DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF MOTOR DRIVEN ENSET DECORTICATOR

By:

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DEPARTEMENT OF MECHANICAL SYSTEMS AND VEHICLE ENGINEERING

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIALS ENGINEERING

A thesis submitted in partial fulfillment of the requirements for the Award of the degree of Master of Science in Agricultural Machinery Engineering

Office of Graduated Study

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the project entitled **"Design, Construction and Performance Evaluation of motor driven Enset Decorticator"** in partial fulfillment of the requirement for the award of the degree of Masters Science in Agricultural Machinery Engineering in an authentic record of my own work carried out from February, 2018 to December, 2018 under the supervision of Dr. Amana Wako Department of Mechanical system and Vehicle Engineering, Adama science and Technology University, Ethiopia. The matter embodied in this project has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this project have been duly acknowledged.

Tarekegn Elias Dalelo	____________	____________
Name	Signature	Date

ADVISOR DECLEARTION

This is to certify that the above statement made by the candidate is correct to the best of my Knowledge and belief. This project has been submitted for examination with my approval.

Dr. Amana Wako	____________	____________
Advisor	Signature	Date

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

School of Mechanical, Chemical and Materials Engineering

Design, Construction and Performance Evaluation of Motor Driven Enset Decorticator

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Approved by Board of Examiners

Chairman, Department Graduate committee	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date
Advisor	Signature	Date

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I praise Jesus Christ my Lord, for his unlimited blessings!

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LIST OF ACRONYMS

MoA	Ministry of Agricultural
ASME	America Society of Mechanical Engineers
CSA	Central Statistical Authority
DITC	Durame Industrial Technology College
ENI	Ethiopian Nutrition Institute
ETB	Ethiopian Birr
GMF	General Metal Fabrication
IAR	Institute of Agricultural Research
INIBAP	International Network for The Improvement of Banana And Plantain
JAMRC	Jimma Agricultural Mechanization Research Center
Kb	Combined shock and fatigue factor applied to bending moment
Kt	Combined shock and fatigue factor applied to torsional moment
LCC	Life Cycle Cost
MARC	Melkassa Agricultural Research center
Mb	Bending Moment
Mt	Torsional Moment
MS	Mild Steel
SNNPR	South Nations Nationalities and People Region
SRTPC	Sodo Rural Technology Promotion Centre
Ss	Allowable stress
WP	Weight of Pulley

ABSTRACT

More than twenty percent of Ethiopia's population used Enset for human food, fiber, animal forage, construction materials, and medicines. In Ethiopia Enset are decorticated traditionally using a locally made bamboo scraper against a wooden plank. This traditional method is inefficient, unhygienic, gender based, less productive and time consuming. To alleviate this problem, the way aimed for developed three horse power engine driven Enset decorticator. Therefore, this thesis work intended to design manufactured and performance evaluation of suitable low horse power Enset decorticating machine. The physical properties of different varieties of Enset sheaves were studied. The developed three horse power Enset sheave decorticating machine consists of cylindrical shaped drum, blade, inclined plate, clearance adjuster, storage device, pair of rollers and three horsepower diesel engine. The developed diesel engine motor driven decorticator was tested in the laboratory and field. In laboratory test machine checked its specification and operational test. The result indicated that the machine was most stable, and the machine was easy to start, operate and stop. The preliminary test conducted at decorticating gap of < 2mm, 2 mm and >2mm with drum speed of 650 rpm, 850 rpm and 1050 rpm shows better decorticating performance but at 2mm decorticating clearance with drum speed of 1050 rpm gave best operation result than others. When compared with traditional Enset decorticating technique, the new developed machine was perform decorticating activity more efficient and effective, hygienic, productive, save time, and gender specific. In general Motor driven Enset decorticator works satisfactorily in the field with required feed rate, with minimum damage to fibre and the operating belt speed of 5.5 m/s. Therefore, there was suitable for decorticating without belt slip and the cost of operation was 42.24 ETB/hr.

Key words*: Enset Decorticator, Design, Drum speed, decorticating clearance, performance*

CHAPTER ONE

INTRODUCTION

1.1. Back Ground and Justification

Among the total population of Ethiopia more than eighty five percent lives in the rural area where crop production and animal husbandry were their main stay. There are different farming systems depending on different agro ecologies found in the country. Root, steam and tuber crops play a major role in food production in Southern, South-West, Western and Central part of Ethiopia. (Spring et al., 1996).

Enset is a diploid herbaceous perennial edible species of the separate genus of the banana family, thus named false banana. Variation within the species to altitude, soil and climate has allowed widespread cultivation in the mid to highlands of western Arsi, Bale, the Southern Nations Nationalities and Peoples Regional State and western Oromia including West Shewa, Jimma, Ilubabora and Welega (Taye, 1984).

It was estimated that a quarter or more than 20 million of Ethiopia's population depends on Enset as staple and co-staple food source, for fiber, animal forage, construction materials and medicines and the area of Enset production in Ethiopia is estimated to be over 321,362.43 hectares **(**CSA, 2016**)**.

The fiber by-product of Enset supplies more than 30 percent of Ethiopia's fiber need (Brandt et al., 1997). Fresh Enset parts are used as fodder for domestic animals during dry season and some Enset clones are reported to have medicinal value to human beings and domestic animals (Temesgen et al., 2014). Based on the level of priority given to Enset cultivation in different zones and regions, three Enset based farming systems have been identified. Enset is the first important food source crop in Gurage, Kembeta, Sidama, Gedio, Hadya, Jemjem and Arero zones (According et al., (2008).

Ethiopia has the capacity to produce more to be self-food secure, which can fully give every person the daily requirement of the balanced diet. The main problem is the inability to produce at a commercial scale and the loss of its product during harvesting, processing and the improper storage of the final product before consumption and lack of knowledge about nutrition. Even though there is enough food, the people are not accustomed to vary their meal to fulfill the nutritional requirement. This is due to the lack of knowledge of the people on the balanced diet, the lack of income to purchase foods, and to use different raw materials as a source of food (Clark, 2006).

Mechanized agriculture is the process of using agricultural machinery to mechanize the work of agriculture, greatly increasing farm worker productivity. The requirement of power for certain operations like seedbed preparation, cultivation decortications and harvesting becomes so great that the existing human and animal power in the Ethiopia appears to be inadequate. As a result, the operations are either partially done or sometimes completely neglected.

Now day industrialization is growing at a much faster rate and among this, food and beverage processing industries cover most of the percentages. Therefore utilization of different raw materials, which are locally available, at a processing scale is necessary in order to sub stain from scarcity of food. In this regard attempted has been made to study the production of Kocho, fiber and bulla in large scale industry.

Enset processing has been carried out by women using traditional tools, and the process is laborious, tiresome, and unhygienic. The processing has been done mostly by women in many Enset cultivated regions; however, men occasionally assisted women. At harvest, leaves and older leaf sheaths are first removed from the designated plants. The internal leaf sheaths (commonly up to two meters in length) are separated from the pseudo steam down to the true stem, which is about a 20 centimeter section between corm and pseudo steam (Endale and Mulugeta, 1994).

Enset's true stem is separated or stumped from the underground corm. The concave side of the leaf sheath is peeled and cut into pieces of about one meter length and split lengthwise in order to shorten the leaf sheath to a workable size. Then the leaf sheath was decorticated using a locally made bamboo scraper while the leaf sheath is held on an inclined (at 45 to 80 degrees from the ground) against a wooden plank. In some groups, women may sit on the ground (often on Enset leaves) and used one leg to hold the leaf sheaths in place, while in other areas they bind the sheath to the board and stand to decorticate. The working area used for decortications was covered with Enset leaves (Atnafua et al., 2008).

In order to alleviate Enset decorticating problem, very few studies had been done. The Ethiopian Nutrition Institute and Areka Rural Technology tried to develop modern devices that enable easy decortication, pulverization and squeezing. Researchers at Ethiopian jimma agricultural research center developed Enset sheave decorticator from wooden plank. In this case women stand and decorticate the sheave on the inclined board to increase hygiene. Melkassa Agricultural Research center, also tried to develop the clamping mechanism Enset decorticating machine. This is a significant development over the traditional method which used the decorticators save time and reduces labor and increase hygienist. However, their work doesn't improve the drive mechanism; performance of the developed decorticator was not evaluated and in generally no attempt was made to improve productivity due to no research was done in technological Enset decorticating system (Temesgen et al., 2014).

The main aim of this study was to designed, fabricated and evaluate the performance of diesel engine motor driven Enset decorticating machine which was made from locally available materials, cheap, but strong enough to perform that tusks. The Enset processing machine was developed and undertaken in the area where one of maximum Enset cultivated zone called Kembeta Tembaro zone in Durame Industrial Technology College. Diesel engine Motor driven decorticator was economic and suitable to perform most field operations. Due to the suitability, this become an economic alternative for Enset holders. Snyder et al., (2006) reported that engine motor driven decorticators are much more productive than manual decortication and they require less time for attendance and preparation, giving the individual farmer more independence and access to modern technology.

The developed three horsepower diesel engine driven Enset decorticator components were decorticating drum with blade, inclined plate, clearance adjuster, kocho collector bucket, pair of rollers and three horsepower diesel engine motor itself for power source. The distance between the two blades was determined by the arc length or the angle created called Ө and the edges of the blade were sharp enough to peel of the sheaves of Enset but blunted at tip. The decorticator can got the power from diesel engine motor for decorticating Enset sheave. This motor powered mechanism was change the power from motor through belt to the rotational movement of a decorticator drum, blade fitted to the shaft. An adjustable decortication clearance with varying from 1mm to 5mm between blade tip and inclined plate.

The inclined plate was made for decortication of sheave on it. It was 45 degree inclined from the horizontal to mount effective decortication and it was mounted on the frame. The decorticating Enset sheave existing on inclined plate feed when the drum with blade rotating in vertically during operation and the operator then put the Enset sheave through entrance and guided by roller and push it into the machine blade. The decorticator blades then contacted the sheaves, stripping the soft parts against the inclined plate and pulled through to the collecting bucket.

1.2. Statement of Problem

Manually Enset processing required intensive labor. Farmers who cultivate Enset in Ethiopia face a series of challenges that limit there over all production and income. One of these challenges was lower yields due to traditional way of decorticating practice. Since Enset processing and decortication were operated by women and they have been suffering of deragery of work. Therefore lost product observed during scraping by bamboo scraper. Particularly, using traditional way of decortication has hygienic problem. Besides, it consumes much energy time consumption. Hence this problem seek attention.

1.3. Objectives

1.3.1. General Objective

Design, construction and performance evaluation of diesel engine motor driven Enset decorticating machine.

1.3.2. Specific Objectives

- Identify the physical properties of Enset sheath and fiber related to Enset decorticator.
- Design and manufacture components of Enset decorticator.
- Conduct performance evaluation of the Enset decorticator in laboratory and field.
- Compare the performance of decorticator with existed traditional decorticating technique.

1.4. Significance of the Study

Enset decorticating is carried out by women using traditional tools, and the process is laborious, gender based, low productive and unhygienic. These study expected to the efforts working towards attaining socially desirable use of kocho and fiber production from Enset. Applying modern decorticator had a great benefit in terms of different aspects. Eases labor, comfortable to operate (ergonomically), had a faster production rate, Improves hygiene of the work (no contact of human feet with food item), needs less skill and more attractive for men to involve in the work that was otherwise an unfairly total woman work. This study therefore has a great significance to achieve the above listed advantage in addition to its benefit of saving the farmer's time and reduce labor requirement for other agricultural activities.

1.5. Scope of the study

The activity of Enset processing includes, selecting matured Enset plant, cutting the Enset plant, peeling, decorticating, squeezing to produce bulla, and transporting the extracted product and digging a pit for fermentation of the kocho. Before starting all the Enset processing activity, the number of matured Enset plant can be decided either by men or women. The main functional difference is decorticating activity. But the decorticating activity requires high human power, does not attract men to be involved in Enset processing, consumes much time and energy, poor sanitation and low productivity. Therefore this study is limited to design, manufacture and performance evaluation of three horse power diesel engine motor driven Enset decorticator to minimize the challenges of decorticating.

CHAPTER TWO

LITERATURE REVIEW

2.1. Origin, Taxonomy and Distribution of Enset

Different hypothesis are proposed on the origin of Enset agriculture. Agronomists and bio-geographers have long considered the Ethiopian high lands to be the primary center of origin for Enset agriculture. In relation with this anthropologists, archaeologists, historians and other scholars have also developed hypothesis that argue for the domestication of Enset in Ethiopia as early as 10,000 years ago (Brandt et al., 1997).

