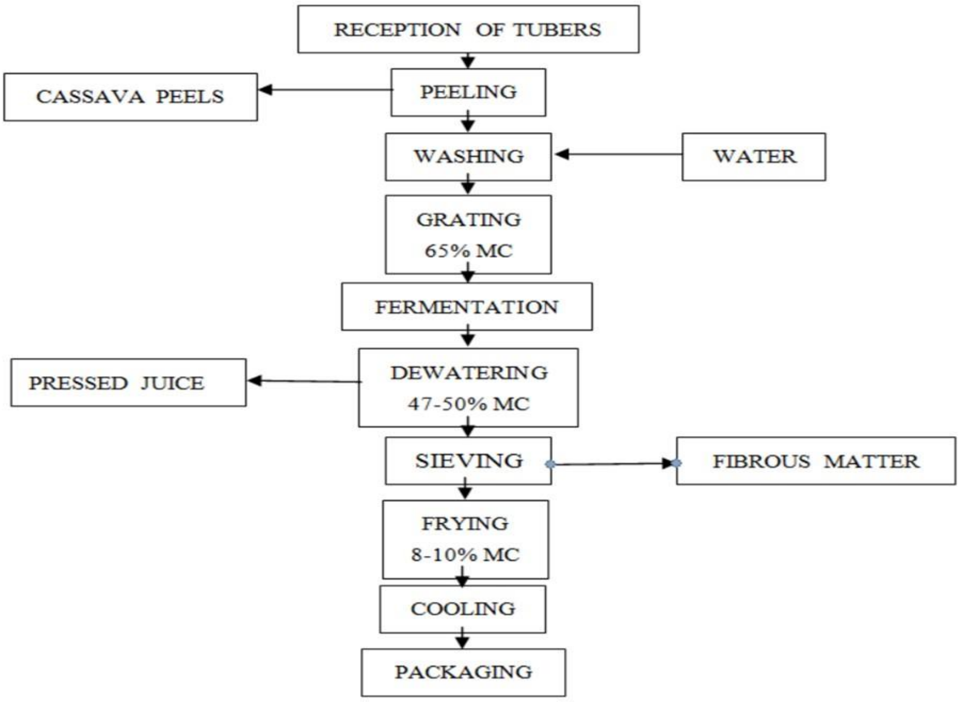


Figure 7. Flowchart of unit operation in cassava processing. Source: Igoni (1991)

2.5.1. Cassava grating

Cassava grating is a size-reduction process that converts peeled cassava tubers into cassava mash. Grating is a size-reduction activity, involving the breakdown of cassava tuberous roots into smaller particles. Grating refers to the process of turning cassava tubers into pulp (Polytechnic, 2012). The most time-consuming and uncomfortable part of the process is almost always thought to be hand grating. When questioned about the difficulties in processing, the ladies who still physically grate the cassava will only point to the palms of their hands. One ton of freshly peeled cassava roots usually requires 10 to 15 men to manually grate (Cock et al., 1985). It goes without saying that grating increases the surface area available for fermentation. This procedure is used for whole tubers occasionally after peeling.

Grating the entire tuber ensures that the cyanide is distributed evenly throughout the product and makes the nutrients in the pulp usable. Grating is the process of milling or grinding cassava tuber into smaller units (granules) by scratching and rubbing the tuber against a rough metal sheet to increase the surface area of the tuber and facilitate the removal of water that contains hydrocyanic acid during the dewatering/fermentation process. After making sure the peeled cassava tubers have been completely cleansed, a grating is often done.

Grating is usually carried out after ensuring that the peeled cassava tubers are thoroughly washed. The conventional method for removing cyanide and making the crop safe for food involves grating the cassava tubers into a mash or pulp. Traditional cassava graters are labor-intensive, slow, and easily dangerous to the fingers, so efficient mechanical graters that make use of grating drums are required to generate enough cassava mush to satisfy market demands and standards. Peeling was the first procedure carried out after the tubers were harvested and cleared of debris. One of the unit procedures in the pulp-making process of cassava tubers is grating. The tubers are mashed in the grater after being washed and skinned.

Cassava grating has been a tradition since the time the crop originated in South America. The anticipated quantity and quality of grating, however, were not achieved because the equipment used for grating changed from stones and wooden flights to a straightforward kitchen knife. The cassava tuber's cross-sectional structure shows a central core known as the parenchyma or the pith, which is surrounded by the starchy flesh, which makes up the majority of the tuber and serves as the main storage area.

2.6. Grating Methods

The grating operation is often done by hand or with power-operated graters of various makes and models, which are more commonly employed in the cassava processing method. Numerous techniques for shredding cassava tubers have been used and put into effect since the invention and manufacture of the tubers. Manual and mechanical techniques are among them. There are benefits and drawbacks to each (Franca & Oliveira, 2011).

2.6.1. Manual grating method

This traditional way of grating cassava is done by manually rubbing the peeled tubers against a roughened surface of galvanized mild steel on a wood or metal frame. Manual grating requires a lot of effort and time and frequently injures the operator's fingers. Because of the constant bending of the backbone, it may also eventually result in the development of back pain. In addition, manual cassava grating results in goods of uneven quality. Even when the same individual operates the machine, the quality can vary (Apodi et al., 2018). The incapacity of the individual to retain tiny bits of cassava during the rubbing process causes hand grating to produce non-uniform particle sizes and significant losses (Haddad, 2015).

Since the beginning of cassava production and use till the present, the manual grating has been done with a variety of equipment. The laborious grating of cassava, however, exposes mold growth on the tuber and is less efficient. Additionally, it is unsuitable for commercial use (Ademakinwa et al., 2021). The manual method still produces the greatest results for regional processors or small-scale farms, despite its severe speed limits, high injury rates, extreme labor intensity, and exposure to mold growth. However, mechanical grating of cassava can grate the cassava in batches, increase processing speed, reduce labor input, and prevent direct contact with the operator when compared to manual grating. Cassava roots can be processed by traditional methods however, this can lead to low-quality products that are contaminated with extraneous objects and disease-causing organisms, have unacceptable amounts of cyanide, and are of poor quality.

2.6.1.1. Traditional graters

Grating cassava tubers using conventional graters makes the process tedious and labor-intensive. Over the years, several designs to reduce the stress in the manufacture and use of graters have been developed. The traditional method of grating cassava was by pounding it in a mortar with a pestle. Later, artisans developed hand graters.

The traditional cassava grating device is a straightforward metal plate with perforations that allows peeled cassava to be grated manually. But using this kind of tool will lead to insufficient crushing and a poor rate of cassava breaking. In the past, peeled cassava roots were either grated by hand power tools or mashed into a dough with a mortar and pestle. Additionally, manual labor not only requires a lot of time and effort but also results in contamination from dust and other foreign objects, which lowers the quality of the final product. Traditional tools used in cassava processing include millstone, grinding stone, pestle, and mortar.

Figure 8. Perforated metal plate grater. Source: Joseph (2017)

Figure 9. Mortar type grater. Source: Nhobgood (1988)

2.6.1.2. Hand graters

It requires about 10 to15 working hours to grate a tonne of peeled cassava (Esteves et al., 2019). Additionally, the entire root cannot be grated. 3 to 5% are ungrated, on average (Caicedo et al., 2018). Only roughly 20 kg/h can be grated by a skilled person. Hand graters are still common in rural and traditional communities. Formed of tin or galvanized iron, it has perforations that are typically made using a 3mm nail and hammer (Doydora et al., 2017b). It is difficult, time-consuming, and unsafe to use hand graters. To prevent grating of the fingertips, caution and dexterity are required.

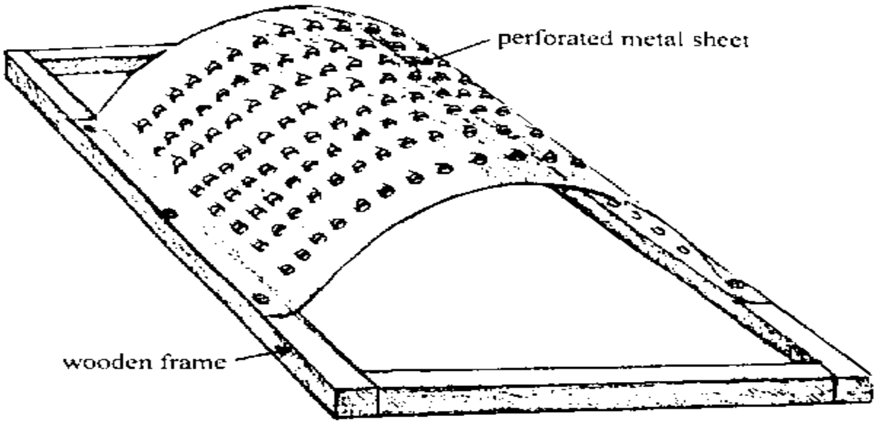


Figure 10. Hand grater. Source: Franklin (2003)

2.6.1.3. Stone graters

The choice of stone was based on the availability of suitable stones. Softer stones may be usable but these tend to wear out faster. The stone-toothed grater and the installation of teeth into graters have been discussed by several authors, including Farabee (1918 and 1924), Goldman (1963), Imthurn (1883), Taylor (1951), Whiffen (1915), and Wilbert (1972). The

Caribbean people have assumed that little stone flakes come from manioc grater boards since grater teeth manufacturing and insertion into the board were exclusively female activities that were passed down from mother to daughter. The teeth of these graters are small, bipolar flakes formed of quartzite, porphy, obsidian, or any other stone, and according to evidence, replication studies, and use-wear analyses, they can shatter in a conchoidal or semi-conchoidal way.

Figure 11. Stone and woody grater. Source: Nuer (2010)

2.6.2. Mechanical grating method

Efficient mechanized graters that use grating drums are needed to produce a sufficient quantity of cassava mash to meet market demand and standards. For large-scale cassava processing, mechanical cassava grating is absolutely necessary. The mechanical grater has many machine components that contact directly with the cassava tuber and subsequently grate it, producing high-quality, fresh end products.

This method primarily targets a bigger batch or quantity of tubers at once. Environmentally safe and non-toxic goods are produced by mechanical graters (Bello et al., 2020). Additionally, mechanical grating techniques finish the grating process in a single step, therefore additional steps are not necessary. Common prototype graters have functional systems including abrasive tools, drums, rollers, teeth, disks, and milling cutters that grate tubers mechanically to avoid risks and lessen labor-intensive manual grating.

It involves mechanical techniques for simultaneously grating and washing that makes use of conveyors, abrasive materials, and water splashes (Hassan, 2012). The cassava roots are ground into a mush by the cylinder surface's abrasive action, which rubs against them (Olumide, 2004). On a commercial scale, this method appears to be the most efficient and practical, but it faces significant difficulties due to the uneven forms, sizes, and lengths of the tubers. The mechanical means of cassava grating were recognized better than the manual way due to the high tuber loss and mechanical damages that occur during its operation (Egbeocha et al., 2016).

2.6.2.1. Mechanical graters

2.6.2.1.1. Dual-operational mode machine

Ndaliman, (2006), in his design of a dual-operational mode machine (operated both manually and electrically), sought to improve on the design of Adejumo (1995) who designed a wooden grater that was low in durability and had an effective performance of 60%. Thus, his design was made mostly of mild steel and had efficiencies of 92.4% and 91.4% when operated manually and electrically respectively.

Figure 12. Dual-operation cassava grater. Source: Ndaliman (2006)

2.6.2.1.2. Modified NCAM motorized grater

The modified NCAM motorized cassava grating machine consists of a trapezoidal shaped hopper made up of 2mm thick stainless steel sheet materials, the grating drum is made up of a cylindrical perforated galvanized sheet and the frame made from 50mmx50mm angle iron. The grating efficiency of the modified grater is 84%, grating capacity is 2.0 tons/day, the mechanical loss is 10.9% and quality performance efficiency is 92.23%.

Figure 13. Modified NCAM grater. Source: Ogunjirin et al. (2020)

2.6.2.1.3. Stationary or mobile cassava grater

The cassava grater (stationary or mobile type) has become a permanent feature of cassava processing in rural areas. This grater can grate at least two tonnes of fresh tubers per day, and the output of the grater differs from 300 kg to 500 kg per hour based on the diameter and speed of the rotary drum and the number of perforations per unit area of the drum surface; these parameters have not been standardized (Opandoh, 2014).

Figure 14. Stationary or mobile cassava grater. Source: Apodi et al. (2018)

2.6.2.1.4. NASENI mobile cassava grater

The grater comprises the main frame, hopper, tire on the wheel, grating drum, shoot, pulley, and a 6.6 Hp mover. It has a capacity of 300 up to 500kg/h. The prime mover can be cooled with water. It has dimensions of 1840 inch length, 1000-inch width, and 1600-inch height.

2.6.2.1.5. ARCADEM grater

It has a power drive of 5.2 Hp petrol or diesel engine and can run a matching electric motor. It has a production capacity of 300kg/h and dimensions (mm) of 1090 height, 1000 length, and 460 widths. Also, it has a grating drum made of stainless steel while the hopper and chute are made of either painted mild steel or galvanized steel.

2.6.2.1.6. Starron's cassava grater

It has a production capacity of 150kg/h which is relatively low and a fuel consumption of 1L/h. The overall dimensions (in inches) are 44×36×24 (Awotide et al., 2014)

2.6.2.1.7. The Jahn's grater

The Jahn grater is made up of a revolving drum and interchangeable flat blades with serrations that resemble saw blades. The individual blades, which come in lengths of 10, 20, and 30 cm, are constructed of mild steel that is roughly 1mm thick. They have a tooth along each long side and are 2 cm broad. The tips of the teeth may be 1.5 to 2.5 mm apart and 2 or 3 mm deep.

2.6.2.1.8. Niji Lukas's electrical grater

This with a capacity of 300kg/h is operated only electrically. It operates on a 3 phase, 5Hp, and 1400 rpm motor. It has the following dimensions (inches); 30×30×42 and costs US$1347.80 and is also quite expensive.

2.6.2.1.9. The International Institute of Tropical Agriculture (IITA)

The IITA Model designed by Y.W. Jeong is made of mild steel. To make the drum, the metal is cut to a circumference preferred by the manufacturer and then rolled with a rolling machine to form a cylindrical shaped drum. The chute is cut and shaped to fit the entrance of the rolling grater (IITA, et al., 2005).

2.6.2.1.10. Other designs

Various types of cassava grating machines have been developed (Akinyemi and Akinlua, 1999; Akande *et al.*, 2005; Ndaliman, 2006; Malomo et al, 2014). As regards the performance evaluation of cassava graters, not much work has been done beyond testing for the capacity and efficiency of the graters (Ndaliman, 2006; Akade 2008; Akanbi, 2014). Most graters are operated by a 5Hp diesel engine. Malomo et al (2014) went more in depth by carrying out a performance evaluation of an automated combined cassava grater or slicer using two cassava species. He found that the machine was affected by the specie and the size of the cassava tuber.

A combined cassava grater or slicer was developed by Temam (2020), this machine was effective with a grating capacity of 114.94 kg/hr with 325ml fuel consumption and a chipping capacity of 30.3kg/hr with 150ml fuel consumption. It comprised both the grating and chipping units; the power motor located midway between the two machines to be shared depending on the operation required.

Figure 15. Existing grater. Source: Temam (2020)

2.7. Power Source for Cassava Grating Machine

Human, engine, and electrical motors are among the well-known power source for cassava grating machines. However; to mechanize cassava grating operation either an engine or electrical motor was used as a power source because human lobar has been used for a longer period of time and no appreciable results were obtained. Because diesel and gasoline are widely available, farmers can employ motorized graters (James et al., 2012). While the electrical motor is also having a problem of affordability for rural areas of farmers but engine power was recommended due to its availability for the rural areas of farmers so, for this reason, diesel engine powered motor was used in this research work

2.8. Research Gap

Based on the literature review for cassava grating several machines were designed and developed. As to cassava processing, several equipment has been designed to replace manual grating. These include mechanized grater, motorized grater, hammer mill, disk grater, and hand grater (Bruinsma & Nout, 2020). Despite being mechanized, these machines had still limitations in grating capacity and efficiency. There were different types of cassava grating machine that was designed in the world, however, some are not economical to be used at a small-scale level but for high industries, the others have low grating efficiency, throughput capacity and food contamination because of mild steel could rust with time and consequently, affect the quality of grated mash. Generally, several cassava grating machines have been developed because of the efforts put in to research field, yet, relatively low-performance evaluation; including grating efficiency, has been the outcome, and this is due to the irregular shapes, weight, and sizes of the tubers (Hassan, 2012).

Most of the research work on the development of cassava grating machine was done out of the country therefore the means of obtaining this developed technology for farmers is not affordable. Thus, considering all the research gaps encountered in cassava grating therefore my research work filled the above-mentioned research gap and the non availability of locally developed and fabricated machines for cassava grating.

Currently, there is no cassava grating machine for the processing of cassava in the south, southwestern, and western parts of Ethiopia as well as in the country as a whole. Still, now cassava producer farmers are faced with a lack of cassava grating and other primary processing technology in Ethiopia. However; the cassava grating machine was developed by Temam (2020), which had the following drawbacks or limitations: The grating capacity of this machine was too low, the efficiency and percentage loss of machine was not evaluated, the outlet of the grating machine was not placed in the proper inclination, the hopper of the grating machine did not have proper length, the inclined part of hopper was not positioned in the proper inclination this forced the users to use wood to push cassava and the length and diameter of drum was too small. So, based on this limitation, all component of developed machine must be redesigned. Therefore, the aim of this study was to redesigned the existing grater and fill the technology gap in cassava processing in cassava growing areas of Ethiopia and to avail the technology for future intervention.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study of the development and performance evaluation of the cassava grating 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, and 39° 20' 0" E latitude, and longitude, respectively.

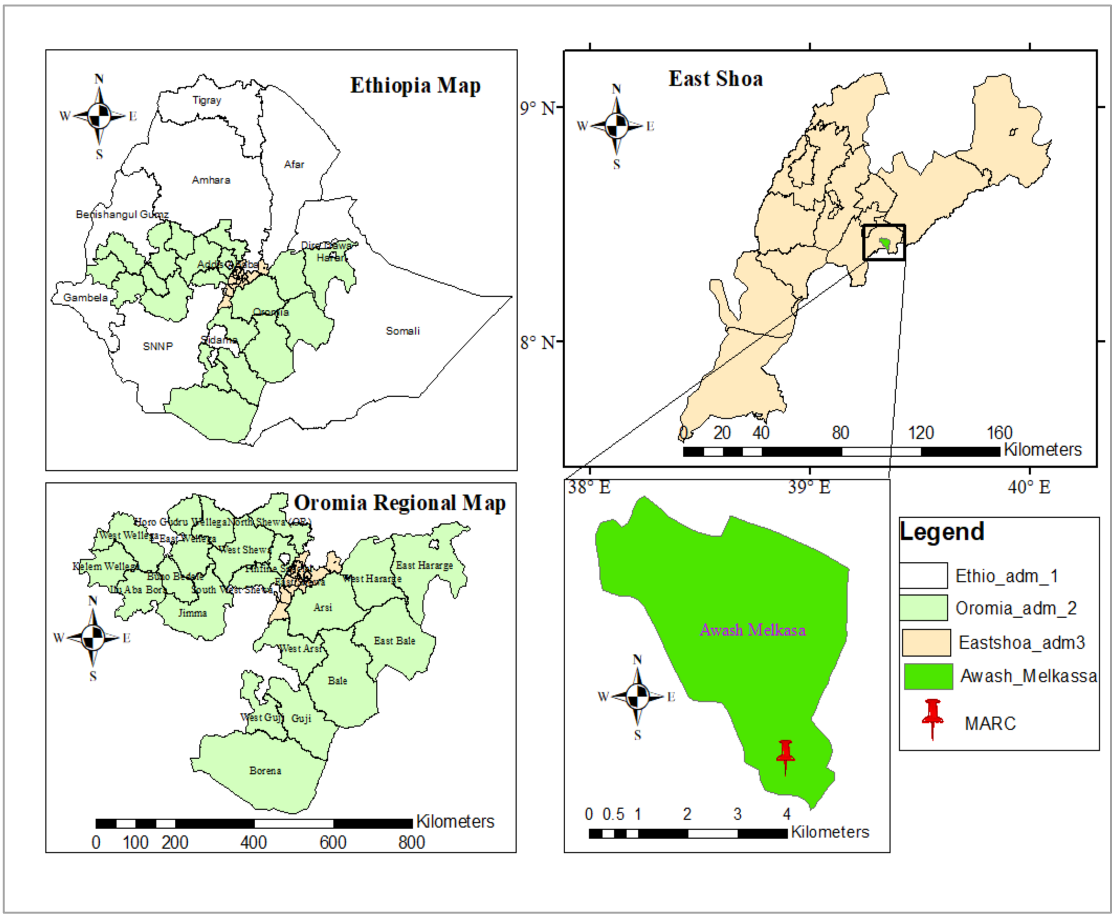


Figure 16. MARC map

3.2. Materials

In this research work to mechanize cassava processing, a mechanical cassava grating machine was constructed from locally available materials. During the fabrication of the grating machine, the strength of materials, and the mechanism were considered. According to Adetan et al. (2005), a good knowledge of the physical properties of the tuber is important to mechanize cassava primary processing.

In the fabrication of the cassava grating machine, the quality of the food as well as the durability of the material for the fabrication 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 fabrication as well as physical properties of the materials to be grated were given due consideration (Alhassan, 2020).

During the fabrication of component of the machine that had direct contact with the cassava tubers like a grating drum, a great concern as given to food contamination. Therefore, the grating drum was fabricated with a stainless-steel sheet metal. Whereas, other parts like the frame, shaft, drum cover, and chute were fabricated from square pipe, milled still round and stainless-steel sheet metal the high thickness and strength materials by considering the durability of the fabricated grating machine to meet the expected working lifetime.

3.2.1. Selection of materials

The materials selected for the manufacturing were based on ease of fabrication, toughness, machinability, availability, and cost. The materials to be used for fabrication were selected based on the engineering properties with an emphasis on consideration for the chemical and aesthetic characteristics of the materials. For this research work due to economic considerations and availability of the raw materials stainless steel sheet metal was mostly used for body parts and chuck materials while aluminum was chosen for the pulley.

Materials known to withstand the effects of vibration and impact forces caused by the motor operation, grating of feed materials, and other operational procedures was used in fabricating the cassava grater. It can also be said that to ensure durability and sustainability, strength, suitability, and local availability have to be considered when choosing design material (Alhassan, 2020).

All the machines, tools, and materials were used for the fabrication of the cassava grater listed below along with their application.

Table 1. Machines, tools, and materials were used for fabrication of cassava grater

No.	Machine/tools	Application	Specification
1	Lathe machine	Turning, facing, and boring	2500mm bed length
2	Drilling machine	Making holes	Radial max 45mm
3	Milling machine	For key way cutting	Universal
4	Rolling machine	Rolling sheet metal	6mm
5	Arc welding	For Welding	380V
6	Power hacksaw	For cutting	
7	Portable grinder	Grinding and cutting	220V
8	Spanner	Tighten and loosen the nut	Open and ring
9	Screwdriver	Tighten or loosen the screw	Open and ring
10	Hammer	kicking	1000g
11	Center punch	Pointing	
12	Bolt and nut	Connecting	(M6×20) mm
13	Paint	Coloring	1000ml
14	Belt	Power transmission	V- belt
15	Pulley	Power transmission	(150×80×30) mm
16	Engine Motor	Power source	5hp
17	Oven	To determine moisture content	
18	Tachometer	To check the rpm of the drum	Non contact
19	Knife	To reduce size	
20	Graduated cylinder	For fuel measurement	1000ml
21	Plastic container	To collect displaced water	15000ml
22	Digital Varner caliper	Measuring	150mm
23	Pocket meter	Measuring	3000mm
24	Measuring balance	Weighting	15000g
25	Labeled cylinder	Volume determination	4000ml

3.2.2. Source of experimental materials

For physical properties determination, preliminary test, as well as performance evaluation of fabricated cassava grating machine the sample of cassava tuber, was collected from Melkassa Agricultural Research Center fruit and vegetable research process and farmers of Wolayta zone, offa and sodo district.

3.2.3. Measuring instruments and tools

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 the 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 grating could be measured with an electronic weighing balance. The time of operation was recorded using a mobile stopwatch application while partial size reduction of cassava tuber was carried out by a knife manually. Therefore, a stopwatch, digital weighing balance, digital Varner caliper, knife, and pocket meter were used in the experiment. The operating speeds of the mechanical cassava grater was determined using a tachometer.

3.3. Methods

3.3.1. Determination of physical properties

3.3.1.1. Geometric mean diameter

The diameters of cassava tubers were measured using a digital venire caliper with an accuracy of 0.01 mm and a measuring range of 0.00 to 150.00 mm. This was done at the major diameter (head) taken as "a", intermediate diameter (middle) as "b", and minor diameter (tail) "c" based on the morphology of cassava tubers. The main concern to determine the diameter of cassava tubers might be to specify the clearance between the plates made by the drum. The mean values of GMD of cassava tubers were calculated (appendix I) using equation 3.1 (Nwachukwu & Simonyan, 2015).

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

Where: GMD = Geometric mean diameter (mm)

a = Major diameter (mm)

b = Intermediate diameter (mm)

c = Minor diameter (mm)

3.3.1.2. 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 could be 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 might be then immersed totally into the water filled container then the amount of water displaced was used to determine the volume of cassava tubers. Therefore, the volume of the cassava tuber determines to know the volume of the grating drum (Joshua & Simonyan, 2015).

3.3.1.3. Bulk density

The bulk density of tubers was determined by weighing the cassava tubers packed in a container of known weight and volume. The container having a volume in liters and a mass in kilo gram was filled with cassava tuber in a way that it might be at the top level of the containers. Then the container together with samples of cassava tuber to be weighted by a weighting balance of accuracy of 0.1g and a capacity of 15kg (Joshua & Simonyan, 2015).

3.3.1.4. Moisture content of cassava tuber

Moisture content for randomly selected and cleaned cassava tubers was determined. The moisture content was determined by dehydrating the samples at 105 ºC for 24 h in a drying oven, according to AOAC approved oven drying method (Memmert Ule500, Germany) (AOAC, 2005). The moisture content was calculated (appendix I) using the formula by Ndirika and Oyeleke (2006) as given in equation 3.2.

$$Mc\ (wb)\ \% = \frac{Ww-Wd}{Ww} \times 100 \qquad \text{……………………………………………………………}3.2$$

Where: Ww = the weight of wet sample (g)

Wd = the weight of dried sample (g)

Mc = moisture content wet basis

3.3.1.5. Angle of repose

The angle of repose of the cassava tubers samples was determined along the length of cassava tuber samples on three test surfaces namely wood, glass and sheet metal. Cassava tuber to be placed on the angle of repose device which was raised slowly until the frictional force between the tuber and the test surface (wood, glass or sheet metal) was overcome by the force of gravity and movement down the slope began. The angle, at which the cassava roots start to slide, was read from a graduated protractor attached to the device which was the angle of repose of the cassava tuber.

3.3.2. Redesign considerations

In the redesign of the cassava grating machine several factors were considered. To achieve optimum function for this machine, proper considerations were made to specify and identify some problems which hindered effective performance as in the former machines and effort was put to identify the factors and constraints as put together. The following were put under consideration:

- Workability and affordability.
- The availability of materials for fabrication.
- Strength of materials used for fabrication.
- Physical properties of materials to be handle.
- Effective grating and minimal loss of useful grated mash.
- Operational procedure.
- Safety, cost and maintenance.
- Easily assembly and disassembly of parts.
- The power, torque, and force required to grate the tubers.
- The quality of food to be handle, hence material that was not contaminate it.

Redesign approach for cassava grating machine

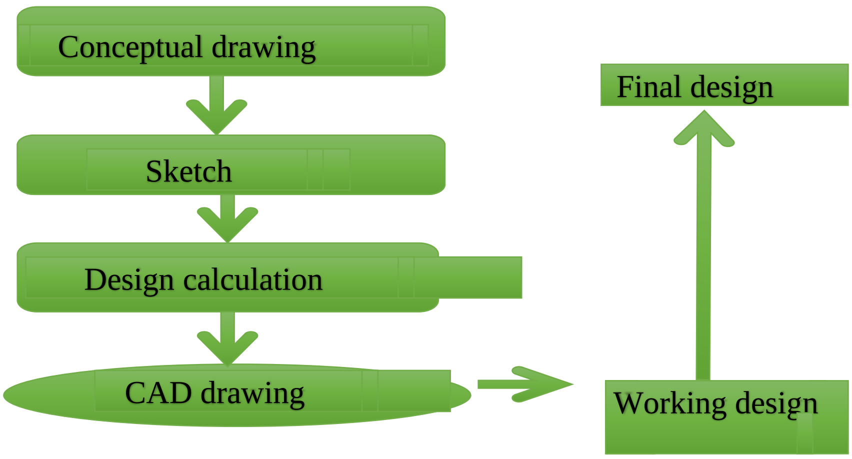


Figure 17. Redesign approach for cassava grater

3.3.3. Description of the developed cassava grating machine

The developed cassava grating machine shown below in figures 18 was composed the following components such as hopper, housing, grating drum, discharge chute, frame, shaft, pulley, bearing, v-belt, engine setting, bolt, and nut. The grating drum was made up of a cylindrical perforated stainless steel sheet metal which was held by a shaft passing through the rolled cylindrical sheet metal and it was welded in both side by circular discs. This drum was then wrapped with the perforated mesh, which were held in position through riveting and bolt. The machine frame supports the other parts of the cassava grating machine, as well as providing stability. It was subjected to the weighs of other members of the machine and also the torque and vibration from the grating drum and motor. The engine driven cassava grating machine consists of a trapezoidal shaped hopper made up of 1.5mm thick stainless steel sheet metal, the hopper was the receptacle through which cassava was admitted into machine for grating. The hopper was fixed at the top center of the housing, and the discharge chute was fixed at the opened bottom of the grating unit.

The grating machine had other components like bearing to enhance smooth rotation of the shaft; and bolts & nuts that fasten other components together. The overall length of the machine was 640mm, width of 440mm and height of 1380mm. When mechanically operated, the grating machine was coupled to an engine motor by a v- belt pulley on the shaft. The fabricated cassava grating machine was widely used in the peeled cassava tubers processing into cassava mash. This cassava grating machine was readily affordable for the farmers due to the fact that it was fabricated from locally sourced materials. The grating machine was simple to operate and it could be used for both household and market purposes. Its grating mechanism could be based on an abrasive cylinder because abrasive cylinder graters are easier to fabricate and have lower power requirements when compared with other type grater when the actual grating operation takes place on it. The continuous abrasive force delivered to the cassava tuber by the rough surface of the drum which was achieved by the rotating grating drum.

The developed machine had the following key features: The tooth angle for each grating surface was done at 32°, to ensure effective contact between the cassava tuber and the grating unit. The machine was fabricated from stainless steel, the reason to select stainless steel for fabrication of grater was as it had direct contact with the food to be processed and prevent contamination. The size of machine component was larger than the existing grater which means drum diameter was 400mm and drum length was 600mm for fabricated machine. A hopper shape was redesigned to guarantee safe feeding and grating. To ensure an effective cassava grating machine with good grating performance, the power required to grate the cassava, force required to grate the cassava, and the torque required to turn the shaft were calculated.

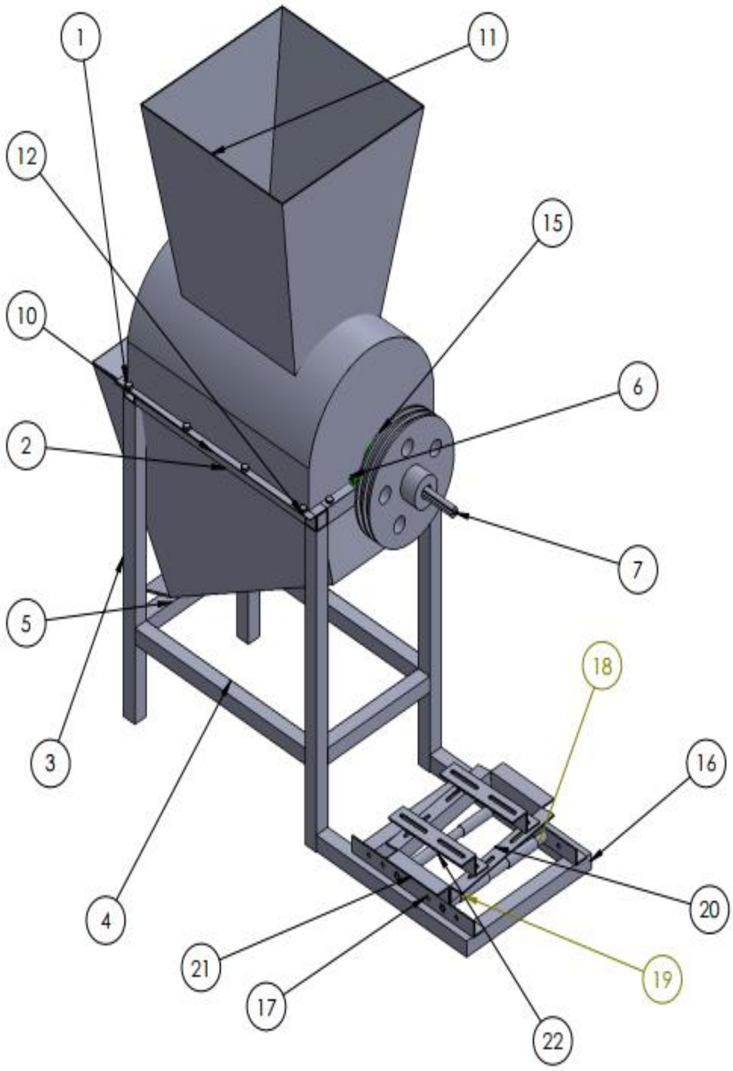


Figure 18. 3D drawing for grater

1. Frame width
2. Frame length
3. Frame height
4. Length support
5. Width support
6. Housing
7. Shaft
8. Grating drum
9. Circular plate
10. Discharge chute
11. Hopper
12. Bolt and nut
13. Rectangular plate
14. Bearing
15. Pulley
16. Rectangular pipe
17. Base angle iron
18. Hallow pipe larger
19. Hallow pipe smaller
20. Lower angle iron
21. Side angle iron
22. Upper angle iron

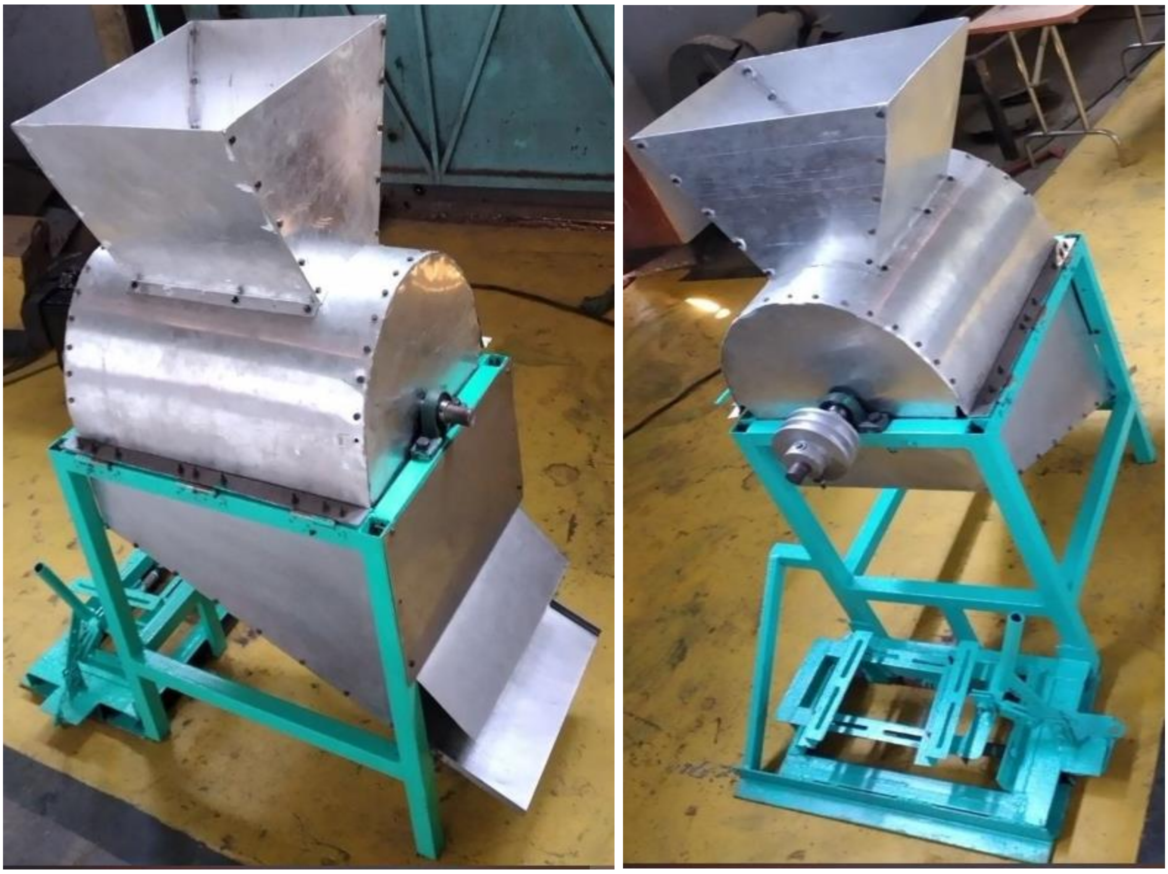


Figure 19. Protype of fabricated grater

3.3.4. Working principles of the developed cassava grating machine

The grating machine was composed of the grating unit where the pulverizing process takes place. The motions of the grating drum were transmitted through the v- belt, pulleys, shafts and bearings by the torque of the engine motor. The cassava tubers were hand fed simultaneously into the grater through the hopper into the grating unit while the grated cassava flows down into the discharge chute. Freshly harvested cassava was peeled manually and washed in clean water then introduced into the machine through the hopper these tubers came in contact with the grating drum, they were macerated into cassava pulp, this was achieved due to the perforations on the surface of the rotating grating drum. The rotating grater then reduces the cassava tuber into pulps. As the grating drum rotates, the perforated grating drum robs the cassava tubers continuously to grate it. It falls and goes through the discharge chute and collected by bowl or sack. The discharge chute was constructed of stainless steel and it would accept the pulp and sent it out into storage container because of its inclination.

Figure 20. Protype during operation

3.3.5. Redesign analysis and description of machine components

3.3.5.1. Hopper redesign

The fabricated cassava grating machine consists of a trapezoidal shaped hopper made up of 1.5mm thick stainless steel sheet metal. The hopper was the receptacle through which cassava was feed into the machine for grating. The machine hopper had the length of 500mm, width of 400 and the height was 400mm, and it was attached to housing and accommodates cassava tuber during grating.

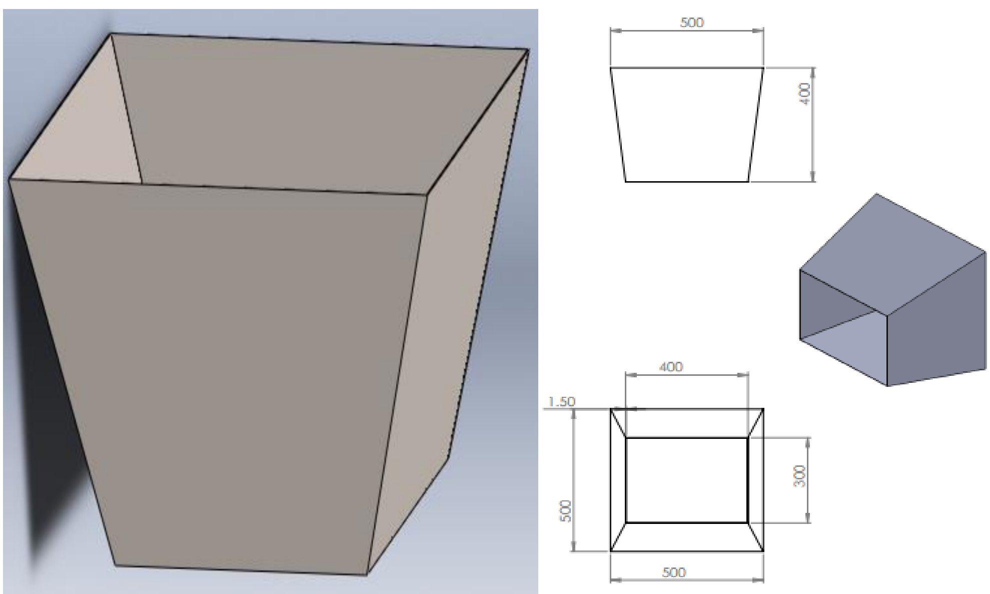


Figure 21. Detail view for redesigned hopper

A hopper with trapezoidal cross section was considered. According to Khurmi & Gupta (2005), the Volume of which was obtained as follow:

$V = \frac{1}{3}AH$………………………………………………..3.3

$V = \frac{1}{3}\ [0.5(0.5+0.4)\times0.4]\ \times0.4$

$V = \frac{1}{3}\times0.18\times0.4$

$V = 0.024m^3$

Where: A = the area of base (m^2)

H = the perpendicular height (0.4m)

b1 = hopper's top breath (0.5m)

b2 = hopper's bottom breath (0.4m)

3.3.5.2. Grating drum redesign

Grating drum was made from (600×400×2) mm stainless steel sheet perforated in cylindrical shape when the actual grating operation takes place on it. The continuous abrasive force delivered to the cassava tuber by the rough surface of the drum which was achieved by the rotating grating drum. The grating drum had a shaft that passed through it and supported by bearings at the two ends it moves in circular motion driven by power from 5hp diesel engine transmitted through the v-belt. This drum was then wrapped with the perforated mesh, it was attached by riveting and bolt. The drum was held by a shaft passing through the rolled cylindrical sheet and it was welded in place by circular discs in both sides. The diameter of the drum tooth was 4mm with 8mm tooth spacing. The tooth angle for each grating surface was 32° to ensure effective contact between the cassava tuber and the grating unit.

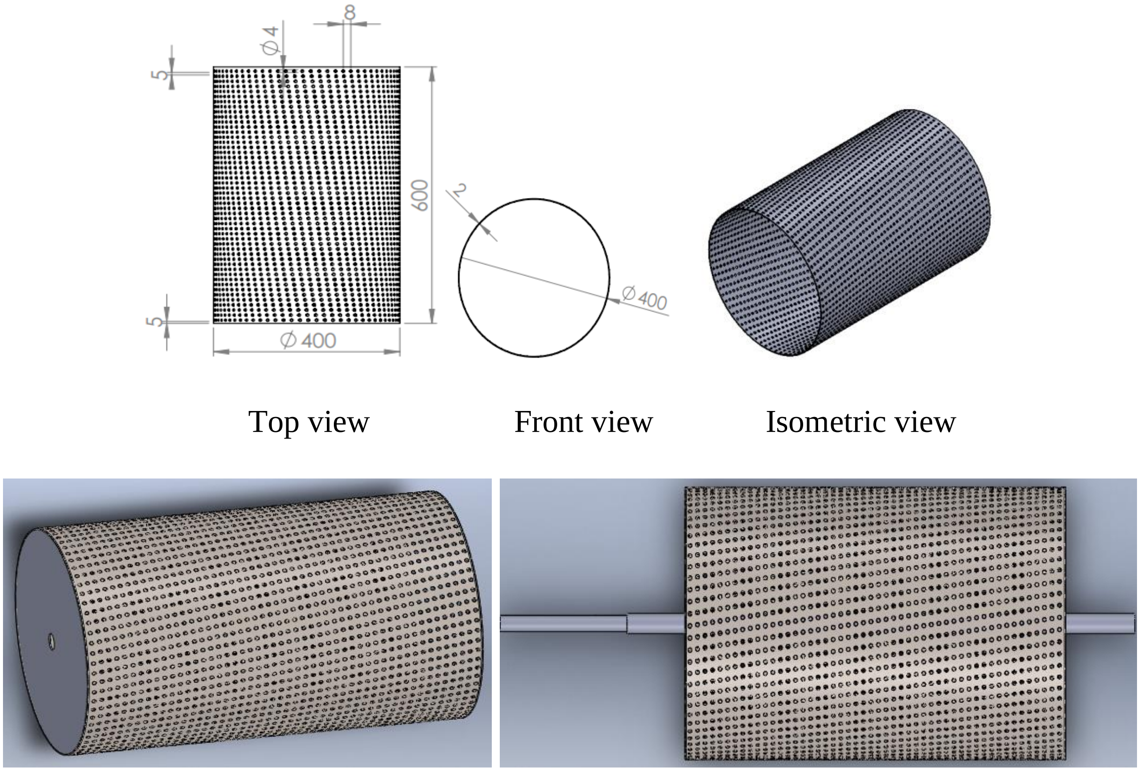


Figure 22. Redesigned grating drum

The grating drum was cylindrical in shape. According to Khurmi & Gupta (2005), the volume of cylinder was determined using equation 3.4

$V = \pi r^2 l$ ……………………………………………………………………………………3.4

$V = \frac{3.14 \times 0.4 \times 0.4 \times 0.6}{4}$

$V = 0.07536 m^3$

Where: V = the volume of cylinder (m^3)

r = the radius of cylinder (0.2m)

l = the length of drum (0.6m)

Circumference of the grating drum was given as:

$C = 2\pi r$……………………………………………………………………………………3.5

$C = 2 \times 3.14 \times 0.2$

$C = 1.256m$

The force acting on the cylinder drum was given as:

$F = V\rho g$……………………………………………………………………………………3.6

$F = 0.024 \times 7500 \times 9.8$

$F = 1,764\ N$

Where: g = the acceleration due to gravity, m/s^2

ρ = the density of a material for stainless, $7500 kg/m^3$

Determination of the grating force of the cassava tubers

The grating force of the cassava tubers can be calculated as follow:

$W = Mt \times g$ …………………………………………………………………………3.7

Where: Mt = total mass = maximum mass of cassava tubers for each cycle of gating + mass of grater.

g = acceleration due to gravity = $9.81 m/sec^2$

Therefore,

Maximum mass of cassava tubers for each cycle of grating = 15kg (Measured)

Mass of grating drum = 14.9kg (determined from mass properties of grating drum using solid work)

$Mt = 15kg + 14.9kg = 29.9kg$

Weight required by the grating machine

$W = Mt \times g = F$

$F = 29.9kg \times 9.81 m/s^2$

$F = 293.3N$

The grating force = 293.3N

Power required to grate the cassava tubers

$P = F \times V$ …………………………………………………………………………3.8

Where: P = Power required to turn the shaft

V = Speed

F= Force

$V = \frac{\pi DN}{60}$ …………………………………………………………………………3.9

Where: V = Speed

D = Diameter

N = Speed in revolution per minute

Therefore,

$P = \frac{Ma\pi DN}{60}$

$P = \frac{29.9 \times 9.81 \times 3.14 \times 0.1 \times 1500}{60}$

P = 2302.55W = 3.08hp

Considering a safety factor of 1.5 for optimum performance, reliability, and durability (Khurmi & Gupta, 2005).