Enset (Ensete ventricosum is a monocot that belongs to the order Schistaminae and family Musaceae. Enset was considered as member of the genus Musa as it strongly resembles banana morphologically and because of this some of the species names formerly given to Enset were Musa Ensete and Musa ventricular (Lye and Edwards, 1997).

Currently, Enset distribution is restricted to south, southwest and central part of Ethiopia and it is not known as food crop in the northern part of Ethiopia. However, historical evidences suggested that Enset may have once played a much more important role in the agricultural practices of central and northern Ethiopia before the mid-19th Century. The possible reasons for total disappearance of Enset culture in the North could be disease, drought and instability in the sociopolitical events between mid-1700 and mid 1800 (Brandt et al., 1997).

2.2. Enset Morphology and Ecology

Enset looks like a large, thick, single stemmed banana plant. Usually it is larger than banana and 6-12 meters tall. The leaves are 5-7 meters tall and 1 meter in diameter and are more erect than a banana plant (Kefale and Sandiford, 1991). The stem has three parts: the pseudo stem, which is made of tightly clasping leaf sheaths, is 2-3 meters in height and with an average of 1 meter diameter with an edible pulp and quality fiber. The underground corm is an enlarged lower portion of the stem with an average of 0.7 meter length and diameter.

The fibrous rooting system of Enset grows out from this part. The true stem is between the pseudo stem and corm near the ground. Usually it grows up during maturity and initiates a single flower head, which forms multiple flower, fruits and seeds. The small banana like fruits produce several irregularly shaped black seeds. Most wild Enset plants are produced from seeds unlike the domesticated ones, which are propagated from suckers (Brandt et al., 1997).

The average temperature Enset growing areas is between 16 to 20°C and the relative humidity of 60 to 80 % (Yohannes and Mengel, 1994). Soil types in the Enset growing areas of Ethiopia are Utric cambisols, Verity soils and Utric nitisols which are moderately acidic to slightly basic with a pH reaction ranges from 5.6 to 7.3. These soils contain 0.10 to 0.15% total Nitrogen and 2 to 3% organic matters.

When the plant matures after 9–14 years, the true stem emerges through the leaf sheaths and produces inflorescences. The best time for harvesting is just after production of 8 inflorescences and seed set. However, Enset sometimes can be harvested when only 3-4 years-old, depending on the clone and growing conditions. If not harvested, the whole plant falls down, shortly after seed set (Taye et al., 1984).

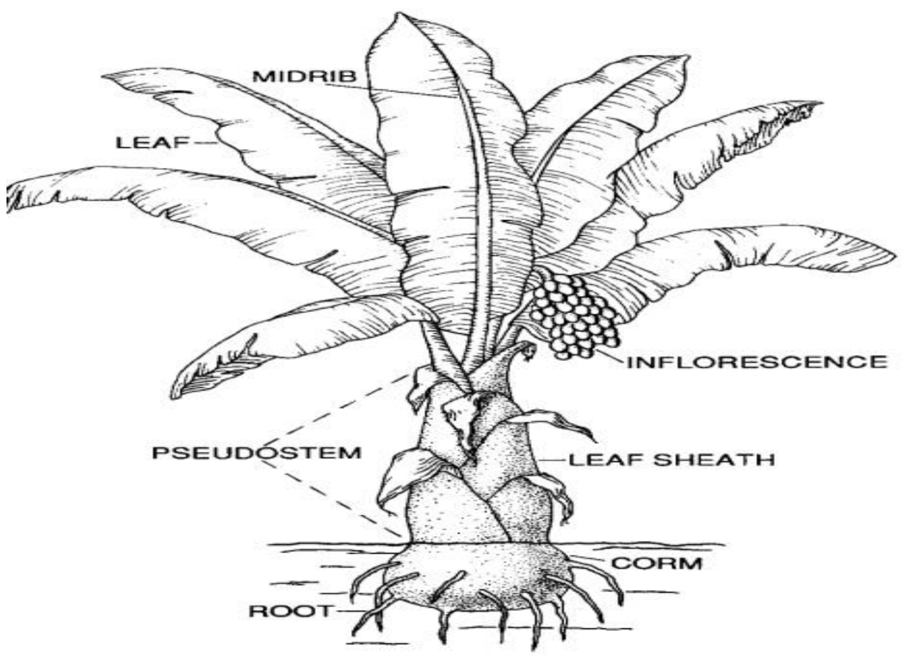


Figure 2.1. Structure of Enset plant

2.3. Emic Categories of Enset Local Varieties

The local people classified their Enset local varieties in two categories (male and female) based on kocho, bulla, fiber and amicho quality, fermentation quality, ease of processing, early maturity, yield, and resistance to decorticate and disease and drought. They distinguished each variety in terms of its maleness or femaleness (Yohannes and Mengel, 1994).

2.4. Economic Importance and Ecological Uses of Enset

Enset is a multipurpose crop of which every part is thoroughly utilized. It is a good source of starch. The corm and the pseudo stem are the most important sources of food (Kefale and Sandiford, 1991).

Enset is one of the major crops that can significantly help to ensure food security in a country like Ethiopia. The average yield of refined enset product kocho ranged from 35 to 51 tons/ha/ year in early maturing enset clones. (Atnafua and Endale, 2008).

Enset is rich in carbohydrate and mineral substances like calcium and iron. The energy yield of Enset is by far higher than that of several cereals. A mature Enset plant could yield 20 times higher than that of barley. Enset energy yield was also reported to be higher than potato, sweet potato and banana. This shows that cultivation of enset can significantly improve food security at household and at national level. Some clones and parts of Enset plants are reported to have medicinal value for both human and animals. These clones are claimed to heal bone fractures, for treatment of diarrhea and delivery problems i.e. assisting to discharge the placenta (Terefe, 1991).

The major food products Enset plants are kocho, bulla, amicho and fiber is the byproduct of enset after decortication.

Kocho is a bulk of fermented starch made from a mixture of the decorticated leaf-sheaths and grated corm. It can be stored for a long period of time without being spoiled. Bulla is obtained by scraping the leaf sheath, peduncle, and grated corm into a pulp, squeezing liquid containing a starch from the pulp, allowing the resultant starch to concentrate into a white powder; and rehydrating with water. Amicho does not require any processing as to kocho and bulla. It is simply the inner part of the corm eaten boiled like potato or grated into kocho. It is usually harvested for immediate consumption or grated in to kocho (Atnafua and Endale, 2008).

Enset fiber accounts for more than 30% of the Etiopia fiber producción and its strength is equivalente to the fiber of abaca (sisal). The fiber extracted by decorticating the leaf sheaths of the pseudo stem is used locally for making ropes, mats, sacks, bags, and sieves and used as construction material (Brandt et al., 1997).

2.5. Traditional Equipment Used In Enset Decortication

In traditional Enset decortication technique women use different kinds of traditional Enset decorticating equipment. But the equipment are different based on what to be decorticated as follows (Tariku and Mogessie, 2011).

2.5.1. Watani

Watani is a local name and made from wooden board. It is about 2 m long and 25-30 cm wide. During Enset decortication Watani is vertically inclined against Enset plant at about 45-60 degree based on women height and sharpness of sibisa in order to keep the number of cutting fiber and Ensure decorticating quality. An Enset sheave (worke) to be decorticate was placed on the slanted Watani against stand Enset and fixed at the middle by raised heel of decorticating woman as shown figure 2.2 (Tariku and Mogessie, 2011).

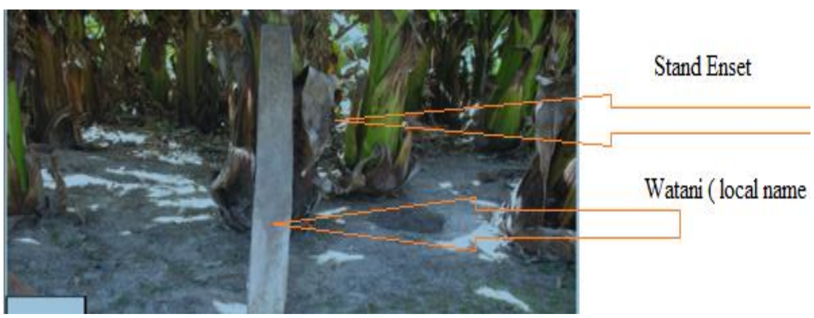


Figure 2.2. Inclined enset decorticator (watani).

2.5.2. Javga

It is a wooden equipment prepared locally with two ends of different functions. One end is serrated and used to pulverize the corm (amicho) and to macerate the contents of bulla during Enset decortication. The flat end is about 10 to15 cm wide and 50 to 70 cm long, and is pointed at the end. This end of javga is used to smash the lower piece of the pseudo stem (Tariku and Mogessie, 2011).

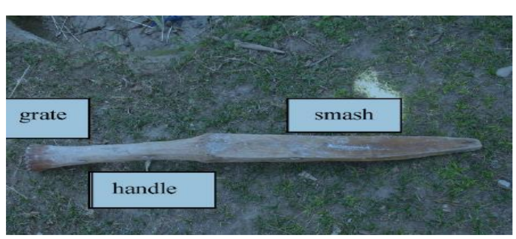


Figure 2.3. Javga

2.5.3. Sibisa

Sibisa (kerka) is a local language of bamboo tree. sibisa is a longitudinally split bamboo (kerka) tree, prepared about 50 cm in length and sharp edge (blade like structure) which is used to scrap the fleshy part of Enset sheave. Sibisa is handled at both ends while scrapping the leaf sheath (worke) (Tariku and Mogessie, 2011).

Figure 2.4. Sibasa

2.6. Traditional Enset Decortication Techniques

Enset (worke) processing is carried out by women using traditional tools, and the process is laborious, boring, and unhygienic. Some of the steps in the traditional Enset processing techniques differ among regions and even among localities. The women scraped the fleshy ventral side of the leaf sheath by using the sibisa.

A woman secured the leaf sheath against a vertically inclined watani at half way of its length with her heel from a sitting position (fig b.) to prevent the leaf sheath from slipping down during scraping of the lower half or from standing position (fig b). Scraping of the soft material yield fibers as a bi-product. The upper half of the leaf sheath was then turned upside down, for scraping. Scraping from sitting position is very common in the country (Tedla et al., 1994).

a. Stand then decorticate b. Sit then decorticate

Figure 2.5.Traditional decorticating technique

2.7. Design and Development of Decorticator Review

Ahmad et al. (2017) designed and developed motor drive sisal leave decorticator to produce fiber in Pakistan. Kanogu et al. (2011) developed a sisal decorticator for small holder farmers, fabrication and field testing in different decorticating clearance in Kenya.

As Million (2003) cited in his research paper, the Ethiopian Nutrition Institute (ENI), and Sodo Rural Technology Promotion Centre (SRTPC) have demonstrated improved Enset processing equipment, namely Enset decorticator and bulla extractor. However, these devices are still on trial and have not yet been made available to the end users due to their high costs, difficult to operate, low productivity and less efficient.

Melkassa Agricultural Research center (MARC), developed the clamping mechanism Enset decorticating machine to minimize the problem related to Enset decortication.

Figure 2.6. Improved decorticator in Melkassa and Jimma

Researchers at Ethiopian Jimma Agricultural Mechanization Research Center (JAMRC), developed Enset decorticating machine and bulla extracting machine separately (Temesgen et al., 2014).

In this case, Enset scrappers with metal clip to improve sanitation during processing. Contrary to reports from technology developers and researchers, the women in this case did not use their feet to hold the sheath to the scrapper. They used rope to hold the sheath to the board. However, no attempt was made to improve productivity due to machine efficiency, easy to operate, machine performance.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study Site Description

The Enset processing machine was undertaken in the area where one of maximum Enset cultivating zone called Kembeta Tembaro zone in Durame Industrial Technology College. Kembeta Tembaro zone is situated roughly at the margin of the great Ethiopian Rift Valley at western margin in North western part of South Nations Nationalities and People Region (SNNPR). It located between 71^0 03' 4"- 75^0 00' 916"N latitude and 37 341' 711- 38 073 87'E longitude. The zone was bordered in East and North East with Halaba Special woreda, in the North it bordered with Hadiya zone, in south Hadiya zone and in west Dawuro zone. Durame is the capital city of Kembeta Tembaro zone and it is 296 km away from Addis Ababa.

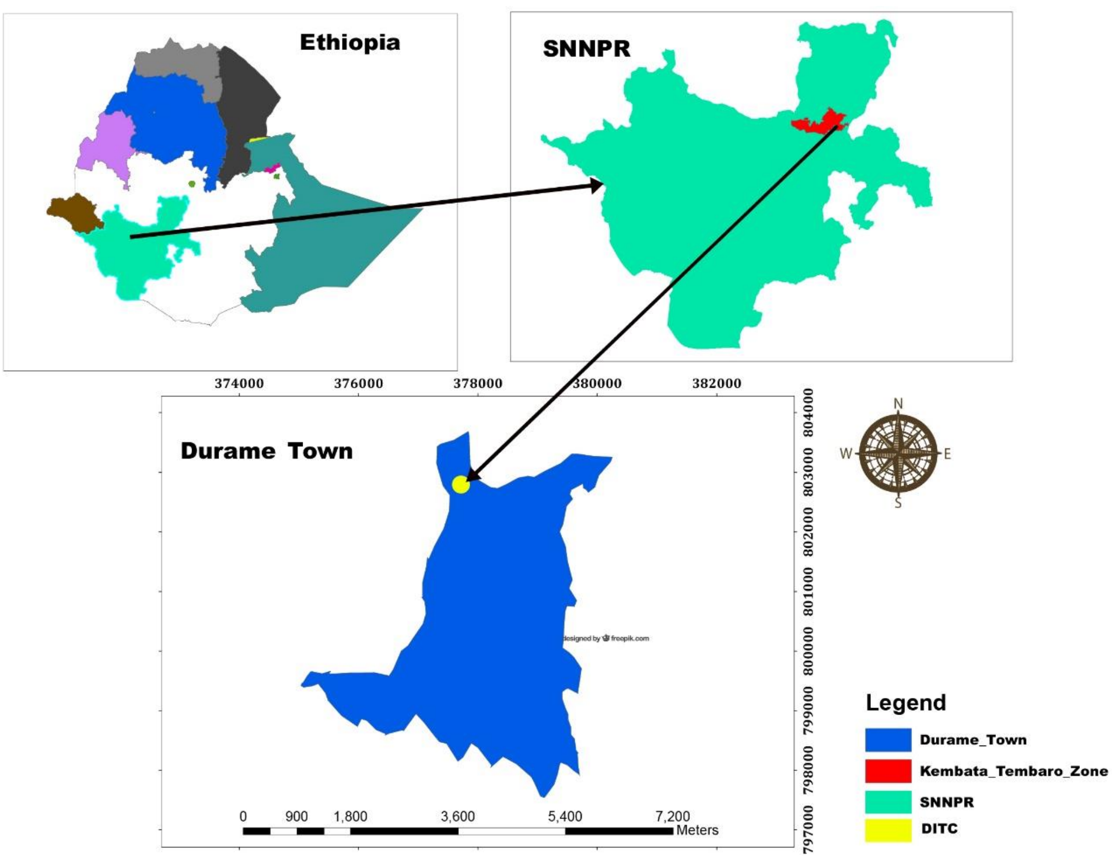


Figure 3.1. Study site map

3.2. Materials Selection

The materials selection was based on durability, cost, availability, strength, rigidity and weight. The material designed to Enset decorticator drum, blade and inclined plate must be free from iron and other heavy metal, but some parts like frame, main shaft, safety guard, pulley and belts were constructed from angled iron and sheet metal.

Table 3.1. Tools used in the fabrication of the machine

Sr. No.	Machine /tool name	Purpose
1	Drills machine	Making hole
2	Lathe machine	Threading /finishing /cutting.
3	Grinding machine	Cutting tool
5	Round file	Smooth rough edges
6	Electric welding machine	Welding
7	Steel tape	Measurement of linear distance
8	Vernier calipers	Measurement of outer and inner diameter
9	Hammer	Used to strike an object
10	Chisel	Cutting
11	Snip	Cutting sheet metal
12	Screw driver	Tighting screw
13	Spanner	Tighting nut and bolt
14	Flat file	Smooth rough edges
15	Bevel protractor	Mearing angle

In addition to these, digital weight balance (0.1gm accuracy), digital caliper of 0.01 mm accuracy, measurement tape (millimeter graduation) and stop watch instruments, 30 kg of enset were used during the field test.

Table 3.2. Materials used for fabrication of Enset decorticator and its specification

Sr.No	Components	Quantity	Material and specification
1	IC Engine	1	Three horse power diesel engine.
2	Blade	8	Made from Stainless steel and Sharp and blunted at the tip with 12 by 1mm cross sectional dimensions and lengths of 500 mm
3	Drum or cylinder	1	Flat sheet metal rolled into circular diameter 300mm, length 500 mm and coated by aluminum sheet.
4	Frame		Angled iron of 1000mm by 500mm by 3 mm cross Sectional dimensions.
5	Inclined plate	1	Made from Stainless steel and Incline to 45^{0} with 500 mm in length and 50 mm height with 3 mm thickness.
6	Shaft	1	Machined from mild steel and the dimensions of the shaft was 30 mm diameter and 700 mm length.
7	Pulley	2	Pulley made from cast iron with Larger Pulley Ø = 100mm, smaller Pulley Ø =75mm
8	Belt	1	belt was highly strong plastic material and total belt length 1300 mm
9	Safety cover	1	Rolled iron sheet, 2 mm thickness developed as per design drawings.
10	Bucket	1	Made from aluminum sheet and 40x30x3mm in volume

3.3. Physical Properties of Enset Leaf Sheath

The physical property of Enset sheath was important factor for the design of motor driven Enset decorticator. The Enset sheath varieties selected for the study were classified as small, medium and large based on the physical properties of namely; dimension, and plant pseudo steam circumference. The performance of feeding mechanism in terms of striping off soft parts from sheave in a given decorticating clearance was influenced by the physical properties of Enset leaf sheath. Three Enset sheath were selected randomly from sample and dimensions were measured. Therefore, sheath properties relevant to the design of Enset decorticator were identified and determined. Parameters like shape, dimension, weight, decortication resistance, diameter of Enset fiber were determined. Length, width and thickness of the sheave were taken using digital Vernier caliper.

The shape of Enset sheath was determined by the shape of Pseudostem. The pseudostem circumference at the middle height point of the Enset was determined by tracing the lateral cross section of it and compared with relative banana sheave shape.

Pseudo stem height was measured from ground level to the start of the leaf petiole and pseudo stem circumference at the middle height point of the enset pseudo stem. The dimension of decorticating sheath was determined by measuring the dimension of the principal axes; major, intermediate and minor of sheath.

From the above figure length (l), width (w) and thickness (t), the size was calculated by equations (3.1) (Mohsenin, 1986).

$$\text{Size} = \sqrt[3]{(l \times w \times t)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.1$$

But the above parameters were varied from one Enset to another. For example randomly selected three matured Enset sheath where measured and recorded as follows and the sample calculation look appendix A.

Table 3.3. Measured value of Enset sheave

Sr. No.	Length (m)	Width (m)	Thickness (m)
1	2.5	0.35	0.030
2	2.3	0.28	0.028
3	1.8	0.32	0.025

Leaf-sheaths (tightly or loosely overlapping part of pseudo stem) were separated from pseudostem and measured for their weight before decorticating using a weight balance. The weight of the sheath was determined by using digital weighting balance.

To determine decortication resistance of plant leaf sheath, leaf sheath was taken randomly and put it on the table and press by decorticator blade tip and the time taken to cut the sheath was measured by using stop watch (Snyder et al., 2006).

According to this study the decortication resistance of the Enset sheath was determined by two ways. The first methods to determine the decorticating resistance of the Enset sheath was putting the decorticating blade tip on the sheave and recording the time by using stop watch as shown appendix (A). The second way of decorticating resistance determination was traditional method.

Enset users can group Enset local variety into two categories of maleness and femaleness. The following table shows the local variety.

Table 3.4. Same local variety Enset

Sr. No	Male Enset variety	Sr.No.	Female Enset verity
1	Geshera	1	Ungame
2	Sisikela	2	Tebare
3	Dirbo	3	Moche
4	Abatmerza	4	Sheleke
5	Gembewa	5	Sebera
6	Dego	6	Etene

Diameters of fibers were recorded by using Optical Microscope which was interfaced with suitable software. Objective lens of 10× (magnification) was used to record at least three diameter readings along the length of 30 individual fibers and the average diameter was calculated by using equation (3.2) (Mohsenin, 1970).

$$d = \frac{d1+d2+d3+\cdots+dn}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

Where. d is the average diameter of the sampled fiber;

$d1, d2, d_3$ ……… dn. is average diameter of individual fibres in the sample;

n is the number of fibres measured in the sample.

3.4. Design Consideration of the Machine.

The design of machine components was based on the principles of operations. It was rotating parts compared with the conventional method, to give a correct shape in form of machine. The details mechanical design was also given with due attention so that it gave adequate functional rigidity for the design of machine. The following design factors that were taken into consideration.

Assumption Made during designing of motor drive Enset decorticating machine, the following assumptions were as follow.

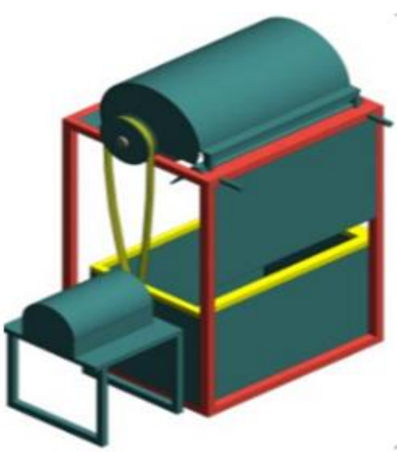
- Fabrication of the machine components were considered for periodic servicing.
- Overall cost of the machine was considered based on the Life Cycle Cost (LCC) of the machine throughout the design stage.
- Physical properties of Enset sheave such as shape, size were considered.
- The machine was constructed with the use of availability of local materials to ensure the need of possible replacement of damage parts that are not expensive.
- Machine factors such as strength, stability, rigidity, appropriately considered.

3.5. Design Analysis of Major Components of the Enset Decorticator

3.5.1. Description of Enset Decorticating Machine.

This session described the criteria for design of diesel engine motor derive Enset decorticator and their functional parts. The machine parts consist of the decorticating drum, blade, shaft, belt, pulley, bearings, bearing housing, safety cover, bucket, three horsepower diesel engine motor, inclined plate, rollers and the main frame. The drum was designed in a cylindrical shaped made from rolled sheet metal and coated by aluminum sheets as shown in fig (3.6).

When in operation the soft part of sheave which was called kocho could be stored in bucket temporary and later transported to fermentation place. The motor drive Enset decorticating machine consists of the following parts as shown fig (3.5).



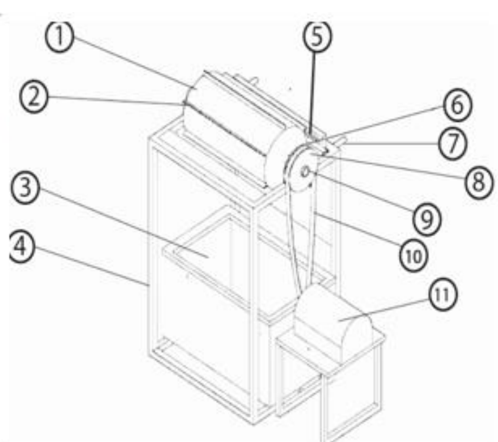


Figure 3.2. 3D Machine model

Figure3.3. Machine parts representati0n

Key

1. Decorticating drum
2. Decorticating blade
3. Bucket with filter
4. Frame

5. Dual rollers
6. Inclined plate
7. Clearance adjuster
8. Drum pulley

9. shaft
10. Belt
11. Diesel engine motor

. The driving mechanism consist of a motor which was used to supply power for operating the machine by transmission units called pulley- belt system. The cost of the machine was affordable due to availability of raw materials. The drum shaft was machined from common shaft material available. Based on the cost, mild steel rod was chosen as the preferred choice.

3.5.2. Estimation of Weight the Decorticator by Using Cattie Software

The weight of each part designed was calculated using Cattie software. The input of the software was part designed which equipped with dimensions and material type selection. The software has its own material types with their densities. Once the part designed was feed with dimensions and material type, the cattie gave the output of the selected component area, volume and mass.