P = 3.08×1.5 = 4.6hp ≈ 5hp

Determination of torque

The torque was obtained from the equation as follows:

T = F×r……………………………………………………………………………3.10

Therefore;

T = 293.3N×0.0635m

T = 18.62Nm

Where: T = Torque, Nm

F = Force, N

r = radius of driven pulley, m

3.3.5.2.1. Redesign of circular plate

For the two ends closing the drum circular stainless steel sheet metal was used and its volume was determined to be 2.512 $\times 10^{-4}m^3$ for a single plate using equation 3.11

$Vcp = \pi r^2 t$……………………………………...……...……………………………3.11

$Vcp = 3.14 \times 0.2^2 \times 0.002$

$Vcp = 0.000251m^3 = 2.512 \times 10^{-4}m^3$

Where: r = Radius of the circle (0.2m)

t = Thickness of plate (0.002m)

Vcp = Volume of the circular plate (m^3)

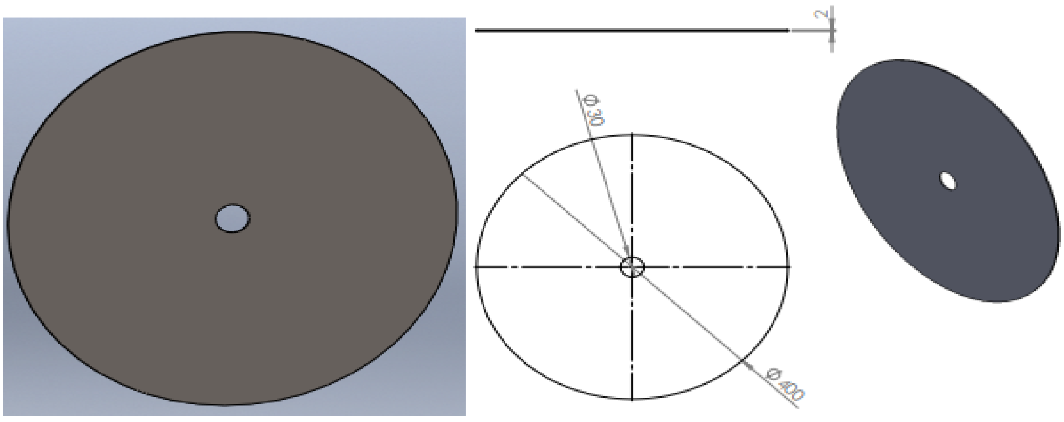


Figure 23. Drawing view of circular plate

3.3.5.2.2. Redesign of rectangular plate

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 3.12 was used to calculate the volume of a single plate that was $1.08 \times 10^{-4} m^3$.

$Vp = L \times w \times t$……………………………...…………………………………………….3.12

$Vp = 0.6 \times 0.06 \times 0.003$

$Vp = 0.000108 m^3 = 1.08 \times 10^{-4} m^3$

Where: L= Length of plate (0.6m)

w = Width of plate (0.06m)

t = Thickness of plate (0.003m)

Vp = Volume of plate (m^3)

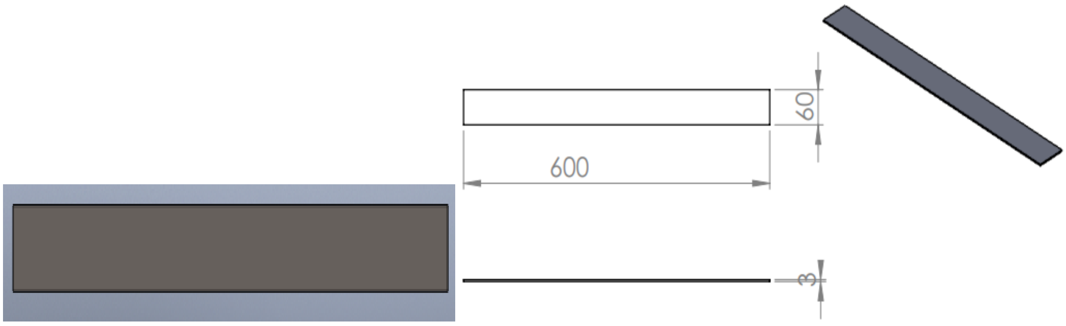
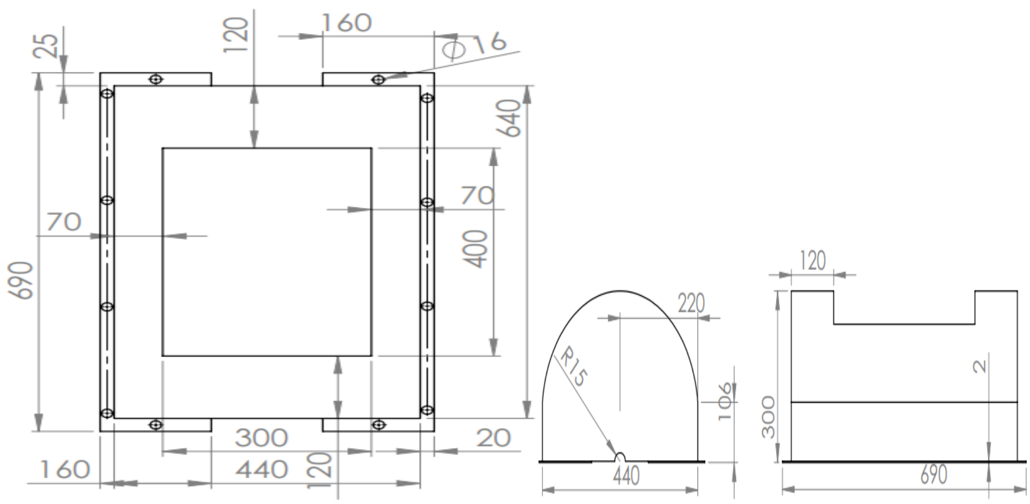


Figure 24. Drawing view of rectangular plate

3.3.5.3. Housing redesign

The grating assembly was enclosed in a cylindrical housing that would hold the cassava tuber. The drum housing was made from stainless steel sheet metal with length of 640mm, width of 520mm, height of 350mm and thickness of 2mm. It had the shape of a half cylinder and was used to protect the specks of cassava tuber to operator and also it was helped for proper grating takes place.



Top view Front view Left view

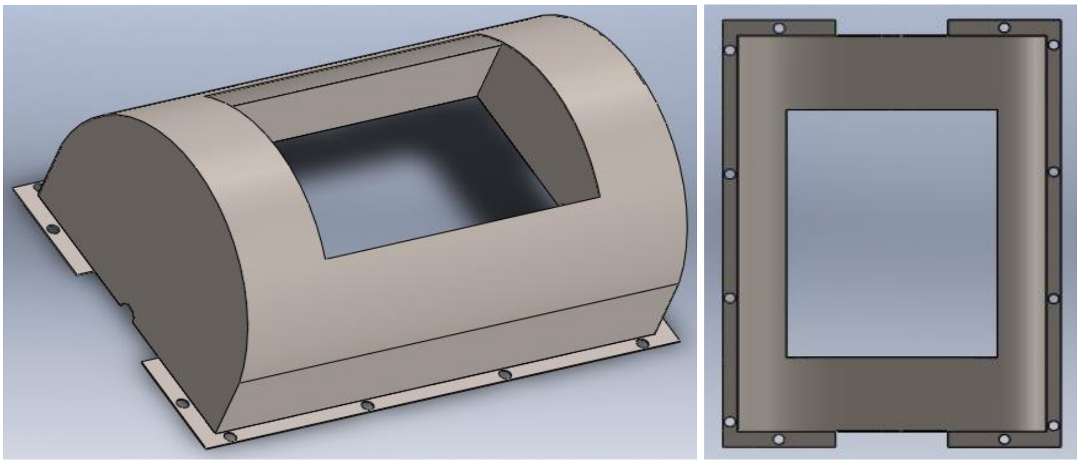


Figure 25. Isometric view for redesigned housing

3.3.5.4. Discharge chute redesign

The delivery chute was made from a 1.5mm thickness of stainless-steel sheet metal with 48.6° inclination. The angle of inclination of the discharge chute was related to the repose angle of the cassava tuber but it is the dependent moisture content of the tubers. The discharge chute was a continuation of the grater's frame connected to the housing. It directs the flow of the grated cassava to a storage pit or receptacle.

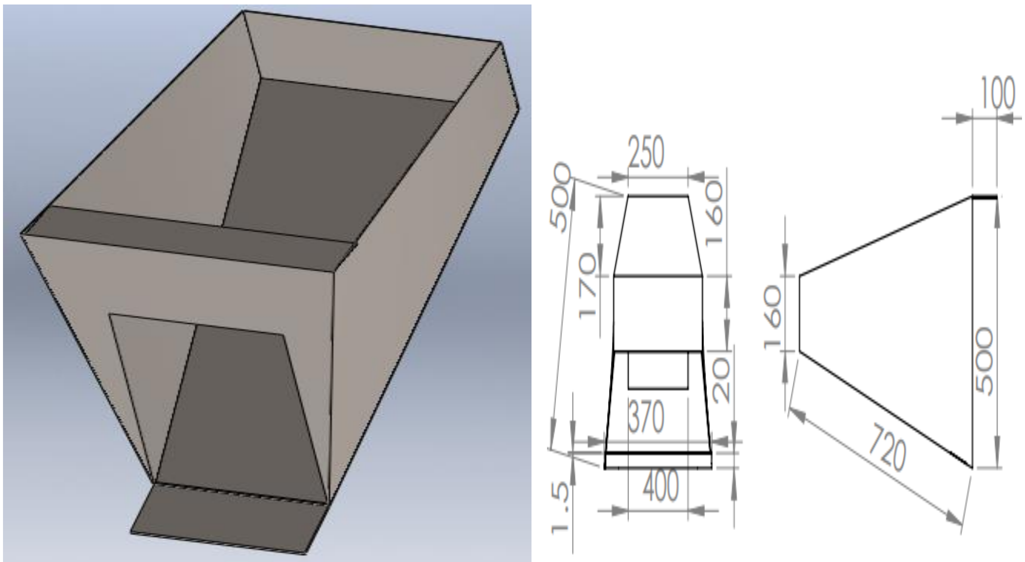


Figure 26. Redesigned discharge chute

3.3.5.5. Frame redesign

The frame of the grating machine was made from hallow square pipe with length of 640mm, width of 440mm and height of 750mm. The machine frame supports the other parts of the cassava grating machine, as well as providing stability. It was subjected to the weighs of other members of the machine and also the torque and vibration from the grating drum and motor. Hallow square pipe mild steel of 4mm thickness was selected for the machine frame. The choice of mild steel material was due to its strength and rigidity for the overall machine. The frame as shown below must be rigid so it can sustain loading.

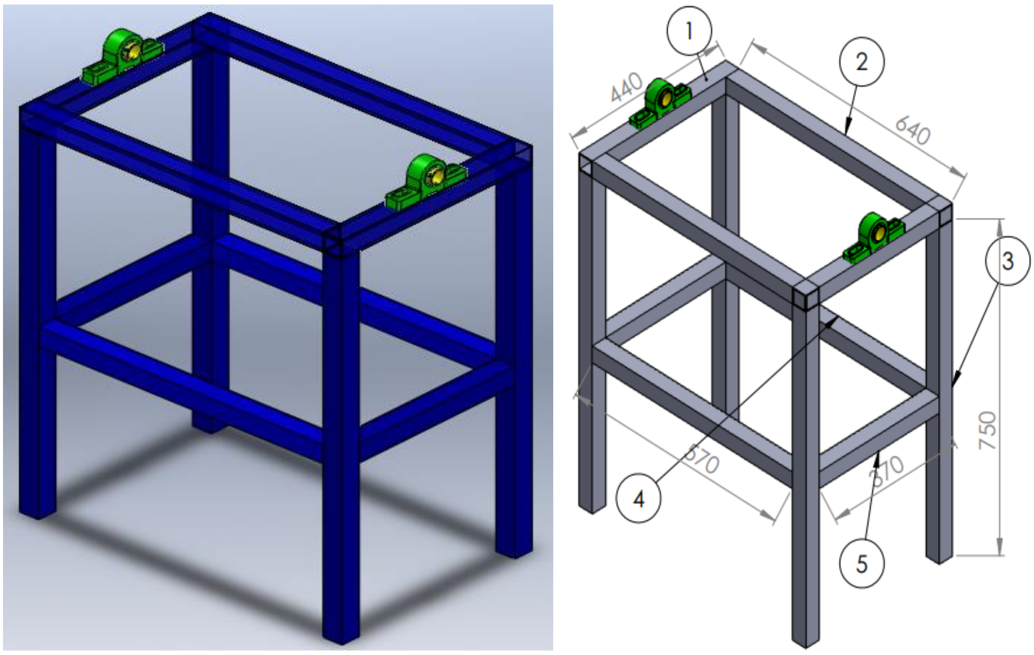


Figure 27. Frame

3.3.5.6. Shaft redesign

A Shaft is a common and important machine element. It is a rotating member, in general, has a circular cross-section and is used to transmit power. In order to transfer the power from the shaft, the various members such as pulleys, bearings, drum etc. are mounted on it.

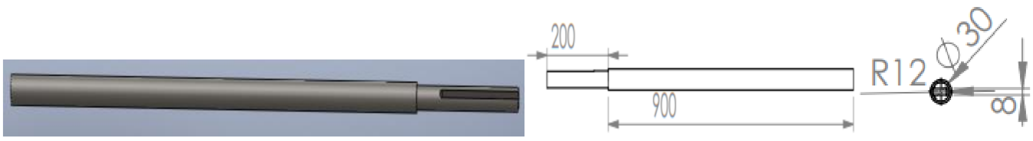


Figure 28. Redesigned shaft

The diameter of the shaft subjected to fluctuated load can be estimated using 3.13 (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 & Gupta, 2005).

$$d^3 = \frac{16}{\pi \tau all}\sqrt{(KbMb)^2 + (KtMt)^2} \quad \text{...} 3.13$$

Where: d = Diameter of the shaft (mm)

τall = Allowable stress (Nm^{-2})

Kb = Combine shock and fatigue factor applied to bending moment

Mb = Bending moment (Nm)

kt = Combine shock and fatigue factor applied to torsional moment

Mt = Torsional moment (Nm)

The amount of torque exerted on the motor pulley by an engine motor of 5hp and speed of 1500rpm was determined to be 23.7Nm by using equation 3.14 (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 29.6Nm.

$$T = \frac{60P}{2\pi N} \quad \ldots\ldots 3.14$$

$$T = \frac{60 \times 3728.5W}{2 \times 3.142 \times 1500rpm}$$

$$T = \frac{223710}{9{,}426}Nm$$

T = 23.7Nm

Where: P = Engine motor power (W)

N = Engine motor speed (rpm) and

T = Torque (Nm)

The torque and tension on the drum side were calculated because the drum side torque and tension were used in the determination of shaft diameter. For the drum side, toque and tension calculations use the relation between speed and torque as equation 3.15 (Khurmi & Gupta, 2005).

$$\frac{Tm}{Tdr} = \frac{N2}{N1} \quad \ldots\ldots 3.15$$

$$Tdr = \frac{N1}{N2} \times Tm$$

$$Tdr = \frac{1500}{1100} \times 29.6$$

$$Tdr = 1.36 \times 29.6Nm$$

Tdr = 40.4 Nm

Tdr = (T1-T2) r2

$40.4Nm = (T1-T2)\ N \times 0.068m$

T1-T2 = 594.1N……………………………………………………………………a’

Where: Tm = Torque on motor pulley (Nm)

Tdr = Torque on drum pulley (Nm)

N1 = Motor speed (rpm)

N2 = Drum speed (rpm)

r2 = Radius of driven pulley (m)

According to Khurmi and Gupta (2005), the wrap angle and angle of the lap for an open belt can be calculated using equations 3.16 and 3.17 respectively.

$$\text{Sin}\alpha = \frac{r2-r1}{c} \quad \ldots\ldots 3.16$$

Where: r1 = Radius of drive pulley (mm)

r2 = Radius of driven pulley (mm

c = Center distance between two pulleys (mm)

$\alpha =$ Wrap angle (°)

$$\theta = 180 \pm 2\sin^{-1}\left(\frac{D2-D1}{2C}\right) \quad \ldots\ldots 3.17$$

Where: θ1 = Angle of lap for driving pulley (rad)

θ2 = Angle of lap for driven pulley

C = Centre to center distance between driving pulley and driven pulley

$$C = \frac{(D1+D2)^2}{2} + D1 \quad \ldots\ldots 3.18$$

Where: D1 = Diameter of drive pulley

D2 = Diameter of driven pulley

According to Khurmi and Gupta (2005), the belt tension can be determined using equation 3.19.

$$2.3\log\left(\frac{T1}{T2}\right) = \mu\theta \quad \ldots\ldots 3.19$$

Where: θ = angle of lap for open belt

μ = coefficient of friction

T1= Tension in the tight side of the belt

T2 = tension in the slack side of the belt

From equations 3.16, 3.17, and 3.18 warp angle, lap angel and center distance for drum side belt and pulley can be calculated as shown below.

$$C = \frac{(D1+D2)^2}{2} + D1$$

$$C = \frac{(0.1+0.136)^2}{2} + 0.1$$

$C = \frac{0.0515}{2}+0.1$

$C = 0.13m$

$\mathrm{Sin}\alpha = \frac{r2-r1}{C}$

$\mathrm{Sin}\alpha = \frac{68-50}{130}$

$\mathrm{Sin}\alpha = 0.138$

$\alpha = 7.95°$

$\theta = 180 \pm 2\sin^{-1}\frac{(D2-D1)}{2C}$

$\theta = 180 - 2\sin^{-1}(\frac{0.136-0.1}{2\times 0.13}) = 164.08°$

Converting the angle from degree to radian;

$\theta = 164.08° \times \frac{\pi}{180°}$

$\theta = 2.86rad$

From belt tension equation 3.19

$2.3\log\left(\frac{T1}{T2}\right) = \mu\theta$

Take coefficient of static friction between the aluminum pulley and rubber belt was 0.4 (Khurmi and Gupta, 2005).

$2.3\log\left(\frac{T1}{T2}\right) = 0.4 \times 2.86$

$\log\left(\frac{T1}{T2}\right) = \frac{0.4\times 2.86}{2.3} = 0.5$, take anti log

$\frac{T1}{T2} = e^{0.5} = 1.65$

$T1 = 1.65T2$………………………………………………………………………………. b’

From equation a’ and b’

$T1 - T2 = 594.1$ and $T1 = 1.65T2$

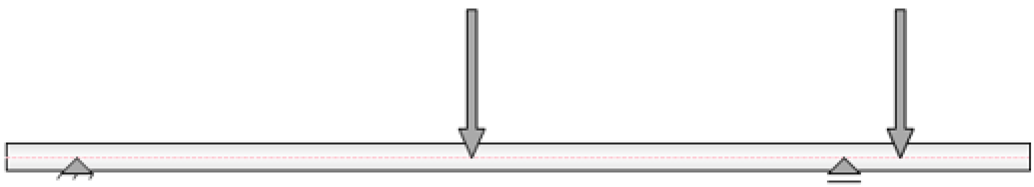
$1.65T2 - T2 = 594.1$

$0.65T2 = 594.1$

$T1 = 1508N$

$T2 = 914N$

Therefore, the load on the shaft due to the belt was the sum of tension on both in the tight side of the belt and in the slack side of the belt. Which means 1,508N + 914N = 2,419N 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 weight determination, the total mass of the drum was 14.9kg and the machine is redesigned to be loaded a maximum of 15kg. Therefore, the weight due to drum and cassava tubers was $29.9\times 9.81 = 293.3N$. The shear force, bending moment and the reaction force correspond to bearing support can be determined by analysis of shaft using Autodesk inventor 2016.