Table 3.5. Cattie software weight determination analysis for each components of machine

Sr. No.	Components	Quantity	Area (m^2)	Volume(m3)	Density (kg/m^3)	Unit mass (kg)	Total mass (kg)
1	Drum	1	0.071	0.00047	7870	3.7	3.7
2	Blade	8	0.000012m	0.000006	7870	0.047	0.85
3	Main frame	1	0.0144	0.00144	7870	11.33	11.33
4	Motor setting	1	0.0375	0.0012	7870	9.44	9.44
5	Inclined plate	1	0.002	0.001	7870	7.87	7.87
6	Gap adjuster	2	0.00314	0.0000524	8000	0.42	0.84
7	Shaft	1	0.00071	0.000495	8000	3.96	3.96
8	Bearing	2	0.0294	0.000162	7870	1.272	2.472
9	Pulley	2	0.0036	0.000216	7870	1.7	3.4
10	Bucket	1	0.00088	0.000527	7870	4.12	4.12
11	Roller	2	0.00011	0.000053	7870	0.42	0.42
12	Angle iron	4	0.021	0.0045	7920	0.362	1.45
	Total weight of component parts						49.85
13	2% for bolts, nuts and other						0.977
	Total						49.85

Therefore the total mass of the machine was 49.85 kg and it's the weight was determined as equation (3.3)

$W = m \times g$ ………………………………………………………………………………. 3.3

Where. W = weight, N

m = total mass of the parts, kg

g = acceleration due to gravity, 9.81m/s^2

W = 49.85 kg × 9.81m = 489.03 N, therefore the total weight of machine was 489.03 Nm

3.5.3. Decorticating Drum and Blade Design

Drum was cylindrical shaped device with stainless steel blades attached at a to-be-determined distance apart from each other around the cylinder. One design of drum had been described mainly as sheet metal as rolled of 300 mm in diameter and covered by aluminum sheet. The drum was fastened onto a horizontal shaft which was mounted on the bearings that were in turn fixed onto a firm base

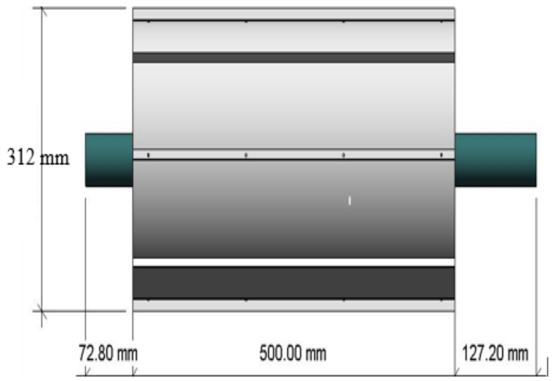


Figure 3.4. Decorticating drum with blade

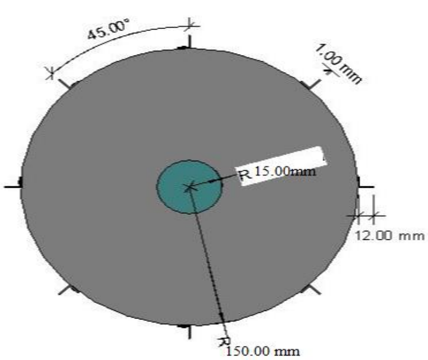


Figure 3.5. Decorticating drum side view

Each of the blades was equal in length, equal space between the blades, having a broad sharp and nearly blunted at the tip.

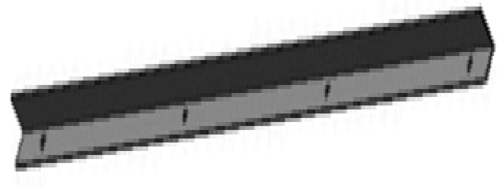


Figure 3.6. 3D Blade model

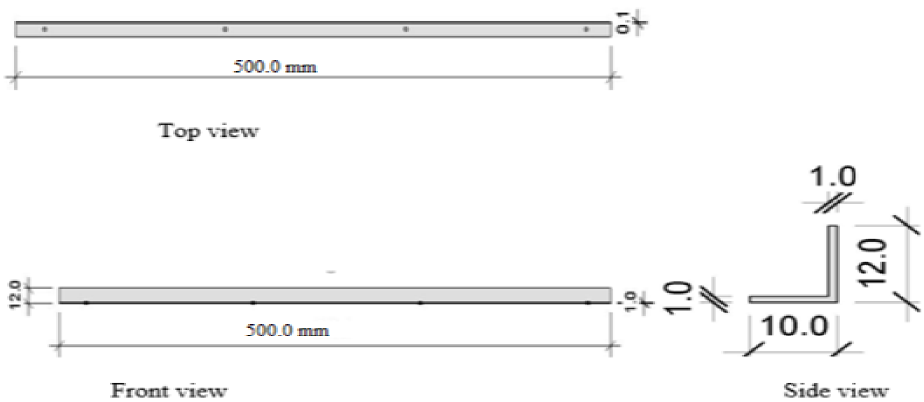


Figure 3.7. Detail blade view

During the process of striping off kocho from Enset sheath the, the blades may be subjected to wear and tear when the sudden/impact load was applied by inclined plate at a cyclic manner or repetitively. By wear and tear, the quality of the kocho, fiber and decorticating efficiency will become very low. To maintain its quality, the new blades have to be replaced.

The number of blade on the cylinder can be determined by the equation (3.4) (Kanogu, et al., 2011)

$$n = \frac{2\pi}{\Theta} \qquad (3.4)$$

Where. n = is the number of blades on the beater drum and Θ = is angle between two successive blades, determined by protractor given, $\Theta = 45^0$ and was said to be arc length between two successive blades. Therefore number of blade on the drum was eight.

3.5.3. Design and Kinematical Considerations of Feeding Mechanism.

In the actual drum working head, the beater drum rotated uniformly about a fixed axis of rotation while the Enset sheave was fed to the beater drum. If it was assumed that the leaf was fed to the beater drum at a uniform rate then the relevant kinematics of the working head may be successfully modeled by considering the leaf was stationary and the beater drum was rotating uniformly about an axis that advances uniformly towards the Enset sheave.

The decorticating Enset sheave existing inclined feed when the drum with blade rotating in vertical direction during operation and the operator then put the Enset sheave through Entrance and guided by roller and push it into the machine blade. The decorticator blades then contacted the sheaves, stripping the soft parts against the inclined plate and pulled through to bucket.

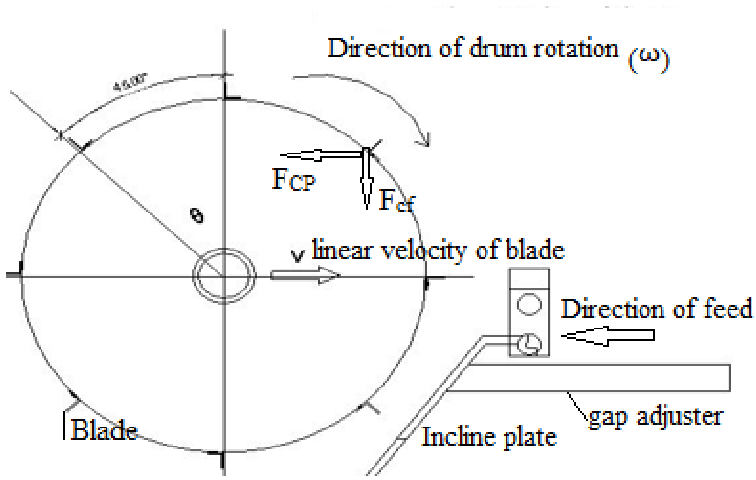


Figure 3.8. Layout of rotating drum with blade

The angular momentum is the tendency of the rotating object to continue with the same angular speed in the same direction. The angular momentum developed at the tip of the beating blade can be determined as.

$M = m \times v \times r$ 3.5

Where. M = angular momentum ($kg.m^2/s$)

m = the mass of Raspador (kg)

v = the linear velocity of the blade tip (m /s)

r = the radius of cylindrical drum from origin to blade tip (m)

Then the angular momentum developed was, M =3.69kg x 5.5 m/s x 0.162 m, = 3.29 kgm2/s

Therefore the angular momentum developed at every beating blade tip on the inclined plate during decortication was 3.04 kgm^2/s.

Centripetal force is a force that causes an object to move in the circle at constant speed because the centripetal acceleration is pointed to toward the center of the circle, then from the newton second law in vector form was calculated as equation (3.6) (Abdulkadir et al., 2009).

$$F_{CP} = \frac{mv^2}{r} \ldots\ldots 3.6$$

Where. F_{cp} = centripetal force

m = mass of decorticating drum with blade

v = linear velocity of blade

r = length of blade

From the above equation (3.6) the centripetal force that causes the drum with blade in circular motion at constant speed was $F_{CP} = \frac{(3.69)\,(5.5)^2}{0.012}$ = 9301.87 N

Centrifugal force is a force that causes an object to move out ward (fly from the center) and hence centrifugal force acts away from the center of the circle, then from the newton third law in vector form was calculated as equation (3.7) (Abdulkadir et al., 2009).

$$F_{cf} = mv^2 \ldots\ldots 3.7$$

Where. F_{cf} = centrifugal force developed by blade

m = mass of decorticating drum with blade

v = linear velocity of blade

From the above equation Centrifugal force that causes an object to move out ward was

$$3.69 \text{ kg} \times (5.5)^2 = 111.62 \text{ N}$$

3.5.4. Design of Decortication Clearance

Decortication clearance (pitch distance) means the gap or the space between the inclined plate and the tip of decorticator blade. It was adjustable in order to maintain fiber breakage. Pitch (P) represents the quantity of soft materials that was scraped off every time at beater blade interact with the Enset sheave. That means when the pitch happens to be too larger, then the decortication was incomplete. In other hand if the pitch was too small the result, the fiber was cut (damaged). The pitch was determine using Equation (3.8) (Snyder et al., 2006).

$$Pt = \frac{2\pi vf}{N2 \times n} \ldots\ldots 3.8$$

Where. Pt = the pitch distance of decortications

Vf = the feed velocity of leaf

N_2 = the angular speed of drum

n = the number of blade attached to Raspador.

The decorticating clearance was represented by diagrammatically as showed in fig (3.11) and the positions of the tips of the two successive beater blades A and B was given by the following parametric equations (3.9 and 3.10)

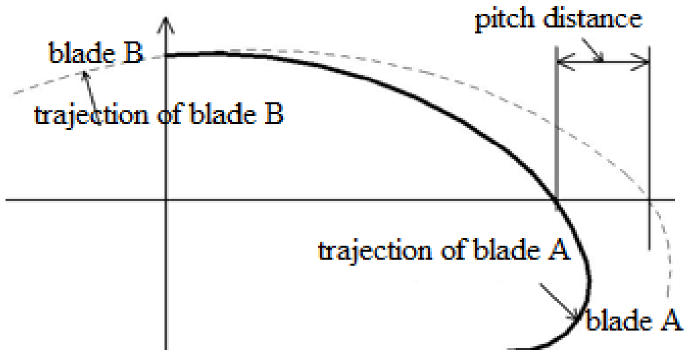


Figure 3.9. Decorticating clearance representation

Illustrated the beater drum at the initial moment of consideration, then, at a subsequent moment in time, *t*, the positions of the tips of the two successive beater blades, A and B as shown below. The position of blade A was given by the following parametric equations (3.9 and 3.10) (Richard et.al, 2011).

$A_B\ (t) = vt + \frac{D}{2} \sin(\omega t)$ ……………………..………..…..……………..…………………… .3.9

Where. A_B = blade A at x axis

V = linear speed of cylinder

D = diameter of cylinder

ω = angular speed of cylinder

t = variable time and initially zero

At the initial moment $vt = 0$, and let taken drum speed of 1050 rpm there fore

$A_x\ (t) = \frac{D}{2} \cos(\omega t)$ …..…..........................3.10

$A_x\,(t) = \frac{0.3m}{2}\cos\,(1050t) = 0.103t$

B was be given by the following parametric equations (3.11 and 3.12) (Richard et.al, 2011).

$B_x\,(t) = vt + \frac{D}{2}\sin(\,\omega t - \theta)$ ……………….....…………………...…...……….……..... ..3.11

Where. B_x = blade B at X axis

V = linear speed of cylinder

D = diameter of cylinder

ω = angular speed of cylinder

ϴ = the angle between two successive blade.

$B_B\,(t\,) = \frac{D}{2}\cos\,(\,\omega t - \theta)$ ………………………………………………………………......3.12

$B_B(t\,) = \frac{0.3m}{2}\cos(\,1050t) - \cos 45^0 = 0.103t - 0.103$ and the difference between position A and B tells how much blade A far apart from blade B.

3.5.5. Design of Pitch Adjusting Device

In Kenya sisal fiber producer used sisal decorticating machine in actual field condition to produce fiber. The machine has two screw to adjusting the decorticating gap to maintain fiber cut (Kanogu et al., 2011). Clearance adjusting device is a basic element of plant leave decorticating machine that used to adjusting the clearance. Therefore this study was the first research on the Enset decorticating machine and developed new idea which minimize the problem happened during Enset decortication. The fiber cutting problem was minimized by designing decorticating clearance adjuster. The machine has two screw to adjusting the decorticating clearance according to the fiber diameter and it were machined from common shaft material available.