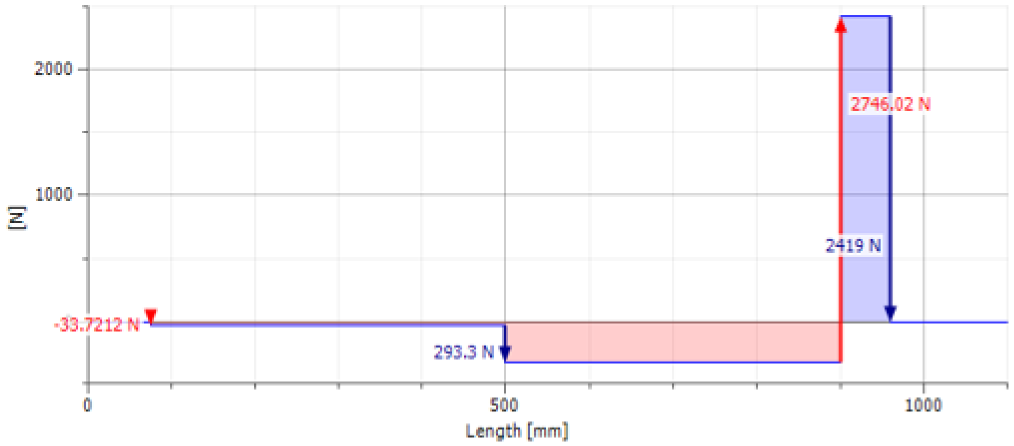


Figure 29. Shear force diagram

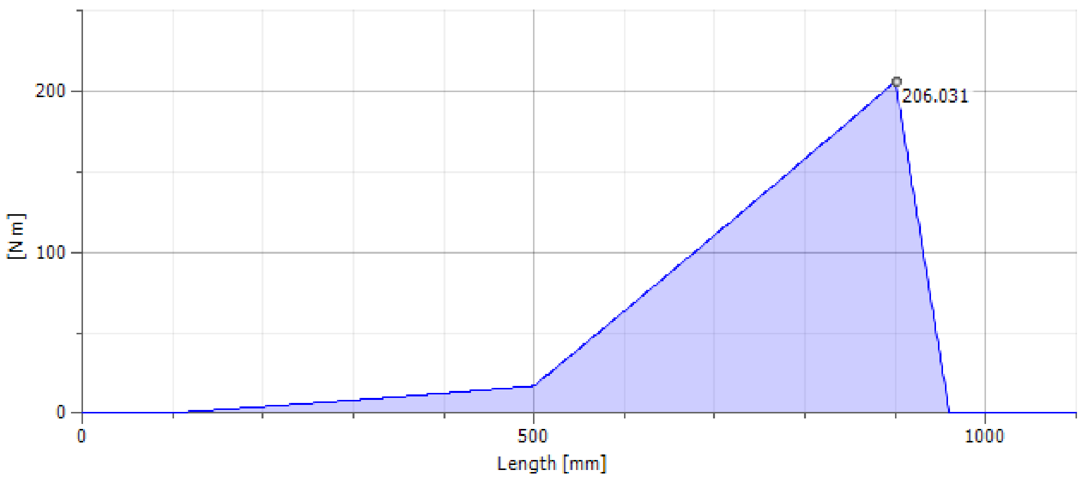


Figure 30. Bending moment diagram

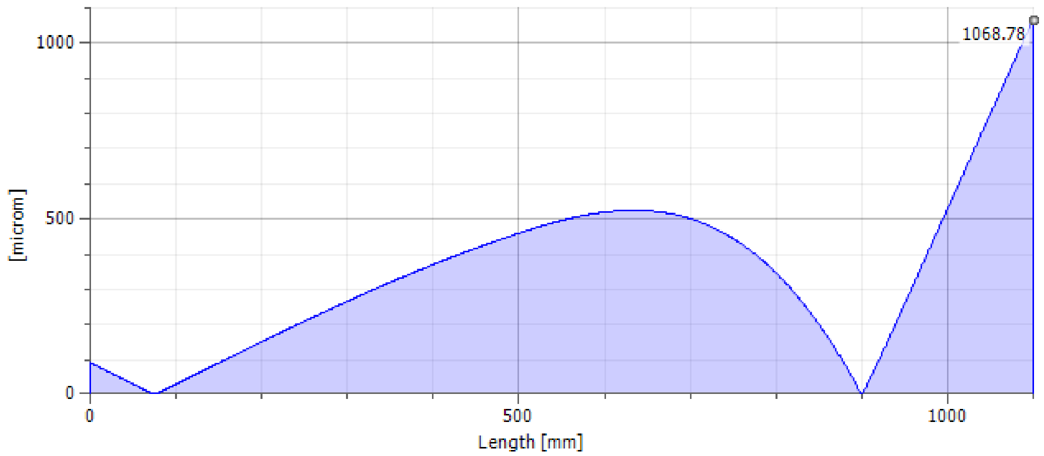


Figure 31. Deflection

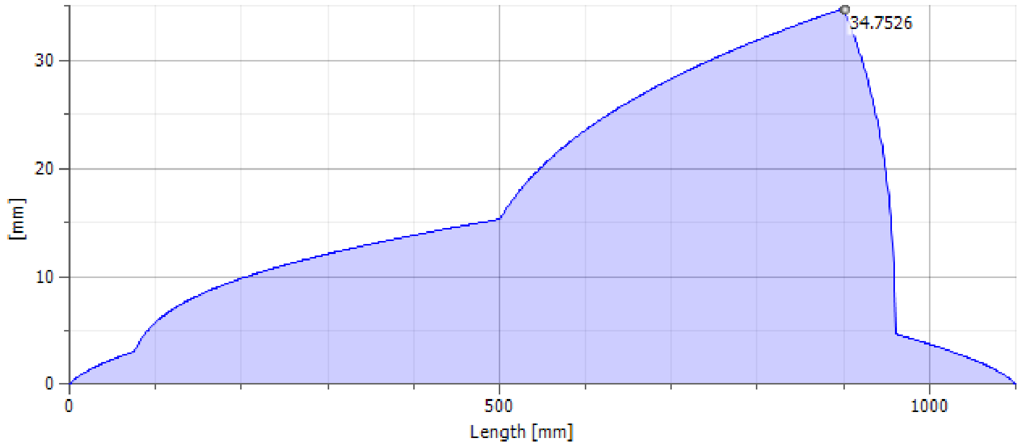


Figure 32. Ideal diameter

For the shaft with the keyway, the allowable stress τ should not exceed 40 MN/m^2 (Khurmi & Gupta, 2005). From the bending moment diagram, the maximum bending moment was Mb = 206031×10^3Nmm, from equation 3.14 the torque applied on the shaft Mt = 23.7×10^3Nmm and from equation 3.13 diameter of shaft can be calculated as:

$d^3 = \frac{16}{\pi\tau all}\sqrt{(KbMb)^2 + (KtMt)^2}$

$d^3 = \frac{16}{3.14\times40}\sqrt{(1.2\times 206031Nmm)^2 + (1.5\times 23700Nmm)^2}$

$d^3 = \frac{16}{125.68}\sqrt{(6.11\times 10^{10}mm^2) + (1.26\times 10^9 mm^2)}$

$d^3 = 0.13\sqrt{6.24\times 10^{10}}mm$

$d^3 = 0.13 \times 249779.97mm$

$d = \sqrt[3]{32471.39mm}$

$d = 31.9mm \approx 30mm$

3.3.5.7. Pulley redesign

Among well-known power transmission elements, pulleys were one of the most common means of power transmission, indeed they require careful design. 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.

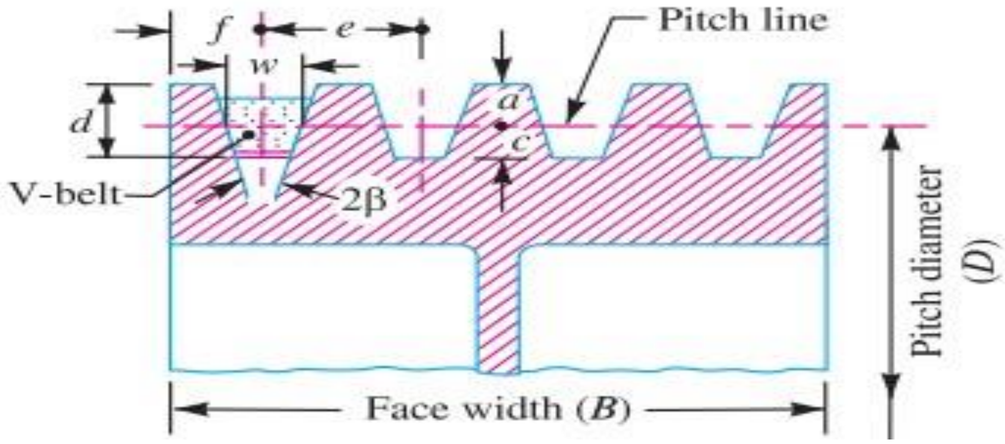


Figure 33. Cross section of v-groove pulley

Table 2. Dimension of standard v-grooved pulley

Types of belts	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 width of the pulley (B) was usually considered to be 25% greater than the width of belt (b) and equation 3.20 as suggested by (Richard and Nisbett, 2011) can be used to estimate the width of the pulley for the design of intended cassava tubers grating machine.

$B = b + 0.25b = 1.25b$……………………………………………………………………3.20

Where: B = Width of pulley (mm) and b = Width of belt (mm)

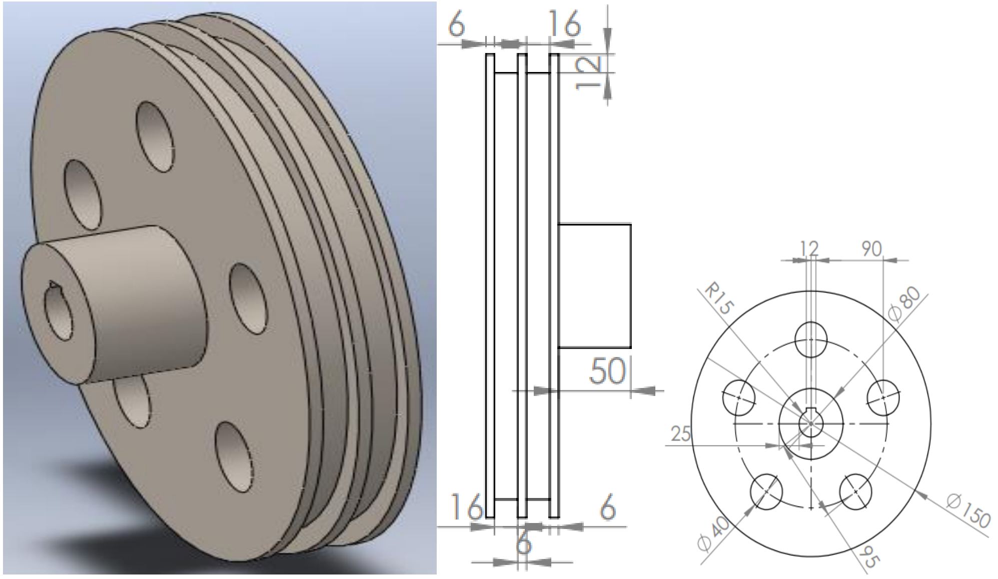


Figure 34. Drawing view for redesigned pulley

Velocity ratio for belt drive is the ratio between the velocity of the driver and the follower (driven). It may be expressed mathematically as:

$$\frac{N2}{N1} = \frac{D1}{D2} \qquad \text{3.21}$$

$$D2 = \frac{N1 \times D1}{N2}$$

$$D2 = \frac{1500\text{rpm} \times 100\text{mm}}{1100\text{rpm}} = 136\text{mm}$$

Where: D1 = diameter of the driver = 100mm

D2 = diameter of the driven

N1 = speed of the driver = 1500rpm

N2 = speed of the driven = 1100rpm

If appropriate speed of motor 1500rpm was selected to be able to overcome the load. The optimum speed of drum was chosen as 1100rpm due to the grating of material in the modified cassava grater. The pulley size decreases, the grating time also decreases. This is because smaller pulleys have faster operating speed than larger ones according to studies by Esteves et al. (2019).

3.3.5.8. Belt selection

Selection of belt needs due integrated consideration about types, dimension 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 3.22 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 3.23 center distance between pulley was calculated.

Table 3. Dimension of standard v-belt

Types of belts	Power range in kw	Minimum pitch diameter of pulley (D)mm	Top width	Thickness (t) mm
A	0.7-3.7	75	13	8
B	2-15	125	17	11
C	7.5-75	200	22	14
D	20-150	355	32	19
E	30-350	500	38	23

Source: Khurmi and Gupta (2005).

Therefore, according to Khurmi and Gupta (2005), the nominal pitch length "L" can be determined using equation 3.22 therefore, the belt length can be obtained as follow:

$$L = 2C+1.57(D2+D1) + \frac{(D2-D1)^2}{4C} \quad \text{……} 3.22$$

$$L = 2(0.13) +1.57(0.136+0.1) + \frac{(0.136-0.1)^2}{4(0.13)}$$

L = 1.14m

L = 1140mm, took as standard 1,270mm

The center-to-center distance between driver and driven pulley was given as:

$$C = \frac{(D1+D2)^2}{2} +D1 \quad \text{……} 3.23$$

$$C = \frac{(0.1+0.136)^2}{2} +0.1$$

C = 0.13m

Where: D1 = the diameter of driver pulley, m

D2 = the diameter of driven pulley, m

L = the length of belt, m

C = the distance between driving and driven pulley, m

Determination of wrap angle

$$\text{Sin}\alpha = \frac{r2-r1}{c} \quad \text{……} 3.24$$

$$\text{Sin}\alpha = \frac{68-50}{130}$$

$\text{Sin}\alpha = 0.138$

α = 7.95°

Where: r1 = Radius of drive pulley (mm)

r2 = Radius of driven pulley (mm)

c = Center distance between two pulleys (mm)

α = wrap angle (°)

Determination of lap angle

However, for open belt, angle of lap was given as:

$\theta = 180 \pm 2\sin^{-1}(\frac{D2-D1}{2C})$……………………………………………………………3.25

$\theta = 180 - 2\sin^{-1}(\frac{0.136-0.1}{2\times0.13}) = 164.0°$

Converting the angle from degree to radian;

$\theta = 164° \times \frac{\pi}{180°}$

θ = 2.86rad

Where: θ = Angle of lap (rad)

C = Centre to center distance between driving pulley and driven pulley

Determination of belt tension

$2.3\log(\frac{T1}{T2}) = \mu\theta$…………………………………………………………………………3.26

$2.3\log(\frac{T1}{T2}) = 0.4 \times 2.86$

$\log(\frac{T1}{T2}) = \frac{0.4\times2.86}{2.3} = 0.5$

$\frac{T1}{T2} = e^{0.5} = 1.66$

T1 = 1.65T2………………………………………………………………………………a

Where: θ = angle of lap for open belt

μ = coefficient of friction

T1= Tension in the tight side of the belt

T2 = tension in the slack side of the belt

Power transmitted by belt

Power transmitted by the v-belt and speed of the belt can be calculated using equations 3.27 and 3.28 (Kuwabara et al., 1998).

P = (T1-T2) V…………………………………………………………………………3.27

3,728.5 = (T1-T2) 7.85

$T1\text{-}T2 = \frac{3728.5}{7.85} = 474.97$

T1 = 474.97+T2……………………………………………………………………………b

Equating both equation a and b

1.65T2 = 474.97+T2

1.65T2-T2 = 474.97

0.65T2 = 474.97

T2 = 730.7N

Therefore;

T1 = 474.97+T2

T1 = 474.97+730.7

T1 = 1,205.7N

T = T1+T2 = 1,205.7N +730.7N = 1,936.4N

P = (1205.7-730.7) × 7.85

P = 3,728.75watt

$V = \frac{\pi DN}{60}$……………………………………………...3.28

$V = \frac{3.14 \times 0.1 \times 1500}{60}$

V = 7.85m/sec

Where: P = Belt power (watts)

V = Belt speed ($msec^{-1}$)

N = Speed of pulley (rpm)

D = Diameter of pulley (m)

The number of belts required to transmit the power of the motor to the drum can be determined using equation 3.29 (Khurmi and Gupta, 2005).

Number of belts required = Motor power/power per belt……………………………….3.29

Number of belts required = $\frac{3,728.5}{3,728.75} = 1$

3.3.5.9. Bearing selection

Bearings are precision design used to support the shaft and permit relative motion between the contact surfaces of the members while carrying load. A bearing can be selected based on its load carrying capacity, life expectancy, and reliability. In addition, a bearing must have a high enough load rating to provide an acceptable combination of life and reliability (Khurmi and Gupta, 2005.

Table 4. Radial bearing numbers and their implication

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

3.3.6. Determination weight of machine component

3.3.6.1. 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 3.36 (Khurmi and Gupta, 2005).

$Ash = \pi \times r^2 sh$……………………………………………………………………3.30

$Ash = 3.14 \times 15^2 = 706.5mm^2$

$Ash = 7.065 \times 10^{-4} m^2$

Where: ASh = Area of shaft (mm^2) and

rSh = radius of shaft (mm).

The volume of the shaft was determined using equation 3.37 (Khurmi and Gupta, 2005).

$Vsh = Ash \times Lsh$…………………………………………………………………3.31

$Vsh = 7.065 \times 10^{-4} m^2 \times 1.1m$

$Vsh = 77.715 \times 10^{-5} m^3$

Where: VSh = Volume of the shaft (m^3) and

LSh = Length of the shaft (m)

The mass of the shaft was determined using equation 3.38 (Khurmi and Gupta, 2005).

$Msh = Vsh \times \rho$……………………………………………………………………3.32

$Msh = 77.715 \times 10^{-5} m^3 \times 7{,}700 kgm^{-3}$

$Msh = 5.98kg \approx 6kg$

Where: MSh = Mass of the shaft (kg)

VSh = Volume of shaft (m^{-3}) and

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

The weight of the shaft was determined using equation 3.39 (Khurmi and Gupta, 2005).

$Wsh = Msh \times g$………………………………………………………………………3.33

$Wsh = 6 \times 9.81 =$

$Wsh = 58.86N$

Where: WSh = Weight of shaft (N)

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

3.3.6.2. Weight of grating drum

The drum was made from a set of perforated stainless steel sheet metal. The mass of the drum was determined 14.9kg from mass property drum using solid work and the weight of the drum was calculated to be 146.17N by using equation 3.40 (Khurmi and Gupta, 2005).

Wd = Md ×g………………………………………………………………………….3.34

Wd = 14.9×9.81

Wd = 146.17N

Where: Wd = Weight of drum (N)

Md = Mass of drum (kg)

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

3.3.6.3. Weight of hopper

Also, the mass of the hopper was determined 1.04kg from mass property of hopper using solid work. The weight of hopper was given as:

Wh = Mh×g…………………………………………………………………………3.35

Wh = 1.04× 9.81

Wh = 10.202N

Where: Wh = Weight of hopper (N)

Mh = Mass of hopper (kg)

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

3.3.6.4. Weight of pulley

The mass of the pulley was determined 3.05kg from mass property of pulley using solid work. The weight of the pulley was calculated using equation 3.42 (Khurmi and Gupta, 2005).

Wp = Mp×g…………………………………………………………………………3.36

Wp = 3.05×9.81

Wp = 29.92N

Where: Wp = Weight of aluminum pulley (N)

Mp = Mass of aluminum pulley (kg)

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

3.3.7. Experimental procedure

Before conducting the actual test of the fabricated machine, a preliminary test can be conducted at four levels of drum speed and three levels of feed rates based on drum speed of 1100rpm, 1200rpm, 1300rpm and 1400rpm corresponding to feed rate 5kg/min, 10kg/min and 15kg/min. During the preliminary test, it was observed that the drum speed of the machine beyond 1400rpm, caused vibration, loss of mash, and return out the feed but the drum speed below 1100rpm also caused too low throughput capacity, stopping operation and ungrated cassava. The four levels of drum speed and three levels of feed rates were selected for evaluating the grater performance on cassava tuber according to studies by Esteves et al. (2019).

The performance test was carried out at the MARC using freshly harvested cassava tuber from farms of Wolayta zone, offa district. For performance evaluation, a total of 360kg of fresh cassava tubers Hawassa 4 variety free from damage, scratches, deterioration, and abrasion might be used for the entire test run. A Hawassa variety should be selected because of its availability and was well known for its high production capacity in the Wolayta zone and other areas of SNNPR. The machine was run using a 1100rpm, 1200rpm, 1300rpm and 1400rpm drum speed for 5kg/min, 10kg/min, and 15kg/min of feed rate with three replications.

3.3.8. Experimental design

The experiment was carried out by randomized block factorial design with drum speeds as a blocking factor and the levels of drum speed with feed rate taken as treatment combination. Each experiment to be replicated three times to have 36 experimental units (4×3×3 = 36).

Table 5. Treatment combination for experiment

No.	Treatment combination	Drum speed (rpm)	Feed rate (kg/min)
1	V1F1	V1 = 1100	F1 = 5
2	V1F2	V1 = 1100	F2 = 10
3	V1F3	V1 = 1100	F3 = 15
4	V2F1	V2 = 1200	F1 = 5
5	V2F2	V2 = 1200	F2 = 10
6	V2F3	V2 = 1200	F3 = 15
7	V3F1	V3 = 1300	F1 = 5
8	V3F2	V3 = 1300	F2 = 10

9	V3F3	V3 = 1300	F3 = 15
10	V4F1	V4 = 1400	F1 = 5
11	V4F2	V4 = 1400	F2 = 10
12	V4F3	V4 = 1400	F3 = 15

V = drum speed, F = feed rate

3.3.9. Independent variables

The independent variables were four level of drum speed (V1 = 1100rpm, V2 = 1200rpm, V3 = 1300rpm and V4 = 1400rpm) and three level of feed rate (F1 = 5kg/min, F2 = 10kg/min and F3 = 15kgmin).

3.3.10. Dependent variable

- Throughput capacity
- Grating efficiency
- Percentage of mechanical loss
- Grating time
- Quality performance efficiency

3.3.11. Performance evaluation

Evaluation of the grater was carried out considering the grating capacity, loss and efficiency. The performance of the machine was evaluated in terms of grating efficiency, throughput capacity, percentage of loss and grating time. The good and bad quality of cassava was measured based on fine or pulverized and coarse grated mash. Using the Philippines Agricultural Engineering Standards (PAES) (2004) methods of testing for similar machines, the following formulas were used in evaluating the performance of the engine-operated cassava grater:

Throughput capacity ($kghr^{-1}$) = $\frac{Wf}{T}$ ……………………………………………3.37

Grating efficiency (%) = $\frac{Wf}{Wi} \times 100$...3.38

Percentage of mechanical loss = $\frac{Wi-Wf}{Wi} \times 100$..3.39

Where: Wf = total weight recovered, kg

Wi = total weight fed in, kg

T = time it took to grate the cassava tubers, hr.

Quality performance efficiency = $\frac{G}{G+B} \times 100$..3.40

Where: G = a good quality = fine grated mash (kg)

B = a bad quality = coarse grated mash (kg)

3.3.12. Economic analysis

Estimation of fixed and operational costs of the cassava grating machine were based on the capital cost of the machine, interest on capital, labor cost and depreciation. The operational cost components of the prototype cassava grater were estimated in Birr (ETB) using the standard procedure. The total cost of operation per hour consists of fixed costs and operating costs. The calculations were based on ASABE Standards 2011(R2020).

$Dp = \frac{\mathrm{SP-SV}}{\mathrm{EL}}, ETB/hr$ 3.41

$\mathrm{IC} = \frac{\mathrm{SP+SV}}{\mathrm{2U}} \times I\%, ETB/hr$ 3.42

$\mathrm{LW} = \frac{\mathrm{DLW}}{\mathrm{DWH}}, ETB/hr$ 3.43

Where: Dp = depreciation

SP = selling price of grater

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

EL = economic life

IC = interest on capital (EB/hr.)

U = annual use

I = interest %

LW = labor wages

DLW = daily labor wage

DWH = daily working hours (EB/hr.)

3.3.13. Statistical data analysis

The collected data were analyzed using Statistix 8 software, a commercial software package developed by the United States Department of Agriculture (USDA). The analyses of the data shown whether there was a relationship between independent and dependent variables. Confidence intervals of 95% was used to show the significance effect of independent variable on dependent variable therefore, $p < 0.05$ indicated that the relationship was significant and comparison between treatment means was conducted by least significance difference (LSD) at 5% level. The data were subjected to two way analysis of variances (ANOVA) by following the appropriate procedure for the design of the experiment (Gomez & Gomez, 1984).

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1. Detailed Description of Machine

The cassava grating machine was powered by a five horsepower (5hp) diesel engine which rotates at a constant speed. The fabricated machine mainly consists of a feeding hopper, housing, grating drum, discharge chute, frame, shaft, and power transmission unit. The grating drum was made up of a cylindrical perforated stainless steel sheet metal which was held by a shaft passing through the rolled cylindrical sheet metal and it was welded on both sides by circular discs. Its grating mechanism could be based on an abrasive cylinder when the actual grating operation takes place on it. The fabricated engine driven cassava grating machine consists of a trapezoidal shaped hopper made up of 1.5mm thick stainless steel sheet metal, the hopper was the receptacle through which cassava was admitted into the machine for grating. Stainless steel was entirely used for the fabrication of the cassava grating machine whereas square pipe and angle iron was used for the fabrication of frame and engine setting. This cassava grating machine was readily affordable for the farmers due to the fact that it was fabricated from locally sourced materials.

4.2. Determination of Physical Properties of Cassava Tuber

During redesigning the cassava grating machine, the physical properties of the cassava tube were considered in order to acquire an effective and efficient primary processing machine. The angle of repose was a very important parameter in redesigning the cassava grating machine which needed for the redesign of the hopper was determined as 29.4° and the discharge chute was determined 48.6°. This could form the basis for hopper and discharge chute redesign. The moisture content of 52.9% in a wet basis was recorded. This value was lower than (Joshua & Simonyan, 2015) reported that the mean moisture content of cassava at harvest was 70%. The test result indicated grating was more effective at a high moisture content of the tuber. From the test result, it was also observed that cassava root had more moisture content which enhances the grating quality of the grater. Table 6 shown that the mean physical properties of the cassava tuber samples were determined. The results indicated that the mean value for geometric mean diameter was 14.05mm while the maximum and minimum values of geometric mean diameter were 15.5 and 13.19mm. The minimum value for the bulk density was 2.08g/cm^3 while the maximum value was 2.25g/cm^3 with a mean of 2.18g/cm^3 based on a result obtained for cassava tuber. The results showed that the mean moisture content of 52.9% in a wet basis for the fresh sample was determined and the maximum value was 53.8% and the minimum value was 52%. The maximum angle of repose of 30° was obtained whereas the minimum angle of repose of 28.7° was obtained with its mean of 29.4°.

Table 6. Physical properties of cassava tuber

Properties	Mean	SD	Mean±SD	Max	Min	CV
Length (mm)	316.7	135.0	316.7±135.0	450.0	180.0	42.6
Geometric mean diameter (mm)	14.05	1.279	14.05±1.27	15.5	13.19	9.1
Sphericity	0.89	0.024	0.89±0.024	0.91	0.87	2.6
Bulk density (g/cm^3)	2.18	0.090	2.18±0.090	2.25	2.08	4.2
Moisture content (%)	52.9	0.9	52.9±0.9	53.8	52	1.7
Angle of repose (°)	29.4	0.665	29.4±0.665	30.0	28.7	2.3

During the test, it was observed that the freshly grated mash was found to be cohesive; it spreads flatter at higher moisture. The angle of repose of 29.4° was obtained from the sample at a moisture content of 52.9% in a wet basis was recorded and the results indicated that the moisture content ranged from 52% to 53.8% with standard deviation values of 52.9% ±0.9%. Generally physical properties of the cassava tuber obtained in this study were lower than the results reported by Joshua & Simonyan (2015). This suggested that mash might need more inclination to move the mash granules within the machine. The results indicated that lower angle of repose indicated a free flowing and higher angle indicated a cohesive or poor flowing mash.

4.3. Performance Evaluation

The performance of the grater was evaluated at four levels of drum speeds and three levels of feed rates at a moisture content of 52.9% for cassava tuber in terms of throughput capacity, grating efficiency, percentage of mechanical loss, grating time, and quality performance efficiency. The machine was started and the speed was regulated to 1100rpm, 1200rpm, 1300rpm, and 1400rpm using a tachometer. The operating speeds of the cassava grater were determined using a tachometer. The drum speed was first measured at no load using the tachometer. Thereafter, the machine was loaded with cassava tubers, one size category after another, and grated. In each case, tachometer readings were taken under load; and the stopwatch was used to measure the time of completion of a grating of each feed rate.

The freshly harvested cassava tuber was manually peeled using knives and washed with water for hygiene, after that the peeled cassava roots were measured in batches for 5kg, 10kg, and 15kg using a weighing scale for each drum speed. The peeled cassava tuber was fed into the grating machine through the hopper allowing the root to fall directly on the grating drum of the machine. The rotating action of the grating drum enables the cassava to be grated. This process would grate the cassava into cassava pulp. After grating the machine was stopped, then weight of the final output mash, total grated mash, grating time, good quality mash, and bad quality mash were measured to ascertain the machine's efficiency, loss, capacity, and quality of mash the machine produced. From test result, it was observed that all peeled cassava roots fed into the machine were grated. During performance evaluation, the fuel consumption of the machine was measured as 1.82L/hr.

4.3.1. Throughput capacity

Table 7 shows the analysis of variance (ANOVA) for the effects of drum speed and feed rate on the throughput capacity of the grating machine. The analysis of variance revealed that the main effect of drum speed was significant at a 5% level because the p value was less than 0.05 ($P < 0.05$). The results implied that the throughput capacity of a machine was affected by operating drum speed. Analysis of variance showed that the main effect of feed rate was significant at a 5% level based on a result obtained (table 7). The results implied that the feed rate did affect the throughput capacity of a grating machine. Therefore, the analysis of variance revealed that both main effects were significant ($P < 0.05$). Also, the interaction effect of drum speed with feed rate (V×F) was significant at a 5% level because the p value obtained in (table 7) was less than 0.05. The results implied that the interaction effect of drum speed with feed rate did affect the throughput capacity of a grating machine.

Table 7. Analysis of variance (ANOVA) for throughput capacity of the fabricated machine

Source of variation	DF	SS	MS	F	P
Block	2	18	9.1		
Drum speed (V)	3	129708	43235.9	589.27	0.0000
Feed rate (F)	2	3519	1759.4	23.98	0.0000
Speed×Feed (V×F)	6	3267	544.4	7.42	0.0002
Error	22	1614	73.4		
Total	35	138125			

C.V = 2.39, grand mean = 358.55, $P < 0.05$, significant at 5 % level, $P > 0.05$, non-significant at 5 % level.

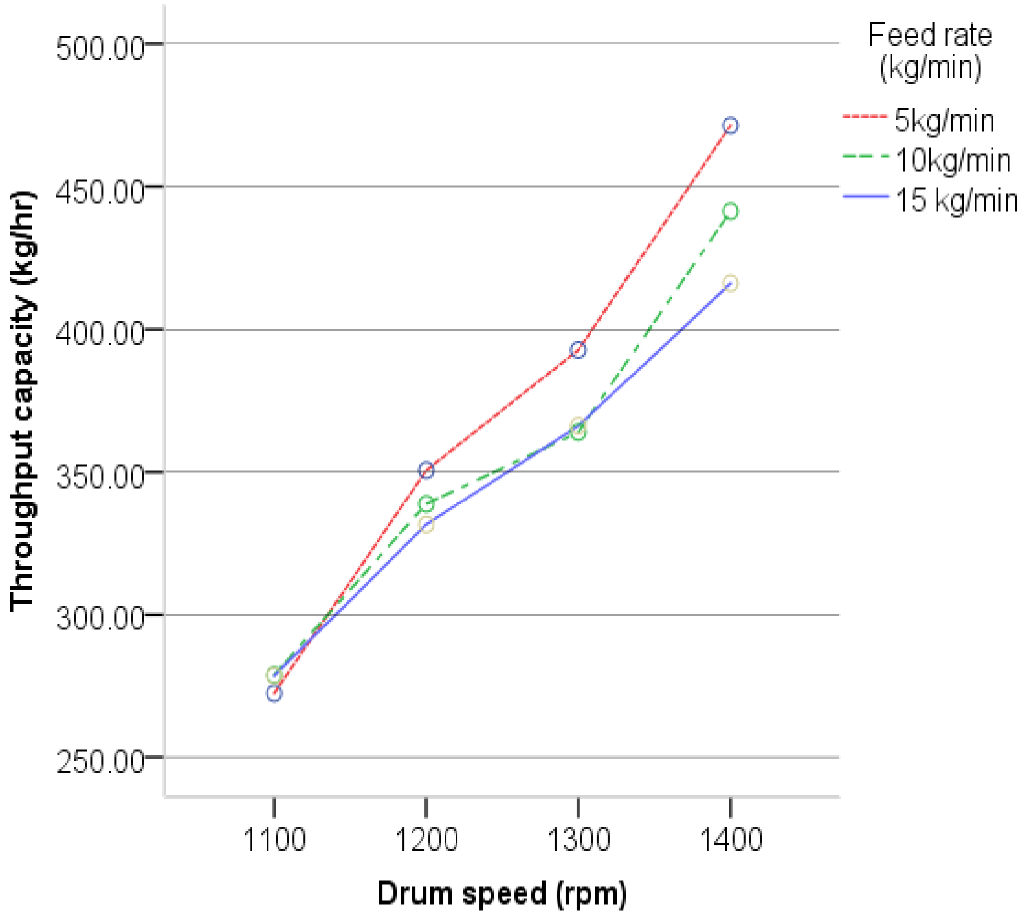


Figure 35. Effect of drum speed and feed rate on throughput capacity

As shown in figure 35 the average throughput capacity of the machine ranged from 272.5kghr^{-1} to 471.4kghr^{-1}. With increasing drum speed from 1100rpm to 1400rpm, throughput capacity increased from 272.5 kghr^{-1} to 471.4 kghr^{-1}. The results shown in the above graph that the throughput capacity of the machine tended to increase with the increase of drum speed and decreased with a feed rate which means throughput capacity had a direct relationship to the drum speed and inversely related to material feed rate. A similar trend for cassava grating machine was reported by Esteves et al. 2019.

As defined in PAES (2004), capacity was the weight of processed material collected per unit time, expressed in kilogram per hour. The grating capacity of the engine driven cassava grater was shown in table 8. Among these treatment combinations, results showed that the treatment combination of V4F1 had the highest grating capacity with a mean, maximum, minimum, and standard deviation of 471.4, 478, 460.4, and 9.59 kilogram per hour followed by V4F2, V4F3, V3F1, V3F3, V3F2, and V2F1 with the means of 441.4, 416, 392.8, 366.2, 363.9 and 350.6kilogram per hour, respectively for the fabricated machine. The highest throughput capacity of 471.4 $kghr^{-1}$ was observed at a drum speed of 1400rpm and feed rate of $5kgmin^{-1}$, while the lowest throughput capacity was 272.5 $kghr^{-1}$ observed at a drum speed of 1100rpm and feed rate of $5kgmin^{-1}$. Since the drum speed of 1400rpm was relatively fast and the grating capacity of this engine-operated cassava grater was expected to be high at the operating drum speed of 1400rpm.

The throughput capacity obtained in this study was higher compared to the value of $114.94kghr^{-1}$ reported by Temam (2020). In comparison, Esteves et al. (2019) reported an average grating capacity of $283.26kghr^{-1}$ at 1424.30 rpm when testing the performance of a motor operated cassava grater. Ogunjirin et al. (2020) reported a grating capacity of $250kghr^{-1}$ at 78.4rpm when grating cassava with a cassava grater. Malomo et al. (2014) reported a machine output of $80kghr^{-1}$ when testing the performance of an automated combined cassava grater. Bello et al. (2020) reported a capacity of $158.9kghr^{-1}$ when testing the performance of an electric motor powered machine.

LSD all pairwise comparisons test of capacity for treatment combination was given below in table 8 then this analysis was subjected to the LSD all pairwise comparisons test of capacity for four levels of drum speed and three levels of feed rate to know significant differences among treatment means. The LSD all pairwise comparisons test showed (table 8) that there were 9 groups (a, b, etc.) in which the treatment means were not significantly different from one another but the treatment means denoted by letters a to h were significantly different from one another except treatment means denoted by letter i at 5% level based on LSD all pairwise comparisons test.

Table 8. Capacity of grater at different drum speeds and feed rates

No.	Treatment combination	Drum speed (rpm)	Feed rate (kg/min)	Capacity (kg/hr) Mean	SD	Max	Min	Cv
1	V1F1	1100	5	272.5i	12.15	284.5	260.2	4.46
2	V1F2	1100	10	278.9^{i}	6.02	284.6	272.6	2.16
3	V1F3	1100	15	278.6^{i}	2.37		277.1	0.85
4	V2F1	1200	5	350.6fg	7.46	359.2	345.8	2.13
5	V2F2	1200	10	338.8^{gh}	5.10	342.9	333.08	1.50
6	V2F3	1200	15	331.6^{h}	2.70	334.3	328.9	0.81
7	V3F1	1300	5	392.8^{d}	16.19	405.9	374.7	4.12

8	V3F2	1300	10	363.9^{ef}	4.90	368.7	358.9	1.35
9	V3F3	1300	15	366.2^{e}	2.95	369.5	363.8	0.80
10	V4F1	1400	5	471.4^{a}	9.59	478.0	460.4	2.03
11	V4F2	1400	10	441.4^{b}	9.01	451.6	434.6	2.04
12	V4F3	1400	15	416.0^{c}	8.33	423.0	406.8	2.0

4.3.2. Grating efficiency

Table 9 shows the analysis of variance (ANOVA) for the effects of drum speed and feed rate on the grating efficiency of the grating machine. The analysis of variance revealed that the main effect of drum speed was significant at a 5% level because the p value was less than 0.05 ($P < 0.05$). The results implied that the grating efficiency of a machine was affected by operating drum speed.

Analysis of variance showed that the main effect of feed rate was significant at a 5% level based on a result obtained (table 9). The results implied that the feed rate did affect the grating efficiency of a grating machine. Therefore, the analysis of variance revealed that both main effects were significant ($P < 0.05$). Also, the interaction effect of drum speed with feed rate was significant at a 5% level because the p value obtained in (table 9) was less than 0.05. The results implied that the interaction effect of drum speed with feed rate did affect the grating efficiency of a grating machine.

Table 9. Analysis of variance (ANOVA) for grating efficiency of fabricated machine

Source of variation	DF	SS	MS	F	P
Block	2	0.285	0.143		
Drum speed (V)	3	339.010	113.003	137.87	0.0000
Feed rate (F)	2	138.868	69.434	84.72	0.0000
Speed×Feed (V×F)	6	113.186	18.864	23.02	0.0000
Error	22	18.032	0.820		
Total	35	609.382			

C.V = 0.97, grand mean = 93.063, $P < 0.05$, significant at 5 % level, $P > 0.05$, non-significant at 5 % level.

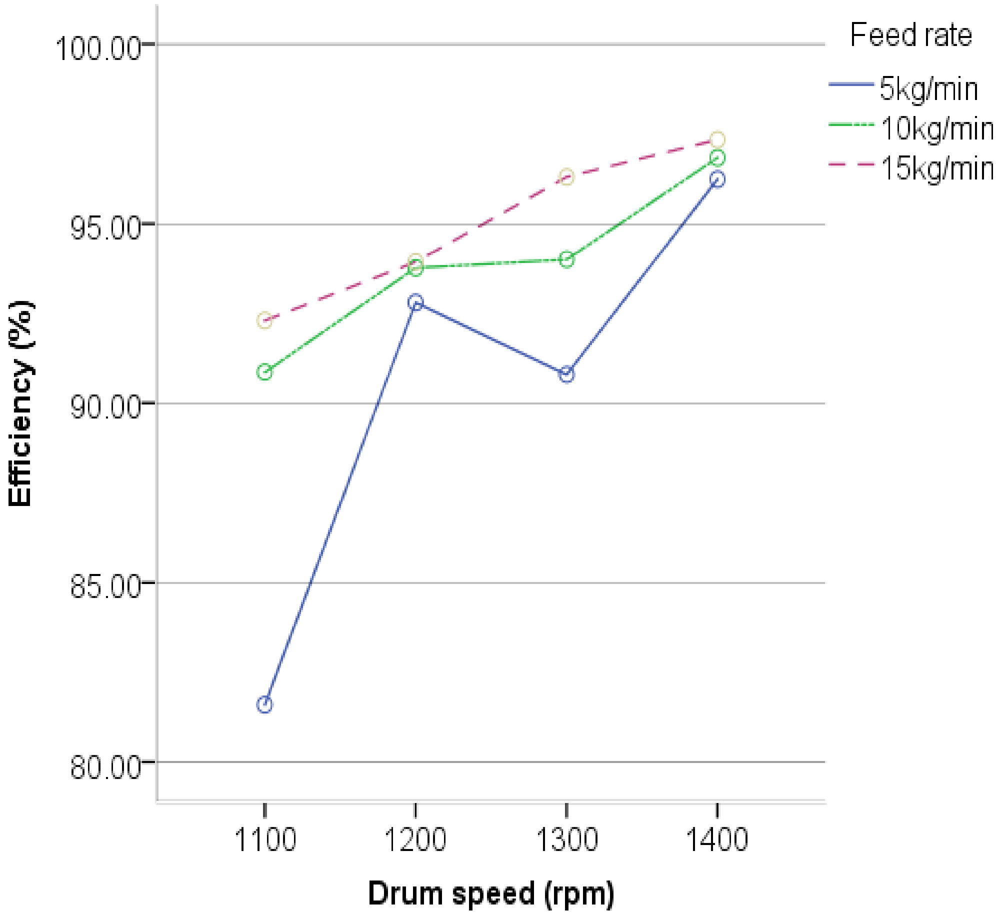


Figure 36. Effect of drum speed and feed rate on grating efficiency

As shown in figure 36 it was observed that the average grating efficiency of the machine ranged from 81.6% to 97.33%. With increasing drum speed from 1100rpm to 1400rpm, grating efficiency increased from 81.6% to 97.33%. The highest grating efficiency of 97.33% was observed at a drum speed of 1400rpm and feed rate of 15kgmin^{-1}, while the lowest grating efficiency was 81.6% observed at a drum speed of 1100rpm and feed rate of 5kgmin^{-1}. The results shown in the above graph that the grating efficiency of the machine tended to increase with the increase of drum speed and feed rate which means grating efficiency had a direct relationship to the drum speed and feed rate of cassava tuber.

As defined in PAES (2004), grating efficiency was the ratio of the recovered fresh grate materials to the total fresh weight of the input of the grater. The grating efficiency of the engine driven cassava grater was shown in table 10. From these treatment combinations, results showed that the treatment combination of V4F3 had the highest grating efficiency with a mean of 97.33% followed by V4F2, V3F3, V4F1, V3F2, V2F3, and V2F2 with the means of 96.83%, 96.29%, 96.23%, 94%, 93.93%, and 93.77%, respectively for the fabricated machine. The maximum grating efficiency of 97.6% was obtained at 15kgmin^{-1} feed rate; at 1400 rpm of drum speed whereas the minimum grating efficiency of 97.1% was obtained with a standard deviation of 0.252 at this feed rate and drum speed. Since the drum speed of 1400rpm was relatively fast and the grating efficiency of this engine operated cassava grater was expected to be high at the operating drum speed of 1400rpm.

The grating efficiency obtained in this study was higher compared to the value of 91.9% reported by Ndaliman (2006). In comparison, Esteves et al. (2019) reported an average grating efficiency of 91.56% at 1424.30 rpm when testing the performance of a motor-operated cassava grater. Ogunjirin et al. (2020) reported a grating efficiency of 84% at 78.4rpm when grating cassava with a cassava grater. Malomo et al. (2014) reported a machine efficiency of 89.7% when testing the performance of an automated combined cassava grater. LSD all pairwise comparisons test of efficiency for treatment combination was given below in table 10 then this analysis was subjected to the LSD all pairwise comparisons test of efficiency for four levels of drum speed and three levels of feed rate to know significant differences among treatment means. The LSD all pairwise comparisons test showed (table 10) that there were 5 groups (a, b, etc.) in which the treatment means were not significantly different from one another at 5% level based on LSD all pairwise comparisons test.

Table 10. Efficiency of grater at different drum speeds and feed rates

No.	Treatment combination	Drum speed (rpm)	Feed rate (kg/min)	Efficiency (%)				
				Mean	SD	Max	Min	Cv
1	V1F1	1100	5	81.6^{e}	0.917	82.4	80.6	1.12
2	V1F2	1100	10	90.87^{d}	0.8021	91.7	90.1	0.88
3	V1F3	1100	15	92.3^{cd}	0.5568	92.9	91.8	0.60
4	V2F1	1200	5	92.8^{bc}	1.400	94.4	91.8	1.50
5	V2F2	1200	10	93.77^{bc}	1.4572	95.3	92.4	1.55
6	V2F3	1200	15	93.93^{b}	0.4509	94.4	93.5	0.48
7	V3F1	1300	5	90.8^{d}	0.7211	91.6	90.2	0.79
8	V3F2	1300	10	94.0^{b}	0.755	94.7	93.2	0.80
9	V3F3	1300	15	96.29^{a}	0.631	97.0	95.8	0.65
10	V4F1	1400	5	96.23^{a}	0.874	97.2	95.5	0.90

11	V4F2	1400	10	96.83[a]	0.874	97.8	96.1	0.90
12	V4F3	1400	15	97.33[a]	0.252	97.6	97.1	0.26

4.3.3. Percentage of mechanical loss

Table 11 shows the analysis of variance (ANOVA) for the effects of drum speed and feed rate on the percentage of mechanical loss of the grating machine. The analysis of variance revealed that the main effect of drum speed was significant at a 5% level because the p value was less than 0.05 (P< 0.05). The results implied that the percentage of mechanical loss of the machine was affected by operating drum speed. Analysis of variance showed that the main effect of feed rate was significant at a 5% level based on a result obtained (table 11). The results implied that the feed rate did affect the percentage of mechanical loss of a grating machine. Therefore, the analysis of variance revealed that both main effects were significant (P< 0.05). There were also, the interaction effect of drum speed with feed rate was significant at a 5% level because the p value obtained in (table 11) was less than 0.05. The results implied that the interaction effect of drum speed with feed rate did affect the percentage of mechanical loss of a grating machine.

Table 11. Analysis of variance (ANOVA) for percentage loss of the fabricated machine

Source	DF	SS	MS	F	P
Block	2	0.392	0.196		
Drum speed (V)	3	357.243	119.081	136.81	0.0000
Feed rate (F)	2	132.011	66.006	75.83	0.0000
Speed×Feed (V×F)	6	120.575	20.096	23.09	0.0000
Error	22	19.150	0.870		
Total	35	629.371			

C.V = 13.60, grand mean = 6.86, P < 0.05, significant at 5 % level, P > 0.05, non-significant at 5 % level.