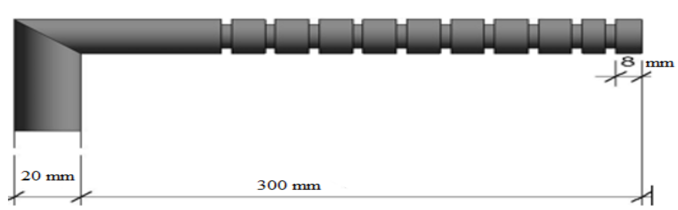


Figure 3.10. Decorticating gap adjuster

3.5.6. Inclined Plate Selection

Inclined plane is a plane inclined between two reference point called horizontal and vertical plane. Therefore inclined plate is a plate inclined on the inclined plane. In traditional enset decorticating techniques rural women used inclined plate or locally said to be watani to place the Enset leave sheave on it and to be decorticate. Watani is flat made from wood board and inclined against standing enset plant about $45^0 – 60^0$ based on women height and sharpness of sibisa in order to keep the number of cutting fiber and ensure decorticating quality (Tedla et al., 1994).

An adjustable inclined breast plate of about 500 mm long and 50 mm width and 3 mm thick was attached to the framework about 800 mm from the ground. The distance between the inclined plate and the knives was regulated so as gave clean decortication without undue strain on the leaves and the fibers. The drum with blade can be driven with a certain angular speed in given pitch distance for effective decortications.

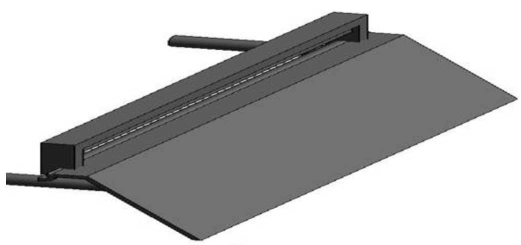


Figure 3.11. 3D model of inclined plate

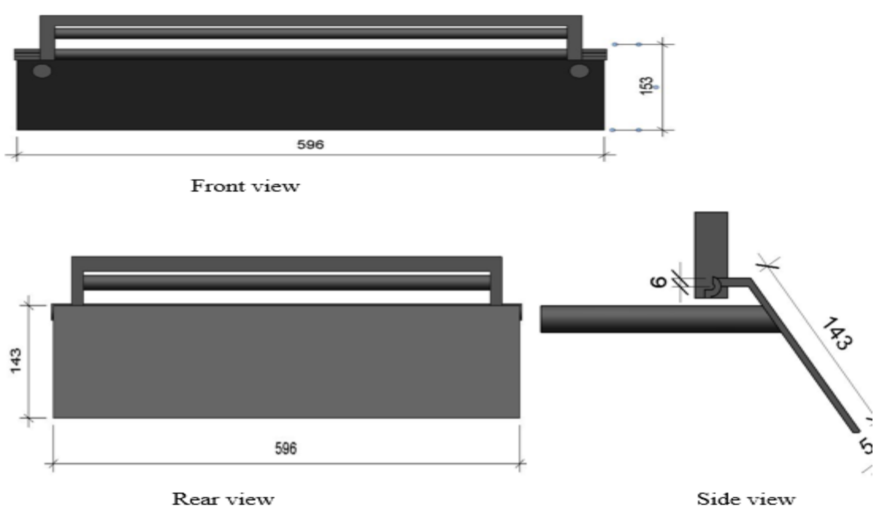


Figure 3.12. Detail view of inclined plate

3.5.7. Design of Frame.

The frame (vertical and horizontal fixed parts) which was the skeleton of the decorticator and supports all other component parts of the machine. The design factors considered in the determination of the material required for the frame were weight, material strength and durability. The size and capacity of the decorticator were determined based on the working mechanism, and that of the power available from worker to resist the load.

The frame is particularly important in field machines because they must be as light as possible to reduce load to move from one field to another, cost and but yet strong enough to resist the shocks due vibration of rotating parts. With light weight construction, there was often considerable deflection and as a rule" self-aligning bearings are necessary (Richy et al., 1961).

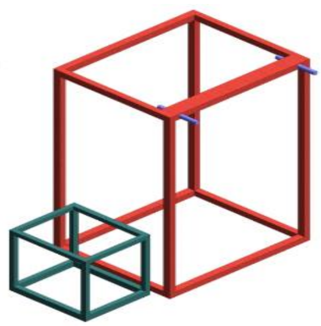


Figure 3.13. Frame

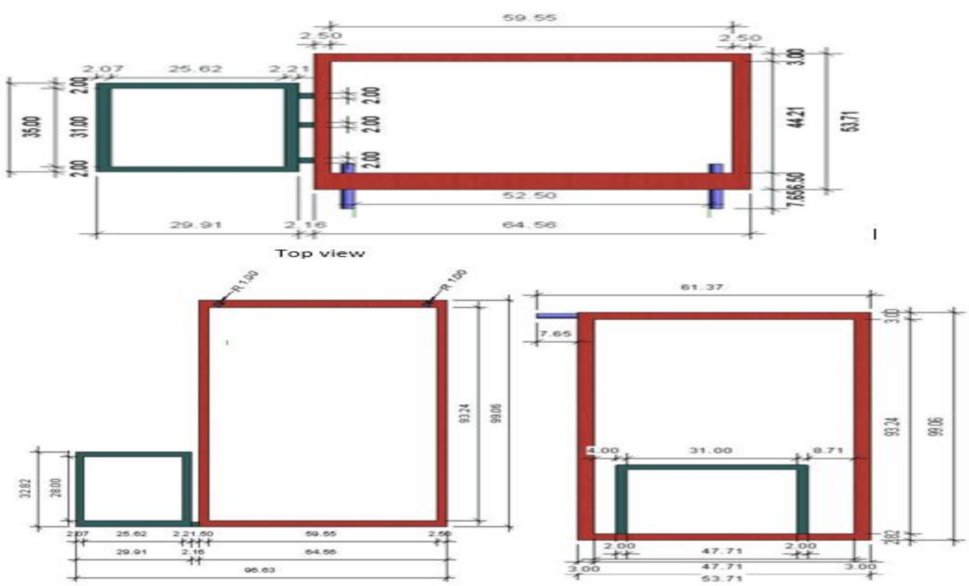


Figure 3.14. Detail view of frame

3.5.8. Bucket Design

Bucket was a device that used to temporary storage of kocho. Kocho decorticated on the inclined plate by blade screwed on the circumference of decorticating drum. When decorticating drum rotating with blade then, the blade tip contact with Enset sheave on the inclined plate and stripe off the soft materials (kocho) and the decorticated kocho then stored in the bucket. Bucket was designed below the drum and incline plate in order to collect the kocho with minimum wastage. Kocho was taken to fermentation area and after fermentation bulla was extracted.

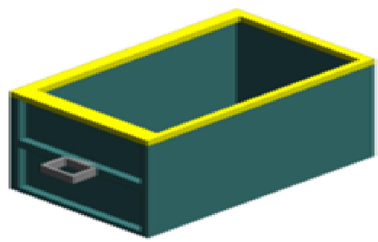


Figure 3.15. Bucket model

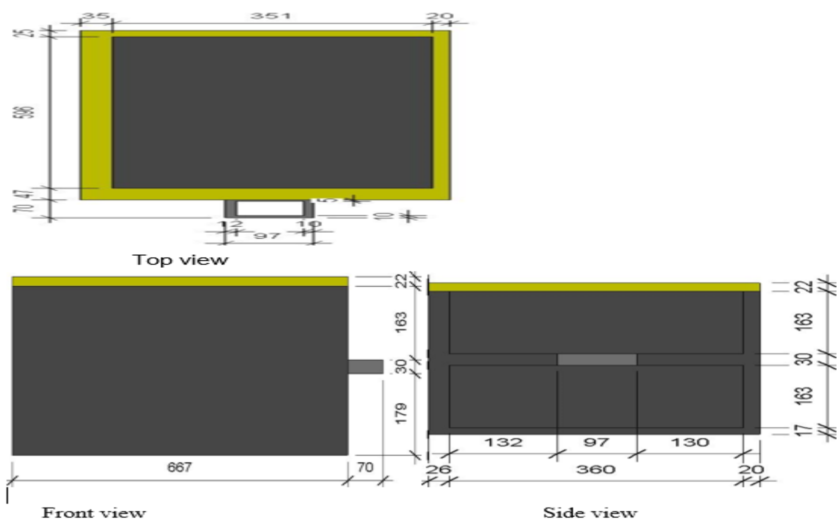


Figure 3.16. Detail drawing of bucket

3.5.9. Power Requirement and Transmission System

The source of power can either be a motor powered by electricity or by use of an internal combustion engine. This design was based on the three horse power diesel engine as the source of power because most of the areas where Enset grown do not have access to electricity. The power required for decortications process was determined using Equation (3.13) (Bashir et al., 2013).

$P_d = \frac{2\pi N2T}{60}$ ……………………………………………...…………………………3.13

Where. P_d = output power required to decorticate the sheave, w

T = twisting moment developed on the drum shaft, Nm

N_2 = Speed of the drum shaft, rpm

$P_d = 2 \times 3.14 \times 1050 \text{ rpm} \times \left(\frac{15.5}{60}\right)$

= 1703.45 W reference equation 3.19

The total power from the power source was three horse power or 2238 watt. Power generated by motor was transmitted to rotating parts of the machine such as drum through belt and pulley system and the maximum power transmitted was 1703.45 W

Pulleys were one of the oldest and most important power transmission elements, but they require careful design. If a belt or cable runs around a fixed shaft, friction between the belt and the shaft can cause the efficiency to be low, and the cable can rapidly wear. A pulley reduces these effects with rolling contact between the cable and the machine, but it must be of sufficient size, typically 20 times the cable diameter, to prevent fatiguing of the cable strands.

In addition, a crown on a pulley can be used to keep a flat belt centered on the pulley even if the pulley was not perfectly aligned. Pulleys transmit power from one location to another, and they can form a transmission ratio. Pulley was a wheel on an axle or shaft that was designed to support movement and change of direction of a cable or belt along its circumference. The drive element of a pulley system can be a rope, cable, belt, or chain that runs over the pulley inside the groove (Bashir et al., 2013).

Belt runs over the pulley inside the groove. A flat belt drive was designed by limiting the maximum tension according to the permissible tensile stress specified for the belt material. Pulley material was generally cast iron or cast steel. A fixed pulley had an axle mounted in bearings attached to a supporting structure. A fixed pulley changes the direction of the force on a rope or belt that moves along its circumference.

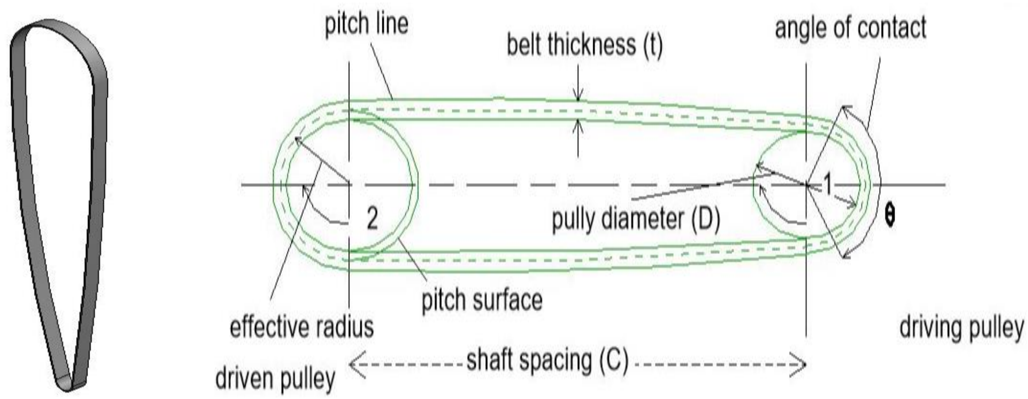


Figure 3.17. Belt Selection

V-belt had diversified use due to its distinct advantages that, it: absorb vibration and shock, intending to transmit only a minimum to the connected shaft. It is quiet, if properly maintained and can be designed to have a long trouble–free life. The length of belt of any machine was calculated from the equation (3.14) (Khurmi and Gupta, 2005).

$$\mathrm{L} = 2C + \pi\frac{Pd1+Pd2}{2} \quad \text{...} 3.14$$

Where. L = Length of belt

Pd_1 = Pitch diameter of small pulley =75 mm

Pd_2 = pitch diameter of big pulley = 100 mm

C = Center distance between the pulleys: = 500mm.