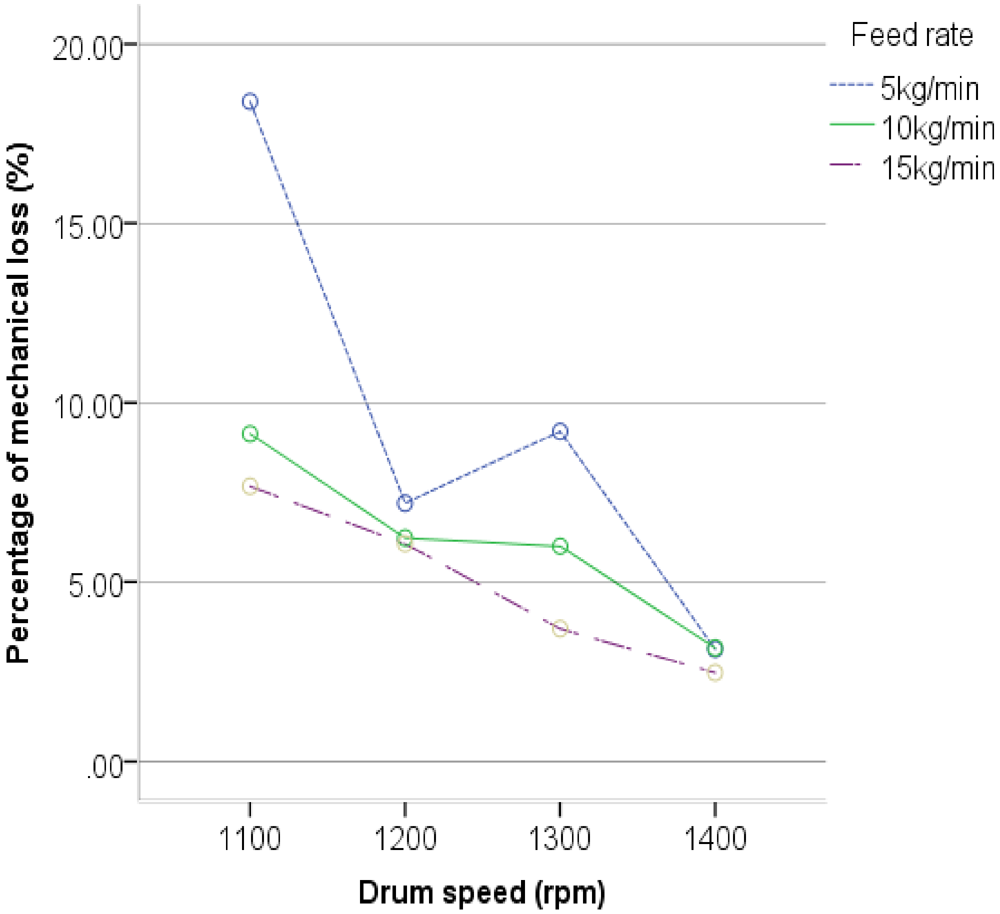


Figure 37. Effect of drum speed and feed rate on percentage of mechanical loss

As shown in figure 37 it was observed that the average percentage of mechanical loss of the machine ranged from 2.45% to 18.4%. With increasing drum speed from 1100rpm to 1400rpm, percentage of mechanical loss decreased from 18.4% to 2.45%. So, the results shown in the above graph that the percentage of mechanical loss of the machine tended to decrease with the increase of drum speed and feed rate which means percentage of mechanical loss had an inverse relationship to the drum speed and feed rate of cassava tuber.

As defined in PAES (2004), the percentage of mechanical loss was the total weight input of material minus the total weight output of material over the total weight input, expressed in percentage. The percentage of mechanical loss of the engine driven cassava grater was shown in table 12. Among these treatment combinations, results showed that the treatment combination of V4F3 had the lowest percentage of mechanical loss with a mean of 2.45% followed by V4F1, V4F2, V3F3, V3F2, V2F3, and V2F2 with the means of 3.13%, 3.16%, 3.7%, 6%, 6.05%, and 6.23%, respectively for the fabricated machine. The lowest percentage of mechanical loss of 2.45% was observed at a drum speed of 1400rpm and feed rate of 15kgmin^{-1}, while the highest percentage of mechanical loss was 18.4% observed at a drum speed of 1100rpm and feed rate of 5kgmin^{-1}. Since the drum speed had the lowest percentage of loss among the other drum speed, the percentage of mechanical loss of this engine-operated cassava grater was expected to be low at the operating drum speed of 1400rpm.

The percentage of mechanical loss recorded in this study was lower compared to the value of 8.45% at 1424.30 rpm reported by Esteves et al. 2019. In comparison, Ogunjirin et al. (2020) reported a percentage loss of 10.9% at 78.4rpm when grating cassava with a cassava grater. Apodi et al.(2018) reported percentage loss of 5.5% when testing the performance of cassava grating machine. Malomo et al. (2014) reported a loss of 10.3% when testing the performance of an automated combined cassava grater.

In the grating machine, some losses were occurred in the grating drum because of the high moisture content of the cassava tuber, some of the grated cassava that remained in the grating drum was detached at high drum speed but the grated cassava was not detached at low drum speed. LSD all pairwise comparisons test of the percentage of mechanical loss for treatment combination was given below in table 12 then this analysis was subjected to the LSD all pairwise comparisons test of percentage of mechanical loss for four levels of drum speed and three levels of feed rate to know significant differences among treatment means. The LSD all pairwise comparisons test showed (table 12) that there were 5 groups (a, b, etc.) in which the treatment means were not significantly different from one another at 5% level based on LSD all pairwise comparisons test.

Table 12. Loss of grater at different drum speeds and feed rates for cassava tuber

No.	Treatment combination	Drum speed (rpm)	Feed rate (kg/min)	Percentage of mechanical loss (%) Mean	SD	Max	Min	Cv
1	V1F1	1100	5	18.4^{a}	0.917	19.4	17.6	4.98
2	V1F2	1100	10	9.13^{b}	0.802	9.9	8.3	8.78
3	V1F3	1100	15	7.653^{bc}	0.54	8.1	7.06	6.99
4	V2F1	1200	5	7.20^{cd}	1.40	8.2	5.6	19.4
5	V2F2	1200	10	6.23^{cd}	1.46	7.6	4.7	23.4
6	V2F3	1200	15	6.05^{d}	0.45	6.5	5.6	7.43
7	V3F1	1300	5	9.2^{b}	0.72	9.8	8.4	7.84
8	V3F2	1300	10	6.0^{d}	0.76	6.8	5.3	12.6

9	V3F3	1300	15	3.7[e]	0.625	4.2	3.0	16.9
10	V4F1	1400	5	3.13[e]	1.14	4.4	2.2	36.3
11	V4F2	1400	10	3.167[e]	0.874	3.9	2.2	27.6
12	V4F3	1400	15	2.45[e]	0.423	2.9	2.06	17.2

4.3.4. Grating time

Table 13 shows the analysis of variance (ANOVA) for the effects of drum speed and feed rate on the grating time of the grating machine. The analysis of variance revealed that the main effect of drum speed was significant at a 5% level because the p value was less than 0.05 ($P< 0.05$). The results implied that the grating time of a machine was affected by operating drum speed. Analysis of variance showed that the main effect of feed rate was significant at a 5% level based on a result obtained (table 13). The results implied that the feed rate did affect the grating time of a grating machine. Therefore, the analysis of variance revealed that both main effects were significant ($P< 0.05$). The interaction effect of drum speed with feed rate was significant at a 5% level because the p value obtained in (table 13) was less than 0.05. The results implied that the interaction effect of drum speed with feed rate did affect the grating time of a grating machine.

Table 13. Analysis of variance (ANOVA) for grating time of the fabricated machine

Source	DF	SS	MS	F	P
Block	2	0.2	0.1		
Drum speed (V)	3	6140.1	2046.7	390.98	0.0000
Feed rate (F)	2	66256.2	33128.1	6328.37	0.0000
Speed×Feed (V×F)	6	1005.4	167.6	32.01	0.0000
Error	22	115.2	5.2		
Total	35	73517.0			

C.V = 2.35, grand mean = 97.50, $P < 0.05$, significant at 5 % level, $P > 0.05$, non-significant at 5 % level.

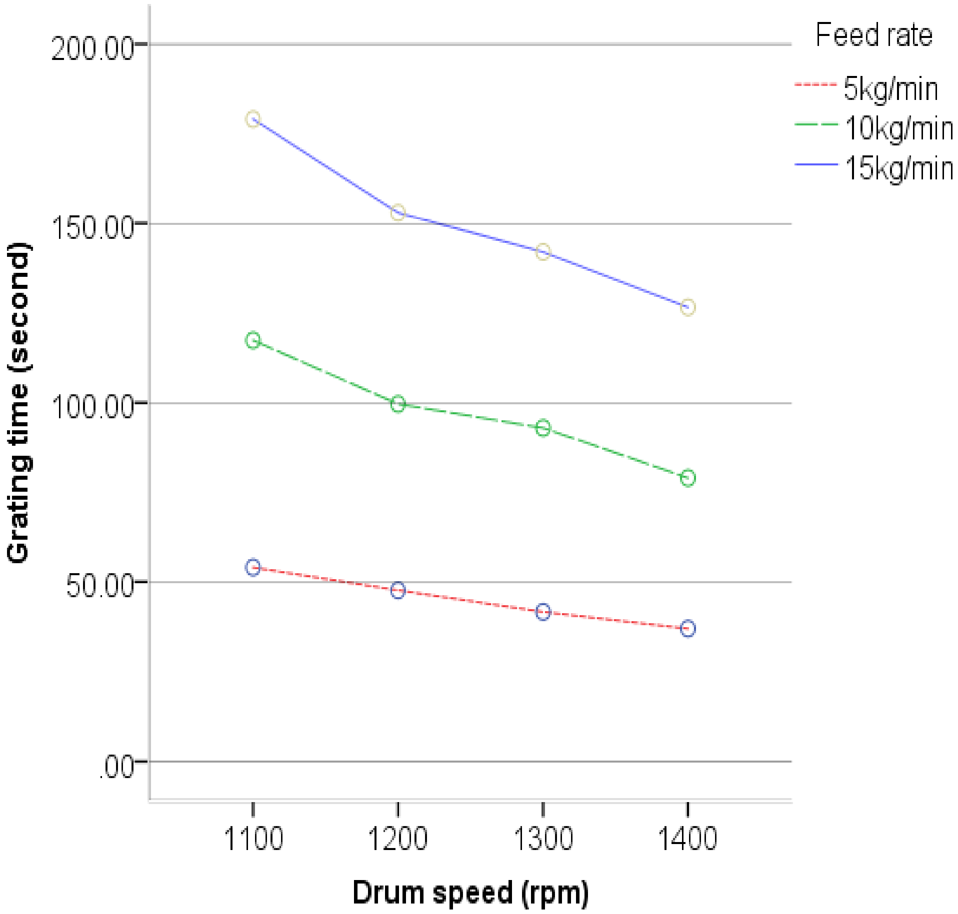


Figure 38. Effect of drum speed and feed rate on grating time

As shown in figure 38 it was recorded that the average grating time of the machine ranged from 37sec to 54sec at the feed rate of 5kgmin^{-1} with drum speed of 1400rpm and 1100rpm. Generally, the results indicated in the above graph that the grating time of the machine tended to decrease with the increase of drum speed at the same feed rate because high drum speed had faster operated than lower drum speed which means grating time had an inverse relationship to the drum speed and a direct relationship to feed rate.

As defined in PAES (2004), grating time was the time that the engine-operated cassava grater took to grate the cassava from the moment it was fed into the hopper. The grating time of the engine driven cassava grater was shown in table 14. From these treatment combinations, results showed that the treatment combination of V4F1 had the lowest grating time with a mean of 37sec followed by V3F1, V2F1, V1F1, V4F2, V3F2, and V2F2 with the means of 41.7sec, 47.67sec, 54sec, 79sec, 93sec, and 99.67sec, respectively for the fabricated machine. The lowest grating time of 37sec was observed at a drum speed of 1400rpm and feed rate of 5kgmin^{-1}, while the highest grating time was 54sec observed at a drum speed of 1100rpm and feed rate of 5kgmin^{-1}. At the same feed rate, with increased drum speed from 1100rpm to 1400rpm, grating time decreased from 54sec to 37sec.

Therefore, the drum speed of 1400rpm was relatively fast and it could grate the cassava tuber within a short period of time, there was also the drum speed had the lowest grating time among the other drum speed, the grating time of this engine-operated cassava grater was expected to be minimum at the operating drum speed of 1400rpm. A similar trend for cassava grating machine was reported by Esteves et al. 2019. LSD all pairwise comparisons test of grating time for treatment combination was given below in table 14 then this analysis was subjected to the LSD all pairwise comparisons test of grating time for four levels of drum speed and three levels of feed rate to know significant differences among treatment means. The LSD all pairwise comparisons test showed (table 14) that all the treatment means were significantly different from one another at 5% level based on LSD all pairwise comparisons tests.

Table 14. Grating time of grater at different drum speeds and feed rates

No.	Treatment combination	Drum speed (rpm)	Feed rate (kg/min)	Grating time (second) Mean	SD	Max	Min	Cv
1	V1F1	1100	5	54.0[i]	3.0	57.0	51.0	5.56
2	V1F2	1100	10	117.3[e]	1.53	119.0	116.0	1.30
3	V1F3	1100	15	179.0[a]	2.0	181.0	177.0	1.12
4	V2F1	1200	5	47.67[j]	1.53	49.0	46.0	3.20
5	V2F2	1200	10	99.67[f]	3.06	103.0	97.0	3.07
6	V2F3	1200	15	153.0[b]	2.0	155.0	151.0	1.30
7	V3F1	1300	5	41.7[k]	2.08	44.0	40.0	4.99
8	V3F2	1300	10	93.0[g]	2.0	95.0	91.0	2.15
9	V3F3	1300	15	142.0[c]	2.0	144.0	140.0	1.40
10	V4F1	1400	5	37.0[l]	1.0	38.0	36.0	2.70
11	V4F2	1400	10	79.0[h]	2.0	81.0	77.0	2.53
12	V4F3	1400	15	126.7[d]	3.06	130.0	124.0	2.41

4.3.5. Quality performance efficiency

Table 15 shows the analysis of variance (ANOVA) for the effects of drum speed and feed rate on the quality performance efficiency of the grating machine. The analysis of variance revealed that the main effect of drum speed was significant at a 5% level because the p value was less than 0.05 ($P < 0.05$). The results implied that the quality performance efficiency of a machine was affected by operating drum speed. Analysis of variance showed that the main effect of feed rate was significant at a 5% level based on a result obtained (table 15). The results implied that the feed rate did affect the quality performance efficiency of a grating machine. Therefore, the analysis of variance revealed that both main effects were significant ($P < 0.05$). There were also, the interaction effect of drum speed with feed rate was significant at a 5% level because the p value obtained in (table 15) was less than 0.05. The results implied that the interaction effect of drum speed with feed rate did affect the quality performance efficiency of a grating machine.

Table 15. Analysis of variance for quality performance efficiency of the fabricated machine

Source	DF	SS	MS	F	P
Block	2	1.292	0.6461		
Drum speed (V)	3	85.135	28.3782	60.07	0.0000
Feed rate (F)	2	162.865	81.4325	172.38	0.0000
Speed×Feed (V×F)	6	21.905	3.6508	7.73	0.0001
Error	22	10.393	0.4724		
Total	35	281.589			

C.V = 0.74, grand mean = 92.38, $P < 0.05$, significant at 5 % level, $P > 0.05$, non-significant at 5 % level.

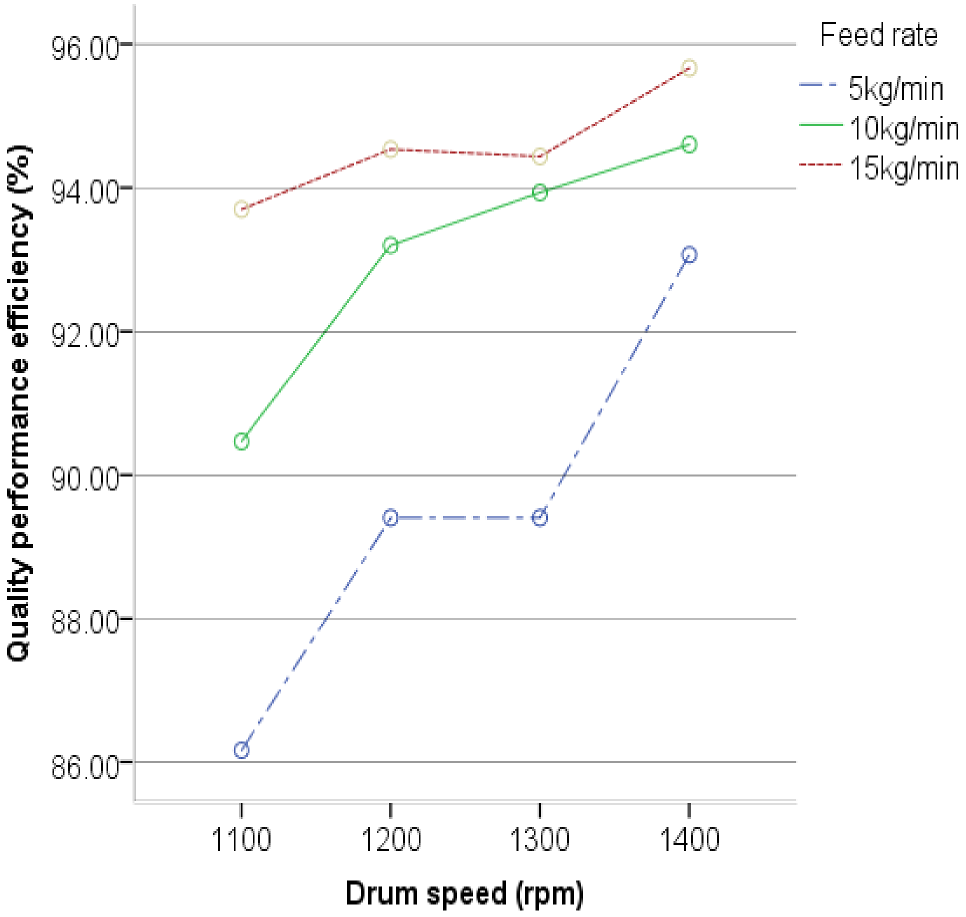


Figure 39. Effect of drum speed and feed rate on quality performance efficiency

As shown in figure 39 it was observed that the average quality performance efficiency of the machine ranged from 86.17% to 95.68%. With increased drum speed from 1100rpm to 1400rpm, quality performance efficiency increased from 86.17% to 95.68%. The results shown in the above graph that the quality performance efficiency of the machine tended to increase with the increase of drum speed and feed rate which implied quality performance efficiency had a direct relationship to the drum speed and feed rate of cassava tuber.

The quality performance efficiency of the engine driven cassava grater was shown in table 16. Among these treatment combinations, results indicated that the treatment combination of V4F3 had the highest quality performance efficiency with a mean of 95.68% followed by V4F2, V2F3, V3F3, V3F2, V1F3, and V2F2 with the means of 94.60%, 94.53%, 94.44%, 93.93%, 93.70%, and 93.20%, respectively for the fabricated machine. The highest quality performance efficiency of 95.68% was obtained at a drum speed of 1400rpm and feed rate of $15kgmin^{-1}$, while the lowest quality performance efficiency was 86.17% obtained at a drum speed of 1100rpm and feed rate of 5kgmin^{-1}. In comparison, Ogunjirin et al. (2020) reported a quality performance efficiency of 92.23% at 78.4rpm when grating cassava with a cassava grater. Malomo et al. (2014) reported a quality performance efficiency of 92.19% when testing the performance of an automated combined cassava grater but the quality performance efficiency obtained in this study was higher.

The maximum quality performance efficiency of 96% was obtained at 15kgmin^{-1} feed rate; 1400 rpm of drum speed whereas the minimum quality performance efficiency of 95.4% was obtained with a standard deviation of 0.322% at this feed rate and drum speed. Since the drum speed of 1400rpm had the finest grates among the other drum speed, the quality performance efficiency of this engine-operated cassava grater was expected to be good at the operating drum speed of 1400rpm. LSD all pairwise comparisons test of quality performance efficiency for treatment combination was given below in table 16 then this analysis was subjected to the LSD all pairwise comparisons test of quality performance efficiency for four levels of drum speed and three levels of feed rate to know significant differences among treatment means. The LSD all pairwise comparisons test showed (table 16) that there were 5 groups (a, b, etc.) in which the treatment means were not significantly different from one another at 5% level based on LSD all pairwise comparisons test.

Table 16. Quality performance efficiency of grater at different drum speeds and feed rates

No.	Treatment combination	Drum speed (rpm)	Feed rate (kg/min)	Quality performance efficiency (%)				
				Mean	SD	Max	Min	Cv
1	V1F1	1100	5	86.17^{e}	1.137	87.1	84.9	1.32
2	V1F2	1100	10	90.47^{d}	0.850	91.3	89.6	0.94
3	V1F3	1100	15	93.70^{bc}	0.60	94.3	93.1	0.64
4	V2F1	1200	5	89.40^{d}	0.568	88.9	90.02	0.63
5	V2F2	1200	10	93.20^{c}	0.529	93.6	92.6	0.57
6	V2F3	1200	15	94.53^{ab}	0.569	95.0	93.9	0.60
7	V3F1	1300	5	89.40^{d}	1.18	90.7	88.4	1.32
8	V3F2	1300	10	93.93^{bc}	0.45	94.4	93.5	0.48
9	V3F3	1300	15	94.44^{b}	0.437	94.9	94.0	0.46
10	V4F1	1400	5	93.06^{c}	0.75	92.2	93.6	0.80
11	V4F2	1400	10	94.6^{ab}	0.30	94.9	94.3	0.32
12	V4F3	1400	15	95.68^{a}	0.322	96.0	95.4	0.34

4.4. Regression Analysis

Regression analysis was conducted to predict how much variance was being accounted in the dependent variables by a set of independent variables. Multiple linear regression was conducted to examine how well independent factors could predict levels of dependent variables. To determine the relationship between independent and dependent variables, multiple linear regression analysis was used. The regression analysis result for throughput capacity showed that 95% of throughput capacity was accounted for by two independent factors collectively, $F (2, 33) = 311.17$, $R = 0.974$, $p = 0.000$. When looking the individual contribution of the predictors, the result indicated that drum speed ($\beta = 0.96$, $t = 24.6$, $p = 0.000$) affect the throughput capacity and the feed rate ($\beta = -0.156$, $t = -4.003$, $p = 0.000$) significantly affect the throughput capacity of the fabricated cassava grating machine. Therefore, both drum speed and feed rate significantly affect the throughput capacity of the machine ($p < 0.05$). The predicted throughput capacity was equal to $249.05 + 53.29V - 11.86F$. As shown in the regression equation, increasing drum speed by a unit would increase the throughput capacity by 53.29 whereas decreasing the feed rate by a unit would result in decreasing throughput capacity by 11.86. This implied that drum speed had a direct relationship with throughput capacity but the feed rate had an inverse relationship with throughput capacity.

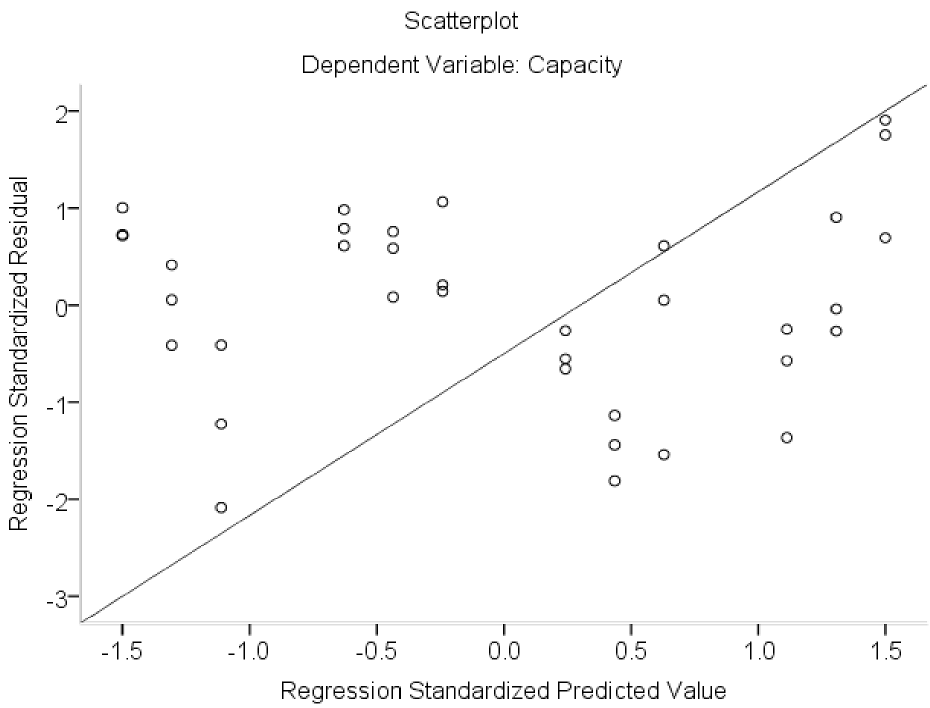


Figure 40. Regression residual for throughput capacity

Regression analysis result for grating efficiency indicated that 70.14% of the grating efficiency was accounted for by drum speed and feed rate together, $F(2, 33) = 38.77$, $p = 0.000$. When observing the individual impact of the factors, the result indicated that drum speed ($\beta = 0.702$, $t = 7.38$, $p = 0.000$) affect the grating efficiency and the feed rate ($\beta = 0.45$, $t = 4.80$, $p = 0.000$) affect the grating efficiency of the fabricated cassava grating machine. So, both drum speed and feed rate significantly affect the grating efficiency of the machine ($p < 0.05$). The predicted grating efficiency was equal to $82 + 2.58V + 2.30F$. As shown in the regression equation, increasing drum speed by a unit would increase the grating efficiency by 2.58 whereas increasing the feed rate by a unit would result in increasing grating efficiency by 2.30. This implied both independent variables had a direct relationship with grating efficiency.

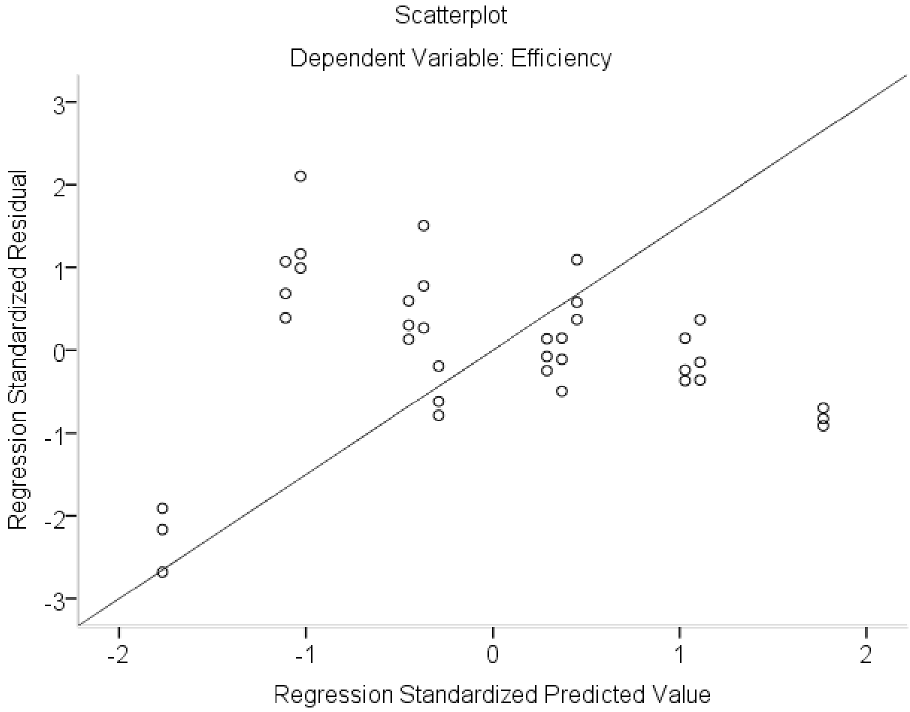


Figure 41. Regression residual for grating efficiency

The regression analysis result for percentage of mechanical loss showed that 70.1% of the percentage of mechanical loss was accounted for by drum speed and feed rate, $F(2, 33) = 38.76$, $R = 0.838$, $p = 0.000$. When looking the individual influence of the predictors, the result indicated that drum speed ($\beta = -0.71$, $t = -7.48$, $p = 0.000$) affect the percentage of mechanical loss and the feed rate ($\beta = -0.44$, $t = -4.62$, $p = 0.000$) affect the percentage of mechanical loss of the fabricated cassava grating machine. Therefore, both drum speed and feed rate significantly affect the percentage of mechanical loss of the machine ($p < 0.05$). The predicted percentage of mechanical loss was equal to 18.03 -2.66V -2.25F. As shown in the regression equation, decreasing drum speed by a unit would decrease the percentage of mechanical loss by 2.66 whereas decreasing the feed rate by a unit would result in decreasing percentage of mechanical loss by 2.25. This implied both independent variables had an inverse relationship with percentage of mechanical loss.

Figure 42. Regression residual for percentage of mechanical loss

Regression analysis result for grating time showed that 98.3% of the grating time was accounted for by drum speed and feed rate collectively, $F(2, 33) = 951.5$, $R = 0.99$, $p = 0.000$. When observing the individual role of the factors, the result indicated that drum speed ($\beta = -0.28$, $t = -12.5$, $p = 0.000$) affect the grating time and the feed rate ($\beta = 0.94$, $t = 41.7$, $p = 0.0000$) affect the grating time of the fabricated cassava grating machine. So, both drum speed and feed rate significantly affect the grating time of the machine ($p < 0.05$). The predicted grating time was equal to 21.3-11.55V+52.5F. As shown in the regression equation, decreasing drum speed by a unit would decrease the grating time by 11.55 whereas increasing the feed rate by a unit would result in increasing grating time by 52.5. This implied that drum speed had an inverse relationship with grating time but feed rate had a direct relationship with grating time.

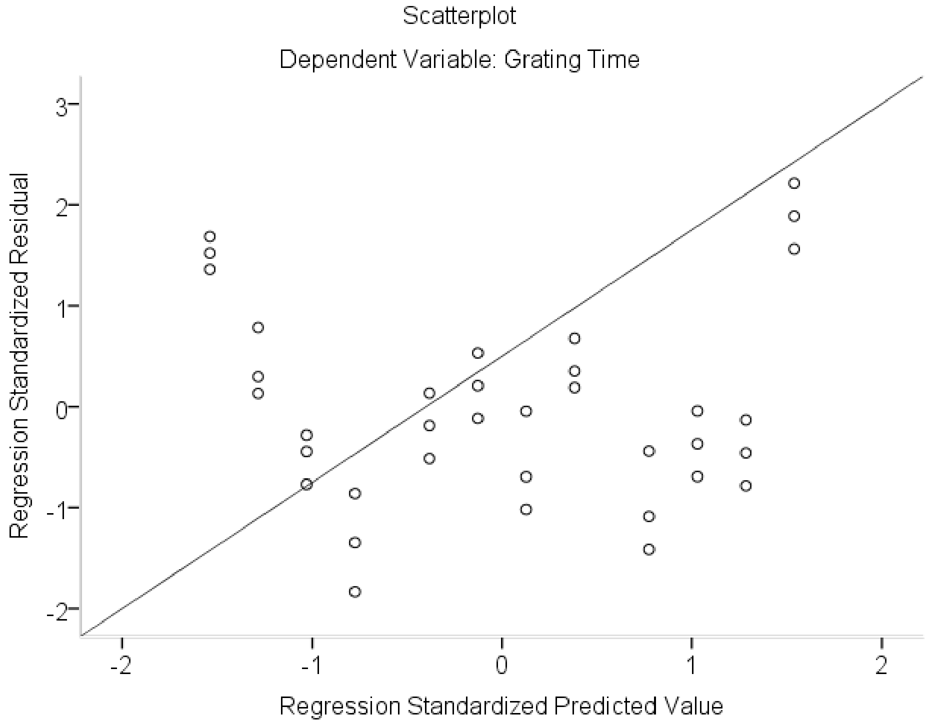


Figure 43. Regression residual for grating time

The linear regression analysis result for quality performance efficiency showed that 82.8% of the quality performance efficiency was accounted for by drum speed and feed rate, F (2, 33) = 79.55, R = 0.91, p = 0.000. When looking at the specific impact of the predictors, the result indicated that drum speed (β = 0.52, t = 7.32, p = 0.000) affect the quality performance efficiency and the feed rate (β = 0.74, t =10.27, p = 0.000) also affect the quality performance efficiency of the fabricated cassava grating machine. Therefore, both drum speed and feed rate significantly affect the quality performance efficiency of the machine ($p < 0.05$). The predicted quality performance efficiency was equal to 84 + 1.32V+2.53F. As shown in the regression equation, increasing drum speed by a unit would increase the quality performance efficiency by 1.32 whereas increasing the feed rate by a unit would result in increasing quality performance efficiency by 2.53. The result obtained in equation indicated both drum speed and feed rate had direct relationship with quality performance efficiency.

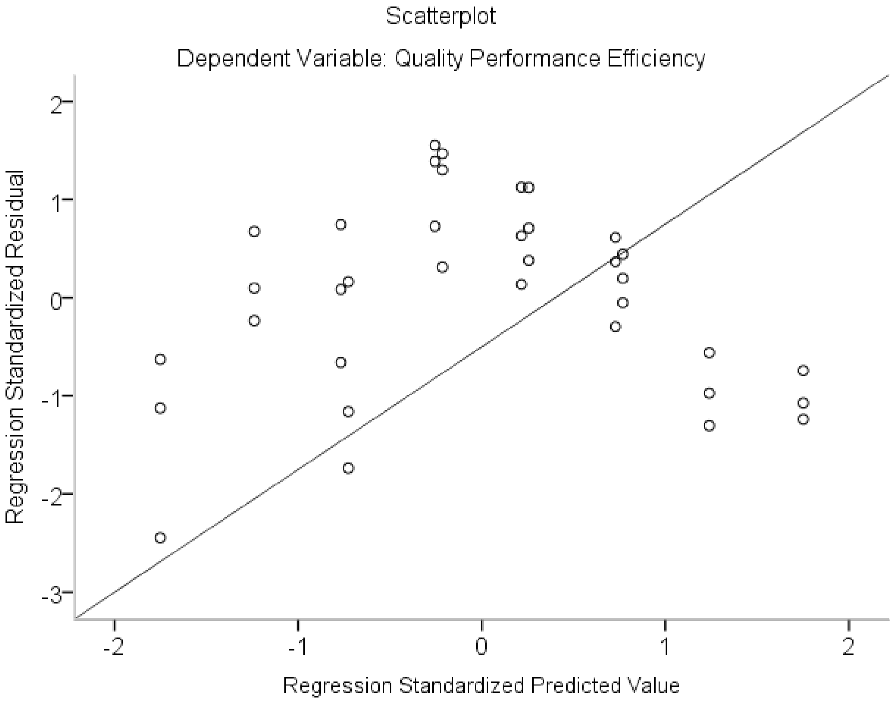


Figure 44. Regression residual for quality performance efficiency

4.5. Economic Cost Analysis

The unit cost of an engine driven cassava grating machine was determined by calculating the cost of different components and their fabrication cost as given in Appendix II. The cost of depreciation was computed as 2.8EBhr^{-1} using the straight-line method. The computed benefit cost ratio showed (Appendix II) that grating cassava using the fabricated cassava grater was economical for cassava producers. The estimated cost of the one unit of an engine driven cassava grating machine was determined as 44,046EB.

Table 17. Cost summary

No.	Cost variables	Cost (EB)
A	Raw materials cost	31,880
B	Materials wastage (2.5%)	797
C	machine cost	1,170
D	Labor cost	870
E	Overhead cost 5% (C+D)	102
F	Profit 10% (A+B+C+D+E)	3,481.9
G	Sells tax 15% (A+B+C+D+E+F)	5,745.1
Selling price		44,046

The cost analysis result showed that the fabricated engine driven cassava grating machine was economical and therefore proposed its use for the cassava grating using 5hp diesel engine operated.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The fabricated machine mainly consists of a feeding hopper, housing, grating drum, discharge chute, frame, shaft, and the power transmission unit. Stainless steel was entirely used for the fabrication of the cassava grating machine whereas square pipe and angle iron was used for the fabrication of the frame and engine setting. To ensure an effective cassava grating machine with good grating performance, the power required to grate the cassava, force required to grate the cassava, the torque required to turn the shaft, bending moment, shear force, and shaft diameter were all calculated. The physical properties of cassava tuber important for redesigning cassava grater were determined. The results showed that the mean geometric diameter, sphericity, bulk density, moisture content, and angle of repose for Hawassa 4 variety cassava tuber were 14.05mm, 0.89, and 2.18gcm^{-3}, 52.9%, and 29.4° respectively.

The performance of the developed cassava grating machine was carried out at four levels of drum speed and three levels of feed rate. The machine was evaluated in terms of throughput capacity, grating efficiency, percentage of mechanical loss, grating time, and quality performance efficiency and they were found to be in the range of 272.5kghr^{-1} to 471.4kghr^{-1}, 81.6% to 97.33%, 2.45% to 18.4%, 37sec to 179sec and 86.17% to 95.68% respectively. Analysis of variance revealed that the main effects of drum speed, feed rate, and their interaction effect were significant at the 5% level which means the drum speed, feed rate, and their interaction effect influence the throughput capacity, grating efficiency, percentage of mechanical loss, grating time, and quality performance efficiency of the grating machine.

Regression analysis was conducted to predict how much variance was being accounted in the dependent variable by a set of independent variables. The regression analysis result for throughput capacity showed that 95% of throughput capacity was accounted for by two independent factors collectively, $F(2, 33) = 311.17$, $R = 0.974$, $p = 0.000$. Also, regression analysis result for grating efficiency indicated that 70.14% of grating efficiency was accounted for by drum speed and feed rate together, $F(2, 33) = 38.77$, $p = 0.000$. Based on the regression analysis result, the percentage of mechanical loss showed that 70.1% of the percentage of mechanical loss was accounted for by drum speed and feed rate, $F(2, 33) = 38.76$, $R = 0.838$, $p = 0.000$.

5.2. Recommendation

The fabricated cassava grating machine was able to be more efficient and effective at operating a drum speed of 1400rpm. The following recommendation should be considered:

- Performance of the machine should be evaluated by a different variety of cassava.
- The fineness modulus of machine should be evaluated.
- The cassava grating machine should be re-tested for corm pulverizing.
- The feeding hopper should be covered with a shatter type of cover.
- The machine should be incorporated with peeling part.
- Machine should include a movable wheel for easy transportation from place to place.
- Promotion and dissemination of fabricated machine should be done to the end users.
- The machine should be cleaned after an operation.
- The care should be taken during operating the machine.

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APPENDIX

APPENDIX I

Determination of physical properties for cassava tuber sample

A. Moisture content (wb)%

Mc = $\frac{\mathrm{Ww-Wd}}{\mathrm{Ww}} \times 100$

i. Mc = $\frac{65.9-31.7}{65.9} \times 100$

Mc = 52%

ii. Mc = $\frac{72.5-34.1}{72.5} \times 100$

Mc = 52.9%

iii. Mc = $\frac{76.4-35.3}{76.4} \times 100$

Mc = 53.8%

The mean value of moisture content was calculated as:

Mc = $\frac{51.8+52.9+53.8}{3}$

Mc = 52.83%

B. Geometric mean diameter

The determination of GMD the test was conducted three times and the mean values were taken.

GMD = $\sqrt[3]{a \times b \times c}$

i. GMD = $\sqrt[3]{15 \times 17 \times 9}$

GMD = 13.19

ii. GMD = $\sqrt[3]{17 \times 20 \times 11}$

GMD = 15.52

iii. GMD = $\sqrt[3]{16 \times 19 \times 8}$

GMD = 13.44

The mean values of GMD = $\frac{13.9+15.52+13.44}{3}$

Mean values of GMD = 14.28

C. Sphericity

Sphericity = $\frac{\mathrm{GMD}}{\mathrm{a}}$

i. Sphericity = $\frac{13.19}{15}$ = 0.87

ii. Sphericity = $\frac{15.52}{17}$ = 0.91

iii. Sphericity = $\frac{13.44}{16}$ = 0.912

The mean values of sphericity = $\frac{0.87+0.91+0.912}{3}$

Mean values of sphericity = 0.89

D**. Bulk density (ρb)**

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

i. $\rho b = \frac{4000g}{1800cm^3}$ = 2.22

ii. $\rho b = \frac{4500g}{2000cm^3}$ = 2.25

iii. $\rho b = \frac{5000g}{2400cm^3}$ = 2.08

$\rho b = \frac{2.22+2.25+2.08}{3}$ = 2.183gcm^{-3}

APPENDIX II

Table 18. Appendix II.1. Raw materials cost

No.	Item description	Unit	Unit cost		Quantity	Amount	
1	Hollow square pipe (40×40×3000×3) mm	pcs	650	00	2	1300	00
2	Stainless Sheet metal (1000×2000×2) mm	pcs	6000	00	3	18000	00
4	Round bar	pcs	400	00	1	400	00
5	Flat iron 6mm thickness	pcs	300	00	1	300	00
6	Angle iron 4mm thickness	pcs	250	00	1	250	00
7	Bolt and nut	pcs	8	00	60	480	00
8	Electrode 2mm thickness	Pack	400	00	1/2	200	00
9	Bearing	pcs	600	00	2	1200	00
10	V-belt	pcs	700	00	1	700	00
11	Pulley	pcs	500	00	1	500	00
12	5 HP diesel engine motor	pcs	8000	00	1	8000	00
13	Antirust	Liter	200	00	1	200	00
14	Paint	Gallon	350	00	1	350	00

Sub-Total	31,880	00

Table 19. Appendix II.2. Machine and labor cost

No.	Types of machines	Machine cost/hr.	Working hour	Cost (EB)	Labor cost/hr.	Working hour	Cost (EB)	Total price (EB)
1	shearing	13	18	234	7.5	18	135	369
2	Bending	5	2	10	7.5	4	30	40
3	welding	8	40	320	7.5	38	285	605
4	Lath	14	15	210	7.5	14	105	315
5	Milling	17	12	204	7.5	6	45	249
6	pressing	6	12	72	7.5	14	105	177
7	Roller	4	5	20	7.5	7	52.5	72.5
8	Drill	5	20	100	7.5	15	112.5	212.5
				1170			870	2040

Table 20. Appendix II.3. Cost summary

No.	Cost variables	Cost (EB)
A	Raw materials cost	31,880
B	Materials wastage (2.5%)	797
C	machine cost	1,170
D	Labor cost	870
E	Overhead cost 5% (C+D)	102
F	Profit 10% (A+B+C+D+E)	3,481.9
G	Sells tax 15% (A+B+C+D+E+F)	5,745.1
Selling price		44,046

APPENDIX III

Economic cost analysis

The cost of operation for the fabricated cassava grating machine was calculated by the following procedure. The total cost includes the fixed and variable costs.