$= 2(500\ mm) + \pi\frac{75\ mm+100\ mm}{2}$ = 1300 mm, therefore the length of the belt was 1300 mm

From the speed ratio of the drum shaft to motor shaft, the speed of the shaft was obtained by the following equation (3.15) (Khurmi and Gupta, 2005).

$N_1D_1 = N_2D_2$.. ...3.15

Where. N_1 = angular speed of motor shaft = 1400 rpm

D_1 = diameter of driving pulley

N_2 = angular speed of the drum shaft

D_2 = diameter of the driven pulley

From the above equation the maximum value of the angular speed of the driven pulley (speed of drum shaft) was 1050 rpm and the speed of the belt was determined by equation (3.16) (Richard et.al, 2011).

$$V = \frac{\pi D1N1}{60} \qquad 3.16$$

V = 5.5 m/s > 5 m/s, therefore the machine can operate with ought belt slip

The tension force on the pulley must be calculated according to the following equations (3.17) (Abdulkadir et al., 2009).

$$F_{cf} = T_c = mv^2 \qquad 3.17$$

Where. m = mass of the drum, = 3.69kg

V = speed/velocity of the belt, = 5.5 m/s

Therefore the value of the T_c was given by 3.69 x $(5.5\ m/s)^2$ = 111.62 N

The input power from the diesel engine motor was 3hp = 2238 watt and the maximum twisting moment developed on the shaft was determined from the input powered as equation (3.18) (Bashir et al., 2013).

$$P_{in} = \frac{2\pi N1T}{60} \qquad 3.18$$

Where. P_{in} = input power from motor = 2238w or 3hp.

N_1 = angular speed of the motor shaft, rpm

T = the twisting moment of the drum shaft, Nm and the value from the above equation was 15.5 Nm

The output power transmitted through the belt T_1 and T_2 of the decorticator was determined as the equation (3.19) (Bashir et al., 2013).

$$P_d = \frac{2\pi N2T}{60} \qquad 3.19$$

Where. P_d = output power required to decorticate the sheave, w

T = twisting moment developed on the drum shaft, Nm

N_2 = angular speed of the drum shaft, rpm

$P_d = 2 \times 3.14 \times 1050 \text{ rpm} \times \left(\frac{15.5}{60}\right)$

= 1703.45 W or 1703.45 kW.

The belt efficiency to transmit power from the power source to drum rotating shaft was determined as the equation (3.20) (Richard et.al, 2011).

$$\text{Efficiency} = \frac{output\ \ power}{input\ powe} \quad \text{.....3.20}$$

Efficiency = 76.12%, therefore the belt can transmitted power effectively.

The total driving force of the decorticator was determined by the equation as (3.21 and 3.22) (Khurmi and Gupta, 1984)**.**

$F = (T_1 - T_2)$…………………………………………………………………………… 3.21

$F = (3T_c - T_2)$……………………………………………………………………..……… 3.22

Where. F = force required to drive the machine (N)

T_1 = Tension on the tight side of belt (N)

T_2 = Tension on the slack side of belt (N)

T_c = centrifugal force (N) and $T_1 = 3T_C$

But the value of the driving force was determined from the output force as shown in the equation (3.23) (Bashir et al., 2013) below.

P = Fv ………………………………………………………………………….…………… 3.23

Where p = output (transmitted) power through belt T_1 andT_2

F = force required to drive

v = velocity of the belt

$$F = \frac{1703.45w}{5.5\ m/s} = 309.72 \text{ N}$$

$T_1 = 3T_C$ ……………………………………………………………………………………. 3.24

$T_1 = 3(198.25) = 594.75$ Nm and from the above equation (3.21), $T_2 = 362.35$ Nm.

3.5.10. Shaft Design

The drum shaft was machined from common shaft material available. Based on the cost, mild steel was chosen as the preferred choice. The shaft used for this machine was subjected to two types of forces namely twisting moment and bending moment. The shaft was expected to be subjected to both torsion and bending moment. This may be due to the rotational effect of the shaft during the rotational motion of the machine. The failure of the shaft was likely to be in shear stress and the design considered this fact. Loading, the diameter was obtained using the ASME code equation (3.25) (Khurmi and Gupta, 2005).

$$d^3 = \frac{16}{Ss}\sqrt{(Kb.Mb)^2 + (Kt.Mt)^2} \quad \text{3.25}$$

Where. d = diameter of the shaft; mm

Mt= torsional moment; Nm

Mb= bending moment; Nm

Kb= combined shock and fatigue factor applied to bending moment;

Kt= combined shock and fatigue factor applied to torsional moment;

Ss= allowable stress; MN/m^2

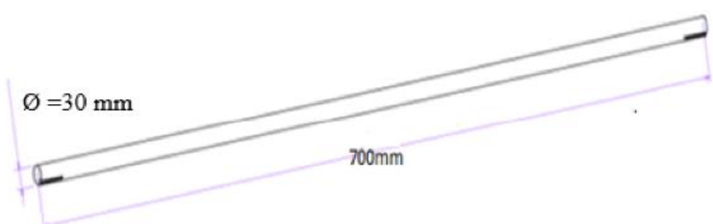


Figure 3.18. Shaft

For rotating shafts, when load was suddenly applied with minor shock, (Khurmi and Gupta (2005) recommended that values of Kb = 1.2 to 2.0 and Kt = 1.0 to 1.50 was used. Furthermore, it was noted that for shaft without key way, the allowable stress Ss must be 55 MN/m^2 and for the shaft with key way the allowable stress Ss should not exceed 40 MN/m^2

Torsional moment (Mt) on the shaft was 15.5 Nm, then the Shaft subjected to bending moment only then the maximum bending moment on the shaft was determined from the bending diagram as equation (3.26) (Richard et.al, 2011).

$$Mb = \frac{\pi fb \times d^3}{32} \qquad 3.26$$

Where. Mb = maximum bending moment (Nm)

Fb. = bending stress of shaft material

d = diameter of drum shaft

$$Mb = 4.29Nm \; 0r \; Mb = 4290 \; Nmm$$

$$d^3 = \frac{16}{Ss}\sqrt{(Kb.Mb)^2 + (Kt.Mt)^2} \qquad 3.27$$

And SS=55 N/mm^2, Kb=2, Kt=1.5 and the value of the shaft was d=12.9 mm.

Therefore, the used shaft was standard withstand to load.

Vertical Forces Distribution on the Shaft

The vertical load diagram on the driven pulley shaft was as shown below

Total weight of the decorticator drum and blade which lay on the shaft was 36.2 N refer section 3.5.2.

$W_A = W_B$ = 18.1N ……………. were Half of total weights

R_A and R_B were support forces at shaft as shown below.

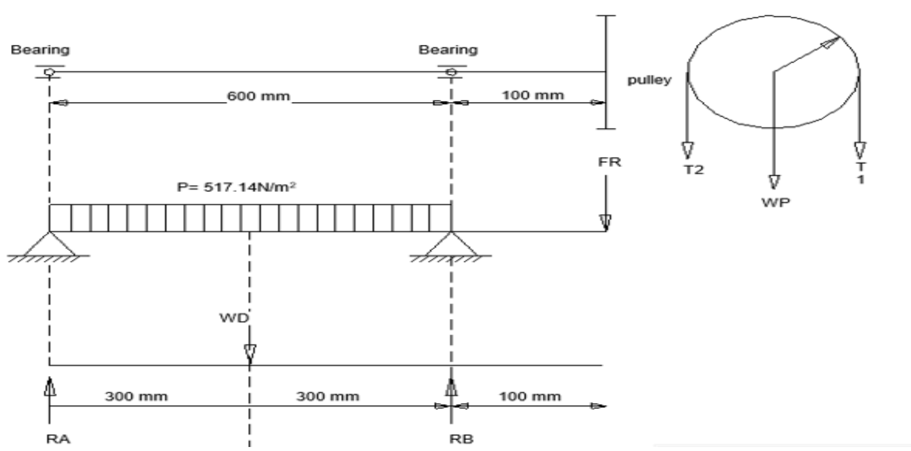


Figure 3.19. Vertical forces distribution on the shaft

To know the unknown forces of R_A and R_B, we use equilibrium equations methods in clock wise direction as shown below.

ΣMA = 0 ……………………………………………………………………………….. 3.28

R_B (0.6 m) - W_D (0.3 m) - W_P (0.7m) - T_1 (0.7m) + T_2 (0.7m) = 0

0.6 R_B + 0.7(362.25 N) - 0.3(36.2 N) – 0.7(7.8 N) – 0.7(594.75) N = 0

R_B = 298.41N and the summation of all forces gave the unknown value.

R_A + 298.41N + 253.57 + 36.2N + 7.8N +594.75N = 0

R_A = 228 N

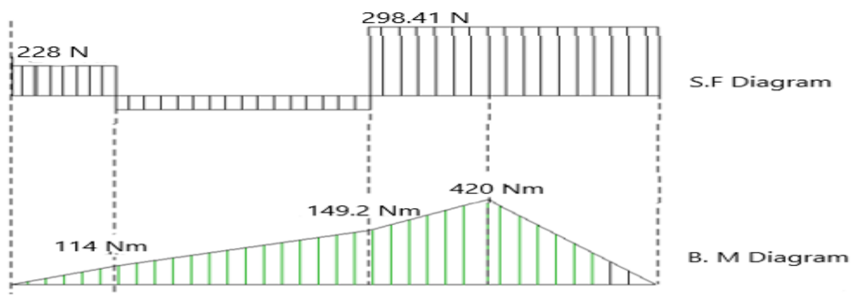


Figure 3.20. Shear force and bending moment diagram

3.5.11. Roller Design

Rollers were the most important element in this machine. It applies necessary guidance to uniform feeding of Enset sheave. Rollers were a cylindrical device used to reduce the size or used to compact the materials in to wanted size. In case of decorticator, rollers were two pair of cylindrical device used to guide and smash the plant leave sheave in order to minimize the thickness (Kanogu et al., 2011).

Figure 3.21. Dual rollers

Rollers were a pair of cylindrical device used to guide the peeled Enset sheave in to certain thickness depending on the decorticating clearance or pitch distance. The shape of rollers were cylindrical with diameter of 40 mm.

3.5.12. Safety Guard

In order to prevent the possibility of operator injury while running the decorticator blade, the machine designed to horizontal feed having a small opening at the entrance to the cylinder drum as well as design a large guard in its general form, ensures that the operator cannot make direct contact with the spinning blades (Kawongolo, et al., 2011).

3.6. Fabrication of Three Horsepower Motor Driven Enset Decorticator

Cattie drawing (fig.3.26) was designed, fabricated and the three horse power diesel engine motor driven Enset decorticator (3.27) was manufactured and assembled. The different component of the decorticator mentioned in previously described subheadings was fabricated and assembled in the workshop of DITC. The decorticator drum was fabricated from flate sheet metal with eight blades screwed on the circumference of decorticating drum and it were fabricated from stainless steel.

All the sides of sheet metal were marked and cut, then joined by welding, screwing, and bolting according to functional requirement. Inclined plate were provided at the Enset sheave feeding side of the machine for the sheave was decorticated on it. The plate adjusted by clearance adjuster. There were two clearance adjuster, one with left side and the other was in right side. In addition to these there were two rollers mounted on the machine.

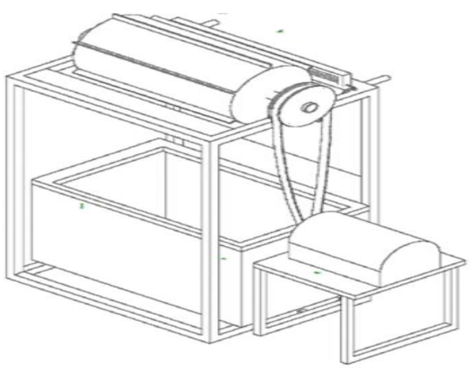


Figure 3.22. Modeled machine

Figure 3.23. Developed machine

The rollers were mounted on the machine in Enset sheave feeding side to guide the sheave in given entrance. The bottom of the drum was cubic box like called bucket. Two pulleys one having 100 mm diameter and other having 75 mm were used to transmit the power from three horse power diesel engine motor to the drum through belt. Larger pulleys was mounted on decorticating drum shaft whereas smaller pulleys was mounted on axle of engine motor. Suitable bearing were used to mount the shaft with the help of bolt on the frame. The pulleys were directly connected by standard pitch roller belt which could be fixed at standard position.

3.7. Survey on the Traditional Enset Decortication Technique

This Section explained that the effectiveness and efficiency of the traditional decorticating technique. In this survey, all the research ethics were considered during data collection. The data collection period, it was adjusted the time with individual willing that farmers were free of work to be able gave information for researcher and the researcher led the overall process and discussion with concerned individuals.

The survey of traditional Enset decorticating (scrapping) techniques was based on the parameters, such as un-hygienic, time and energy consumption, productivity, was it a gender based, used locally available materials and fiber breakage. In cases where farmers were challenged to give enough information (such as quantification of Enset product and estimation of product per hour). The number of people interviewed were sixteen and from sixteen of them fourteen were women because traditionally Enset decorticating technique was depending on the women. The following data located in the table was collected from respondents.

Table 3.6. Survey on major strengths and weakness of traditional Enset processing

Sr. No.	Particulars	No. of respondents	
	Total number of questioners (N=16)	Yes	No
1	Unhygienic	12	4
2	Time and energy consuming	14	2
3	Increased household income (productivity)	6	9
4	Using locally available materials	15	1
5	Decortication was based on women only	13	3
7	Fiber breakage	6	9

3.8. Performance Evaluation of the 3 HP Motor Driven Enset Decorticator

The Developed three horse power diesel engine motor driven Enset decorticator was tested in the laboratory (with ought to load) and Field (with load). It was tested on the Durame Industrial Technology College for its performance evaluation.

3.8.1. Laboratory Test

The main objectives of tested machine with ought load condition was to study the specifications, observe the performance of the components developed and to undertake such study that would assisted in the modification and improvement of the developed machine. The items examined were as follows:

- Specifications of the machine.
- Visual observations

3.8.1.1. Specifications

The decorticator was kept on the firm level and horizontal surface of the workshop floor and various dimensions were measured as reported in table No. 4.1

3.8.1.2. Visual Observations

The Enset decorticator was inspected thoroughly paying attention towards the power transmission components and other moving parts, tightness of nuts and bolts, etc.

3.8.2. Field Test

The performance of Enset decorticating machine was evaluated at DITC. The Enset sheave was washed to remove the soils, insects, dusts and any unwanted impurities which may decrease the machine efficiency and quality of the product. After harvesting leaves and older leaf sheaths were first removed from the designated plants. The internal leaf sheaths were separated from the pseudostem down to the true stem.

Sheave were fed manually between the drum blade and inclined plate and the kocho (bulla) and fibre were produced by the scrapping action of beater blades.

Machine feed rate, Output capacity, percentage of cut fiber, Fiber clearing efficiency, Percent un-decorticated kocho, Decorticating efficiency and weight lost were machine performance parameters.

3.8.2.1. Feed Rate

The decorticating capacity (feed rate) was calculated by considering weight of Enset sheave fed into the decorticator per unit time. The decorticating capacity (kg/hr.) was determined using Equation (3.29) (Cantalino et al., 2015).

$$\mathrm{Dc} = \frac{\mathrm{W}}{\mathrm{t}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.29$$

Where. D_C = decorticating capacity

W = total weight of Enset sheave feed

T = total time taken in minute

3.8.2.2. Machine Output Capacity

This is the quantity of kocho (bulla) and fiber decorticated in a given time by the machine. Output capacity was calculated by considering the weight of kocho collected under the bucket and fiber removed. The capacity of Enset plant sheave was determined with product mass balance as determined from the following diagram (Shank and Ertiro, 2008**).**

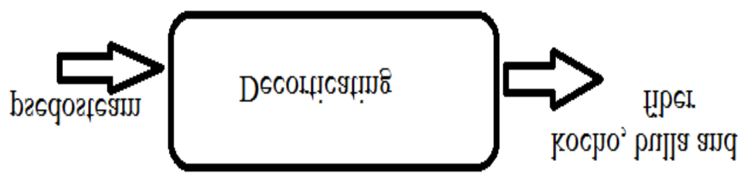


Figure 3.24. Enset sheave product balance.

The output capacity or material capacity was determine using Equation (3.30) (Cantalino et al., 2015).

$$\mathrm{O/P\ capacity} = \frac{W_k + W_f}{t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.30$$

Where: O / P = output capacity

W_k = weight of decorticated kocho

Wf= weight of unbroken fiber

3.8.2.3. Percent Un-Decorticated Sheave

This is the ratio of the mass of un-decorticated sheath (un-cleared fiber) to the total mass of the Enset sheave expressed in percentage was determine using Equation (3.31) (Snyder et al., 2006).

$$\%\ \mathrm{Us} = \frac{\mathrm{wUs}}{\mathrm{W}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.31$$

Where. Us = non decorticated Enset sheave in percent

W = total weight of Enset sheave before decorticated wUs =weight of un-decorticated Enset sheave.

3.8.2.4. Decorticating Efficiency

This is the ratio of the mass of the decorticated kocho which is collected in the bucket and mass of cleanly decorticated fiber to the total mass of the enset sheave expressed in percentage was determine using Equation (3.32) (Cantalino et al., 2015).

$$\eta = \frac{WK+Wf}{W} \times 100 \quad \ldots\ldots 3.32$$

Where. η = decorticating efficiency

W = total weight of Enset sheave before decorticated

Wk = weight of decorticated kocho and bulla.

Wf = weight of clear (unbroken) fiber.

3.8.2.5. Fiber cleaning efficiency

This is the ratio of the mass of clean decorticated fiber (un-broken fiber) to the total mass of fiber expressed in percentage was determine using Equation (3.33) (Cantalino et al., 2015).

$$\eta f = \frac{Wf}{Ft} \times 100 \quad \ldots\ldots 3.33$$

Where. ηf = fiber cleaning efficiency

Wf = weight of unbroken fiber

Ft = total fiber obtained.

3.8.2.6. Percentage of Broken Fiber

This is the quantity of fiber loss from the total quantity of fiber expressed in percent and the formula used for calculating percentage of broken fiber was determine using Equation (3.34) (Naik et al. (2013).

$$\%\,Fb = \frac{Fb}{Ft} \times 100 \quad \ldots\ldots 3.34$$

Where. Fb = broken or cut fiber.

Ft = total fiber (clean un-broken fiber + broke) fibre obtained.

3.9. Cost Analysis

The cost of operation for the machine was worked out by calculating the material cost was presented in appendix D and cost summery, fixed and variable costs were presented in Appendix E. Estimation of hourly operational costs of the decorticator was based on capital cost of the decorticator, interest on capital, cost of repairs and spare parts, labor cost, and depreciation (Kepner et al., 2005 and Kamboj et al., 2012). The operational cost components of the prototype machine were estimated in Birr (ETB).

3.9.1. Fixed Cost

3.9.1.1. Depreciation

It was a measure of the amount by which value of the machine decreased with the usage of the time. According to the Kepner et al. (2005), the annual depreciation was calculated as follows.

$$D = \frac{C-S}{L \times H} \quad \text{……} 3.35$$

Where. D = Depreciation per hour, ETB/hr.

C = Capital investments, ETB

S = Salvage value, 10% of capital investment, ETB

L = Life of machine in hours or years

3.9.1.2. Interest

Interest is calculated on the average investment of the machine taking into consideration the value of the machine in the first and last year. The annual interest on the investment can be calculated as (Kepner et al., 2005).

$$I = \frac{C \times S}{2} \times \frac{i}{H} \quad \text{……} 3.36$$

Where. I = interest per hour, ETB/hr.

I = Interest per hour (10 % per year)

3.9.1.3. Taxes and Insurance

Insurance charge is taken based on the actual payment to the insurance; it taken as 1% of the initial cost of the machine per year (Kepner et al., 2005).

3.9.2. Variable Cost

3.9.2.1. Repair and Maintenance Cost

The repair and maintenance cost is a product of machine's cost price and repair and maintenance percentage factor (Kepner et al.,2005 and Kamboj et al., 2012).

RM = 2.5 % × purchase price or capital investment per year………………………………...3.37

3.9.2.2. Fuel Cost

Fuel cost is calculated based on actual fuel consumption for the operation.

3.9.2.3. Lubricants

It can be determined depending upon the maintenance cost or depending upon the oil price or oil consumption. Average lubrication cost is taken as 1.5% of fuel cost in ETB//hr. (Kamboj et al., 2012).

3.9.2.4. Wages of Operator

Wages are calculated based on actual wages of workers per hour. It differs from country to country.

3.9.3. Total Cost of Operation per Hour

The total cost per hour of the developed machine can be calculated by summation of total fixed cost per hour with total variable cost per hour and the total cost analysis was given as equation (3.38) below.

Total Cost/hr. = Fixed Cost per hour + variable Cost per hour ……………………………... 3.38

3.10. Data Analysis

The data obtained from field test was analyzed, in to tables and graphs by using software Microsoft Excel (2013) and descriptive statistics.

CHAPTER FOUR

RESULTS AND DISCUSSION

The three horse power diesel engine driven Enset decorticator was designed and fabricated. In this section, Enset sheath engineering properties related to the design and fabrication of Enset decorticator were studied. The performance evaluation of the designed diesel engine driven Enset decorticator, the results of the studies related to these aspects, the working principle of designed machine and their discussion and compared the performance of traditional and new introduced technology were presented.

4.1. Details of Motor Driven Enset Decorticator

The developed diesel engine motor driven Enset decorticator was consist of decorticating drum, blade, inclined plate, decorticating clearance adjusting device, frame, double rollers, bucket, and others elementary component. Blade was sharp enough to scrape of the fleshy ventral side of the leaf sheath. It was screwed on the circumference of drum with equal distance from one blade to next. The distance between the two blades was determined by the arc length or the angle created called ϴ; measured by protractor and it was 45 degree. The inclined plate was made for decortication of sheave on it. It was 45 degree inclined from the horizontal to mount effective decortication.

The decortication clearance or pitch distance could be varied above 2mm or below 2mm depending on the diameter of the Enset fiber but the exact diameter of fiber was not known. 2 mm decorticating clearance was recommended clearance for leaf fiber producing machine. The power transmission system consist of pulley-belt drive mechanism to efficiently transmit power. The diameter of larger pulley was 100 mm and the diameter of smaller pulley was 75 mm which gave the gear ratio of 1:1.3. The average belt length was 1300 mm. The frame was made from the angled iron with 1000mm x 500mm x 5mm and gives the stability to the machine in field work. The maximum labor required to operate the new developed machine was two but it was possible to operate single person. The cost of machine was calculated by considering material required and fabrication charges as calculated in appendix D. Therefore, the cost of operation of Enset decorticator was 42.24 ETB/hr.

4.2. Working Principle of Enset Decorticator

The machine operator turned on and started the engine motor. When the machine attained optimum speed, the operator inserted Enset leave sheave into the decorticator feed tray with the sheave end butt first while still holding the tip ends on the feeding plate. The already rotating decorticator blades then comes into contacted with the leaves thus stripping the soft part of sheave against the inclined plate. Then the operator pulled the sheave out and inserts the tip ends which were also decorticated. When in operation the soft part of sheave which was called kocho could be stored in bucket temporary and later transported to fermentation place and bulla was squeezed from kocho after fermentation. After operation the decorticator can be stopped off by switch off the motor. In order to prevent the possibility of operator injury while running the decorticator, the feed tray had an opening just enough for the leaf sheave, thus made sure the operator cannot come into direct contact with the spinning blades.

4.3. Physical Properties of Enset Sheath

Enset sheave properties were important for optimizing the designed parameters of the decorticator. The physical properties of sheaves were among the most important factors considered for selecting a suitable to designed decorticating clearance and feeding mechanism for its better performance.

The most popular varieties of Enset like Geshera, Sisqela, Dirbo, Abatmerza, Gembewa, Dego, Ungame, Tebare, Moche, Sheleqe, Sebara and Etene were selected and studied their physical properties. The attempt was made to study the physical properties of Enset grown around DITC. The internal Enset sheave were separated from the pseudostem. The physical properties of sheave namely; local Enset variety, shape, size, weight and decortication resistance were measured using the ASBE standard procedure. The shape of the Enset sheave of randomly selected Enset variety were concave (shape of pseudostem). Which was similar result with the shape of banana sheave. According to Mohsenin, (1970) the shape of banana sheave is concave. The geometrical parameters namely dimension of the principal axes (l was length, w was the width and t was the thickness) of randomly selected Enset sheave were measured using digital Vernier caliper and the calculated size of Enset sheave were range from 243.3 mm to 300 mm, and the weight of the sheave was measured by digital beam balance. The average diameter of fiber was registered as much as smaller than 2mm. and it is a similar result was observed with

(Naik et al. 2013) the average value of fiber diameter of much less than 2mm but it is difficult to identify exact value of the size of fiber. The decortication resistance of Enset sheave was higher for male than female. During decortication the male Enset sheave needs more power or take long time than female.