Some estimation was made as follow:

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

- The expected life of the machine = 10 years
- Expected operational hour per year (annual use) = 1440 hr.
- Salvage value = 10% of total cost of the machine
- Interest rate 13%
- Maintenance Cost = 30% of machine cost

Cost of machine

Fixed cost of grater

1. Depreciation (Dp)

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

$$Dp = \frac{44{,}046EB - 4{,}404.6EB}{10 \times 1440hr}$$

Dp = 2.8EB/hr

Where: Dp = depreciation cost

SP = selling price of grater

SV = salvage values (10% of selling price)

EL = economic life

2. Interest on capital (IC)

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

$$IC = \frac{44{,}046EB + 4{,}404.6EB}{2 \times 1440hr} \times 15\%$$

IC = 2.5EB/hr

Where: IC = interest on capital

SP = selling price

SV = salvage value

U = annual use

I = interest

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

Total fixed cost = Dp + IC

Total fixed cost = 2.8EBhr^{-1} + 2.5EBhr^{-1}

Total fixed cost = 5.3EBhr^{-1}

Variable cost

1. Labor cost

Labor cost of 160EB per day, 8hr in a day.

$$LC = \frac{DLC}{DWH}$$

$$LC = \frac{160EB}{8hr}$$

LC = 20EBhr^{-1}

Where: LC = labor cost

DLW = daily labor cost

DWH = daily working hour

2. Fuel cost

Fc = Fs×F

Fc = 1.82L/hr×100EB/L

Fc = 182EB/hr

Where: Fc = fuel cost

Fs = fuel consumption

F = fuel cost per liter

Total variable cost = labor cost + fuel cost = 20EBhr^{-1} +182EBhr^{-1}

Total variable cost = 202EBhr^{-1}

Total cost = Total fixed cost + Total variable cost

Total cost = 5.3EBhr^{-1}+202EBhr^{-1}

Total cost = 207.3EBhr^{-1}

For the economic analysis, the payback period of the engine-operated cassava grater was assessed. The labor cost, Fuel cost, material cost, maintains cost and machine cost was calculated. At 240 working days a year, to compute the net cash and the payback period, the following formulas were used:

Maintenance Cost = 30% of machine cost

Maintenance Cost = 2,808

Income = ($\frac{\text{Price of grated cassava}}{\text{kg}} \times \frac{\text{kg}}{\text{day}} \times \frac{\text{days}}{\text{year}} \times \text{efficiency}$)

Income = $\frac{0.47\text{EB}}{\text{kg}} \times \frac{471.4\text{kg}\times 8}{\text{day}} \times \frac{240}{\text{year}} \times 97.3$

Income = 983,565.2

Net cash = income - (material cost + labor cost + Fuel cost + maintains cost)

Net cash = 983,565.2 - (31880 + 6960 + 1456 + 2808)

Net cash = 940,461.2

Payback period = $\frac{\text{income}}{\text{net cash}}$

Payback period = $\frac{983{,}565.2}{940{,}461}$

Payback period = 1.05 ≈ 1year

By taking the mean grating capacity of 442.9Kghr^{-1} and efficiency 97.3% for drum speed of 1400rpm, the cost to grate one kilo gram can be calculated as:

Cost of grating one kilo gram cassava tubers by machine =

$$\frac{\text{total cost per hour}}{\text{grating capacity of machine per hour}}\text{EB}$$

Cost of grating one kilo gram cassava tubers by machine = $\frac{207.3}{442.9}$EB = 0.47EB

Cost of grating one kilo gram of cassava tubers by manually = $\frac{20}{18.7}$EB = 1.06EB

Cost-Benefit Ratio

The average manually grating capacity was also determined for one person so the average labor grating capacity of cassava tubers was determined 18.7 Kghr^{-1} and the labor cost of 160birr in the day (eight hours) per person was 20EBhr-1

Cost of grating cassava by machine = 0.47EBkg^{-1}

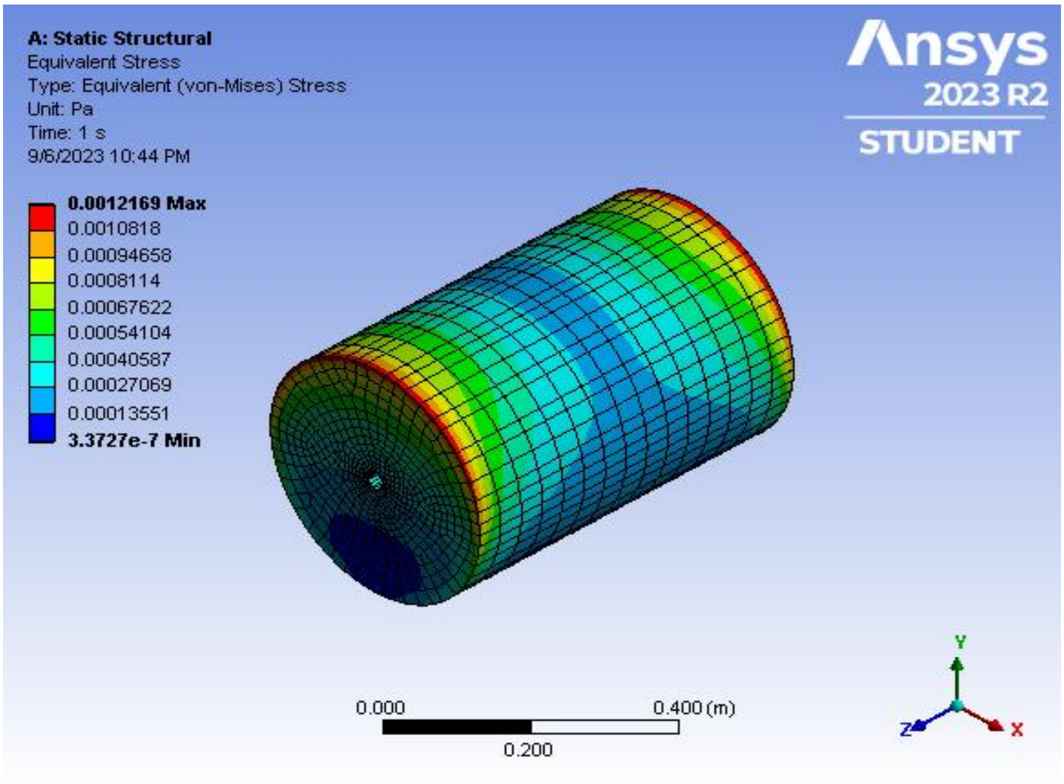
Cost of grating cassava by manually = 1.06EBKg^{-1}

So, grating one kilo gram of cassava tuber manually was determined 1.06EBkg^{-1} while the determined cost to grating tuber was 0.47EBkg^{-1} using a fabricating cassava grating machine. Therefore, cost-benefit ratio = 1:2.3

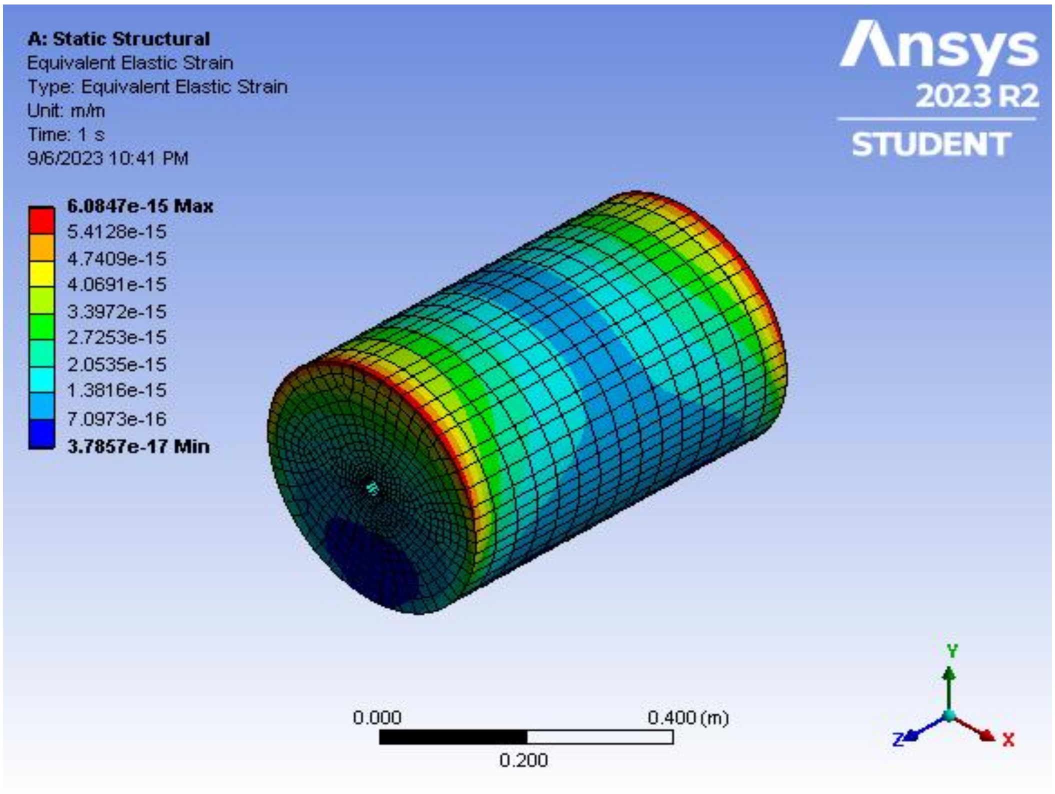
Table 21. Appendix III. Comparison of grating machine with traditional method

No.	Method of grating	Capacity (kghr^{-1})	Efficiency (%)	Percentage of loss (%)
1	Grating machine	358.55	93.06	6.85
2	Traditional method	18.7	53.3	46.7

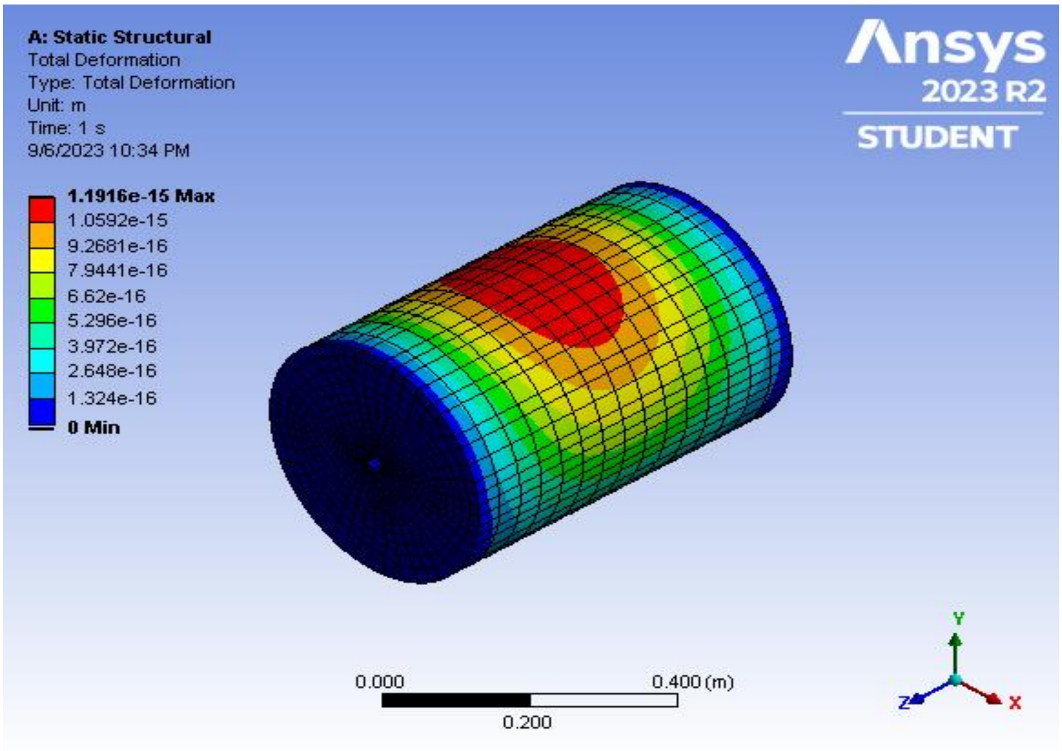
The von-Mises stress affected on the drum for AISI 1020 steel. It could be noticed that the maximum stress was generated at the grating drum was 1.2169 x 10^{-3}Pa, which was below the yielding stress of the AISI 1020 steel.



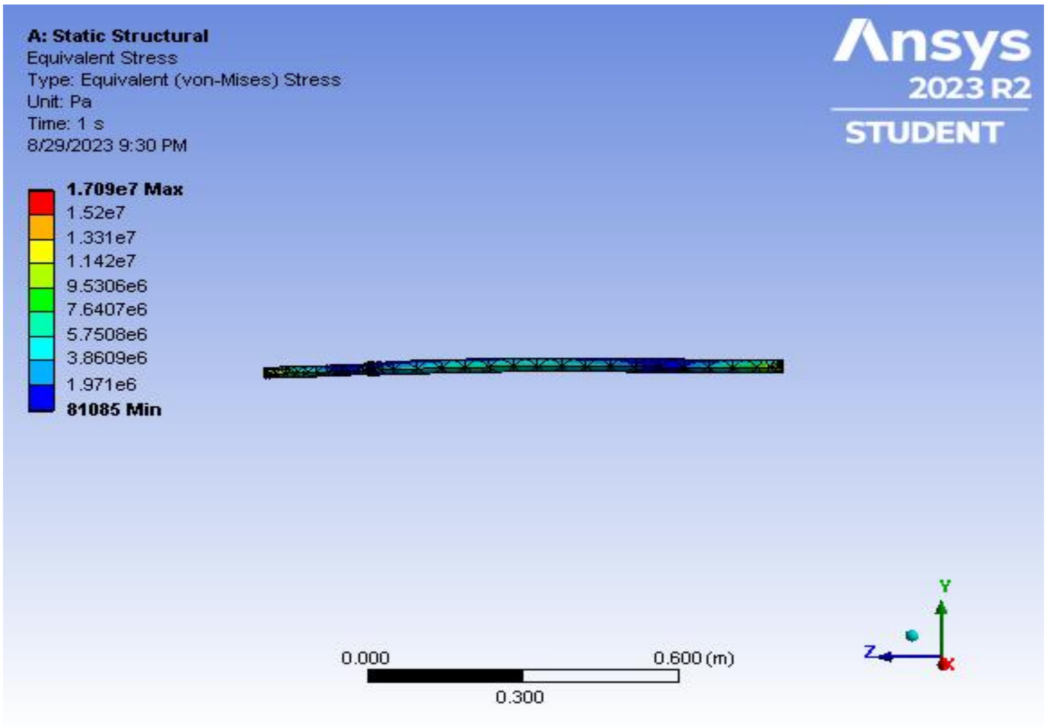
The analysis of the equivalent elastic strain on drum for AISI 1020 steel. The selected maximum elastic strain was 6.0847 x10^{-15}.



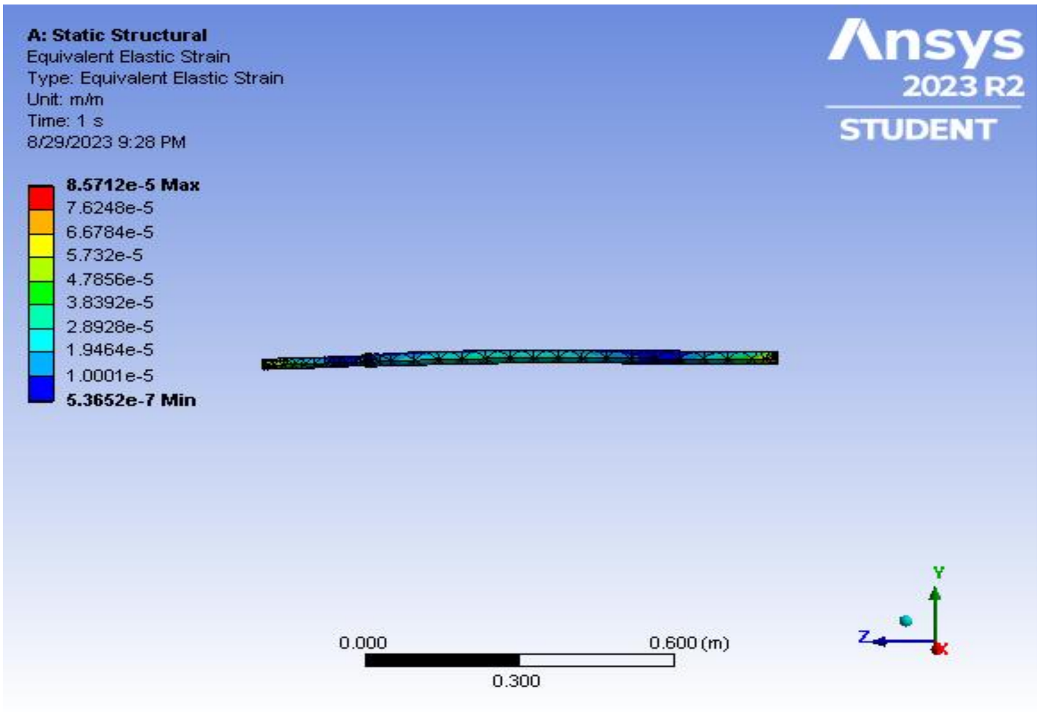
The analysis of the total deformation on drum for AISI 1020 steel. The selected maximum total deformation was 1.1916 $x10^{-15}$.



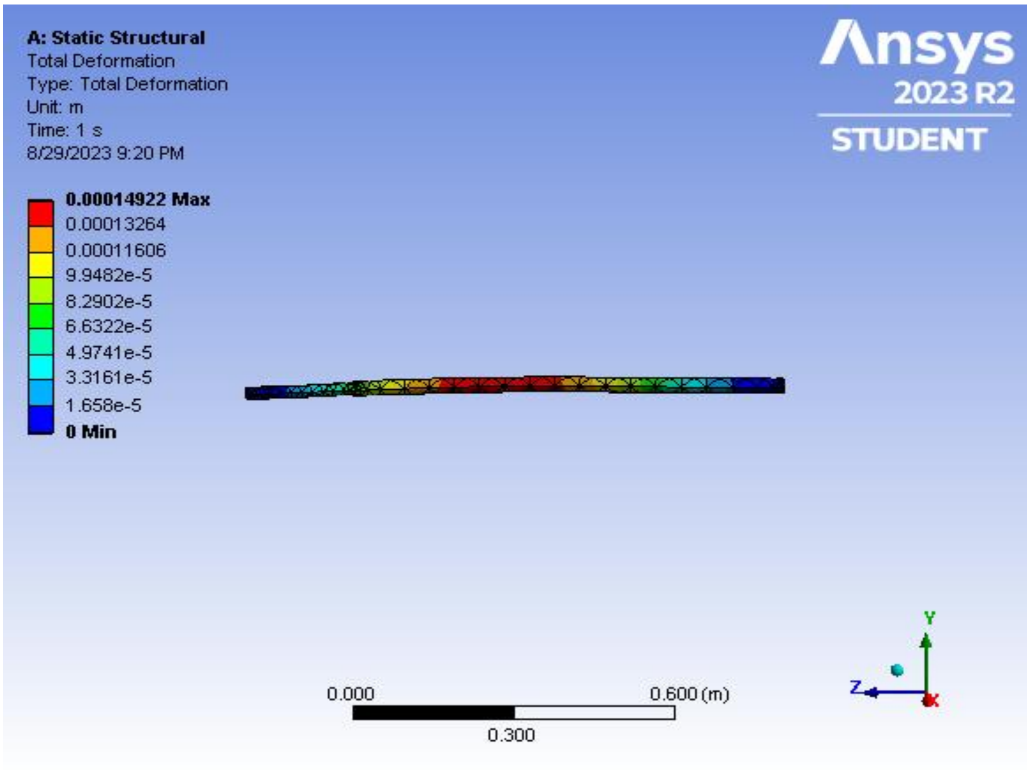
The von-Mises stress affected on the shaft for AISI 1020 steel. It could be noticed that the maximum stress was generated at the shaft was 1.709 x 10^{-7}Pa, which was below the yielding stress of the AISI 1020 steel.



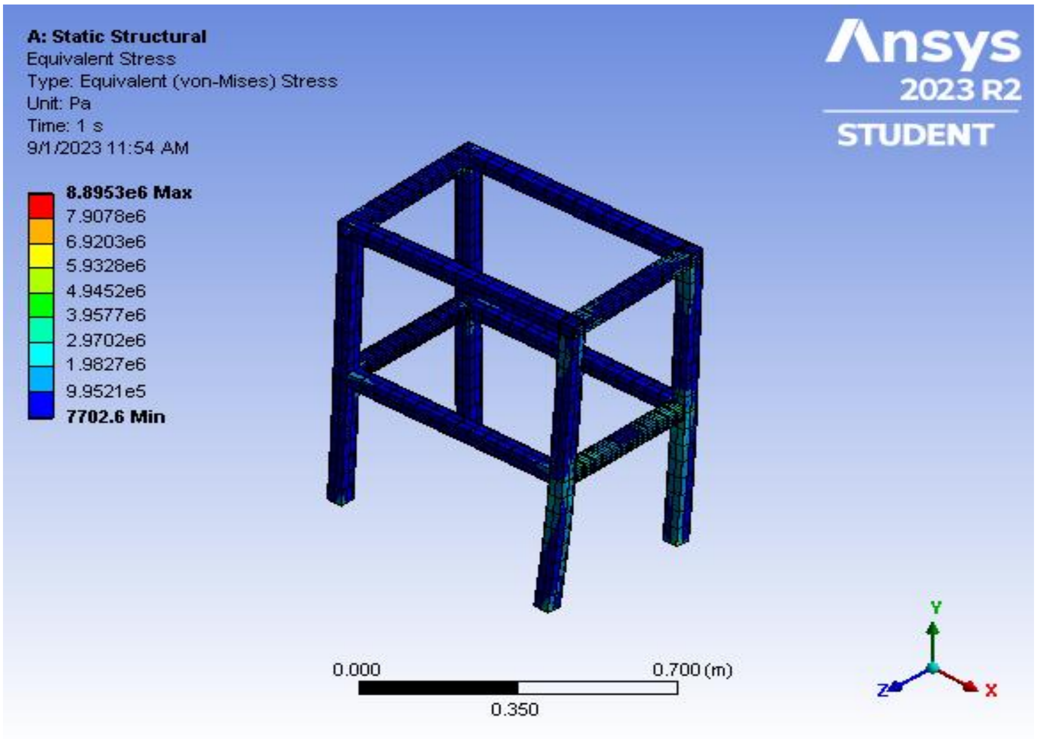
The analysis of the equivalent elastic strain on shaft for AISI 1020 steel. The selected maximum elastic strain was 8.5712 $x10^{-5}$.



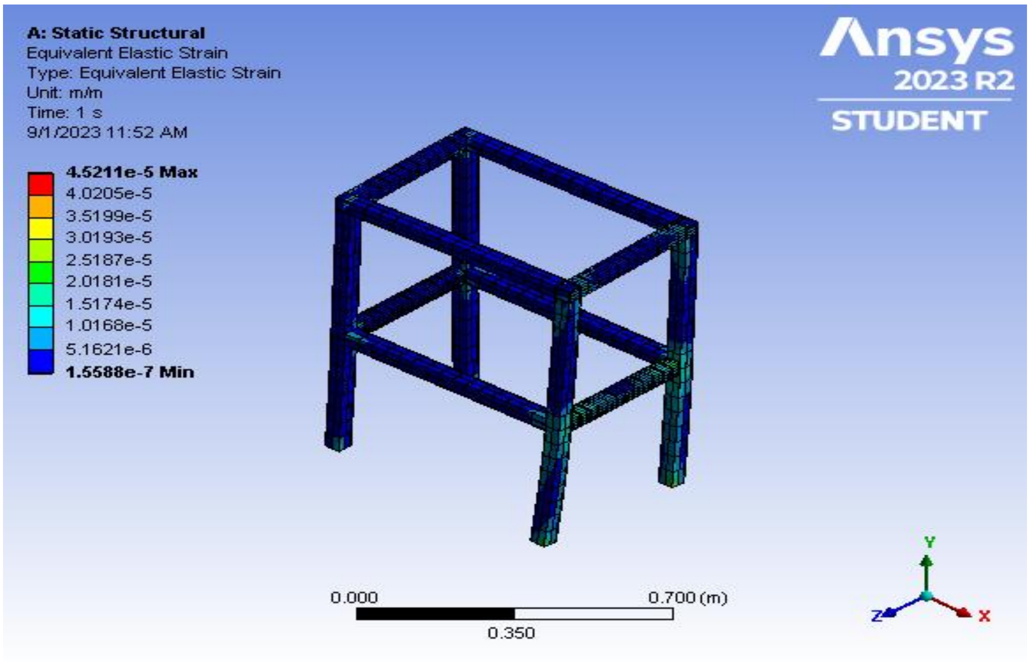
The analysis of the total deformation on shaft for AISI 1020 steel. The selected maximum total deformation was 1.4922 $x10^{-4}$.



The von-Mises stress affected on the frame for AISI 1020 steel. It could be noticed that the maximum stress was generated at the frame supports was 8.8953 x 10^{6} MPa, which was below the yielding stress of the AISI 1020 steel.



The analysis of the equivalent elastic strain on frame for AISI 1020 steel. The selected maximum elastic strain was 4.5211 x10^{-5}.



The analysis of the total deformation on frame for AISI 1020 steel. The selected maximum total deformation was 1.1897 $x10^{-4}$.