The decortication resistance of male Enset varieties were higher than that of the female Enset varieties with the same power source. It is a similar result was observed with (Million, 2003). According to Million (2003), rural peoples who cultivate Enset can be differentiate Enset variety into two namely, male and female due to the decortication resistance, fiber strength and kocho quality. Therefore it concluded that the male Enset variety can resist decortication than female Enset variety.

4.4. Performance Evaluation of Enset Decorticator

Performance evaluation of enset sheave decorticator was carried out by conducting both laboratory test and field test at Durame Industrial Technology College. Three horsepower diesel engine motor was used to drive the machine.

4.4.1. Laboratory Test Result

Table 4.1. Specifications sheet for enset decorticator

Particulars	Specifications
Type of machine	Diesel engine motor driven Enset decorticator.
Decorticating drum	Circular hollow sheet metal with diameter 300 mm, length 500 mm and coated by aluminum sheet
Overall width of blade	L = 500mm, w = 12mm and t = 1mm
Power transmission system	Belt – pulley system
Number of blades	8
Linear velocity of blades	5.5 m/s
Weight of machine	489.03 N
Input power	Three horse power

Visual observations: - The functional operation tests with ought to load were conducted in the GMF (General Metal Fabrication) Laboratory and the results indicated that

- The machine was running smoothly with negligible vibrations.
- The machine could be operated smoothly at different drum speed
- The machine was easy to start, operate and stop.
- Tightness of bolts and nuts and other fasteners were tightened appropriately

4.4.2. Data Analysis of Short Duration Tests on load condition

The data of short duration tests (on load condition) were analyzed to determine decorticating efficiency, machine output capacity, feed rate, percent un-decorticated sheave, percent broken fiber, fiber cleaning efficiency and weight lost. The data obtained from field test was analyzed, in to ANOVA tables and graphs by using software Microsoft Excel (2013). Result obtained from the short duration test of Enset decorticator in different decorticating clearance and three decorticating drum speed was reported in table C1, C2 and C3 in appendix C.

The machine was operated at different drum speed and the gap was varied between 1 mm to 5 mm but the decortication process was not found so effective in every decortication clearance. The reason was that the Enset leaf sheaves were either partially decorticated or fiber was broken, which requires an enormous clearance to scrap off flesh material to yield kocho (bulla) and fiber. The relation between drum speed, decortication clearance and the quantity and quality of kocho and fiber was showed in the ANOVA tables and figures below.

Table 4.2. Decorticating efficiency at different drum speed and decorticating clearance

Speed	Average value in different Clearance		
	< 2 mm	2 mm	> 2 mm
650	80.15	86	72.67
850	83.02	89.5	78.3
1050	89	93.12	83
Mean	84.06	89.54	78.99
SD	4.5	3.56	5.32
CV	5.35	3.9	6.74

Machine efficiency increased with the increase in drum speed as shown in ANOVA Table 4.3. The test result showed that the mean values of decorticating efficiency varied from 80.15 % to 89 % at < 2 mm decorticating clearance. In the same way the mean value of decorticating efficiency varied from 72.67 % to 83 % and from 86 % to 93.12 % at > 2 mm and 2 mm decorticating Clearances respectively.

The coefficient of variation (CV) is the ratio of the standard deviation to the mean. The higher the CV, the less the precision of the experiment for a determined parameter. From table 4.3, it was showed that the machine efficiency with the interaction of decorticating clearance and decorticating drum speed.

It was noticed that the increased in drum speeds increased the decorticating efficiency of the Enset decorticator with maximum mean values were at 1050 rpm for all decorticating clearances but maximum machine decorticating efficiency obtained from 2 mm decorticating clearance. Cantalino et al., (2015) stated that decorticating efficiency of sisal leaf increased as drum speed increased. The following fig (4.1) showed the relationship between decorticating drum speed and machine efficiency.

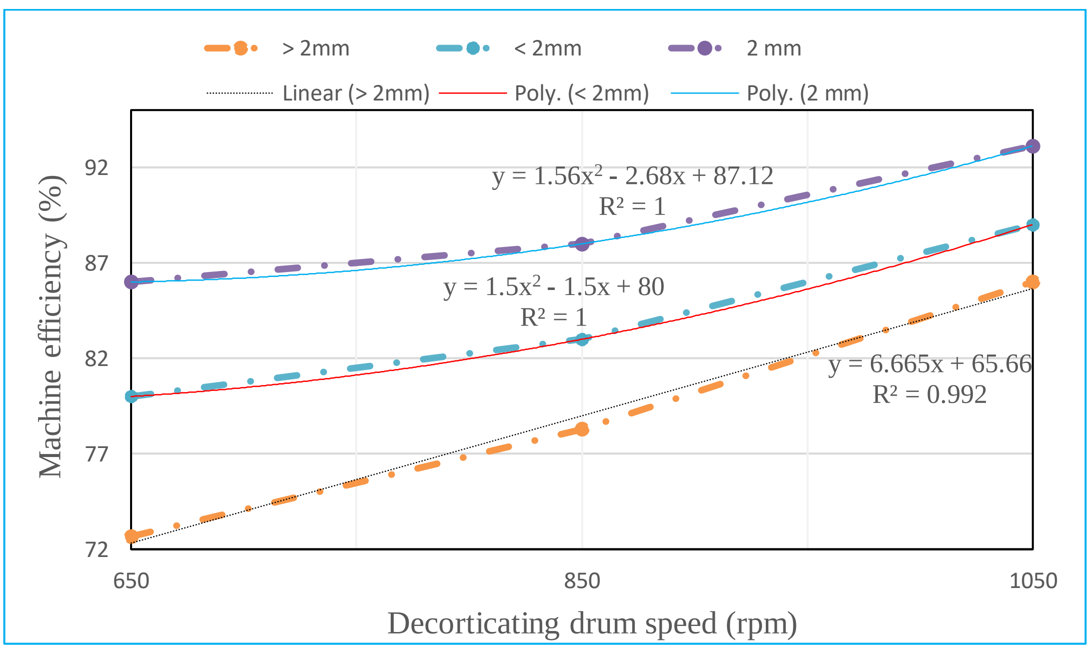


Figure 4.1. Average decorticating efficiency versus drum speeds at different clearance

The positive correlation between decorticating efficiency at different decorticating clearance interacted with drum speed was showed in Fig. 4.1. The data obtained from the tested were analyzed, first and second-degree polynomial regression showed strong correlation between decorticating efficiency and drum speed in all trials, with a high coefficient of determination (R^2 = 0.992, R^2 = 1 and R^2 = 1) were observed with > 2mm, < 2mm and 2 mm respectively. Polynomial regression indicated that the Enset decorticating machine efficiency increases with increasing drum speed in different decorticating clearance.

4.3. Machine output capacity (kg/hr) at different drum speed and decorticating clearance

Speed	Average value in different Clearance		
	< 2 mm	2 mm	> 2 mm
650	44.64	51.9	42.97
850	46.69	53.93	43.5
1050	53.05	57.2	45.46
Mean	48.13	54.48	43.98
SD	4.38	1.25	1.25
CV	0.09	0.022	0.028

The test result showed that the mean values of decorticating capacity varied from 42.97 kg/hr. to 45.46 kg/hr. at >2 mm decorticating clearance. In the same way the mean value of decorticating capacity varied from 44.64 kg/hr. to 53.05 kg/hr. and from 51.9 kg/hr. to 57.2 kg/hr. at <2 mm and 2mm decorticating clearances respectively.

The lower the CV, the higher the precision of the experiment for a determined parameter. From table 4.4, it was showed that the machine capacity with the interaction of decorticating clearance and decorticating drum speed. Therefore the result showed that as the machine output capacity increase the decorticating drum speed increase.

It was noticed that the increased in drum speeds increased the decorticating capacity of Enset sheave decorticator with maximum mean values were at 1050 rpm for all concave clearances.
Figure 4.2 below showed that the decorticating capacity increased with increased of drum speeds but it was varied with decorticating clearance.

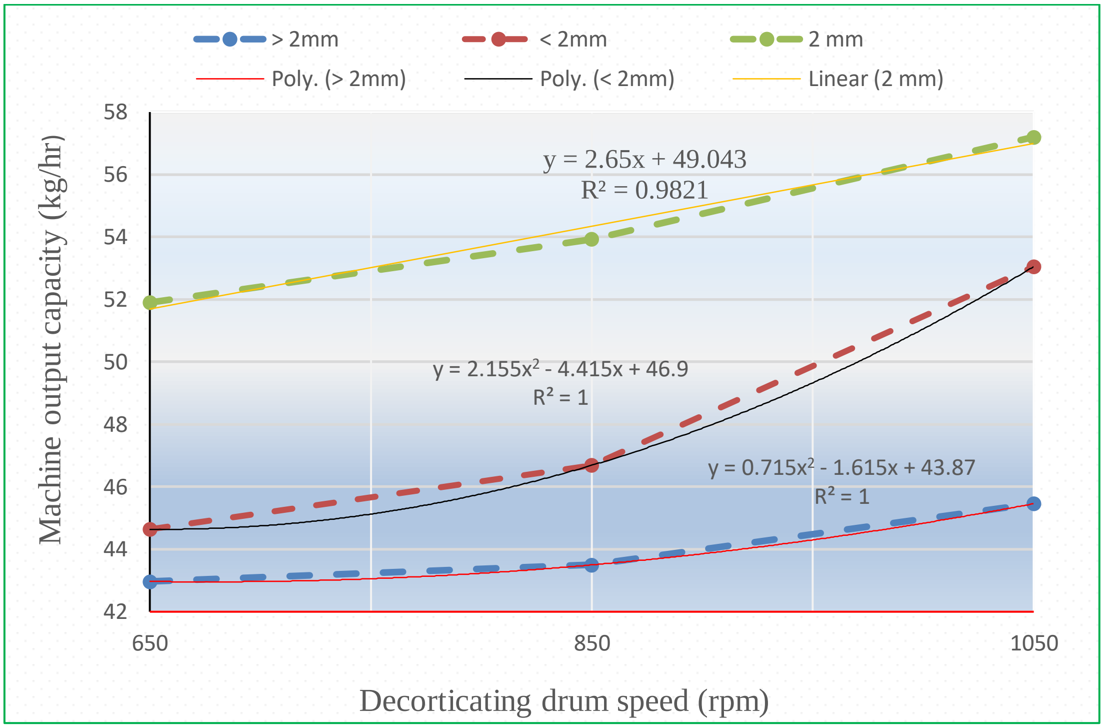


Figure 4.2. Average decorticating capacity versus drum speeds at different clearance

The positive correlation between machine output capacity at different decorticating clearance interacted with drum speed was showed in Fig. 4.2. The data obtained from the tested were analyzed, first and second-degree polynomial regression showed strong correlation between decorticating machine output capacity and drum speed in all trials, with a high coefficient of determination (R^2 = 1, R^2 = 1 and R^2 = 0.9821) were observed with > 2mm, < 2mm and 2 mm respectively. Polynomial regression indicated that the Enset decorticating machine output capacity increases with increasing drum speed in different decorticating clearance.

Table 4.4. Feed rate (kg/hr) at different drum speed and decorticating clearance

Speed	Average value in different Clearance		
	< 2 mm	2 mm	> 2 mm
650	54.08	56	53
850	56.5	57.5	55.02
1050	57.8	62.12	56.05
Mean	56.12	58.21	54.69
SD	3.2	3.1	3.17
CV	0.057	0.054	0.058

From the ANOVA result table above, the test result showed that the mean values of feed rate varied from 53 kg/hr. to 56.05 kg/hr. at >2 mm decorticating clearance. In the same way the mean value of decorticator feed rate varied from 54.08 kg/hr. to 57.8 kg/hr. and from 56 kg/hr. to 62.12 kg/hr. at <2 mm and at 2mm decorticating clearances respectively.

The lower the CV, the higher the precision of the experiment for a determined parameter. From table 4.5, it was showed that the machine feed rate with the interaction of decorticating clearance and decorticating drum speed. Therefore the result showed that as the feed rate increase the decorticating drum speed increase.

It was noticed that the increased in drum speeds increased the feed rate of Enset decorticator with maximum mean values were at 1050 rpm for all concave clearances but varies with decorticating clearance.

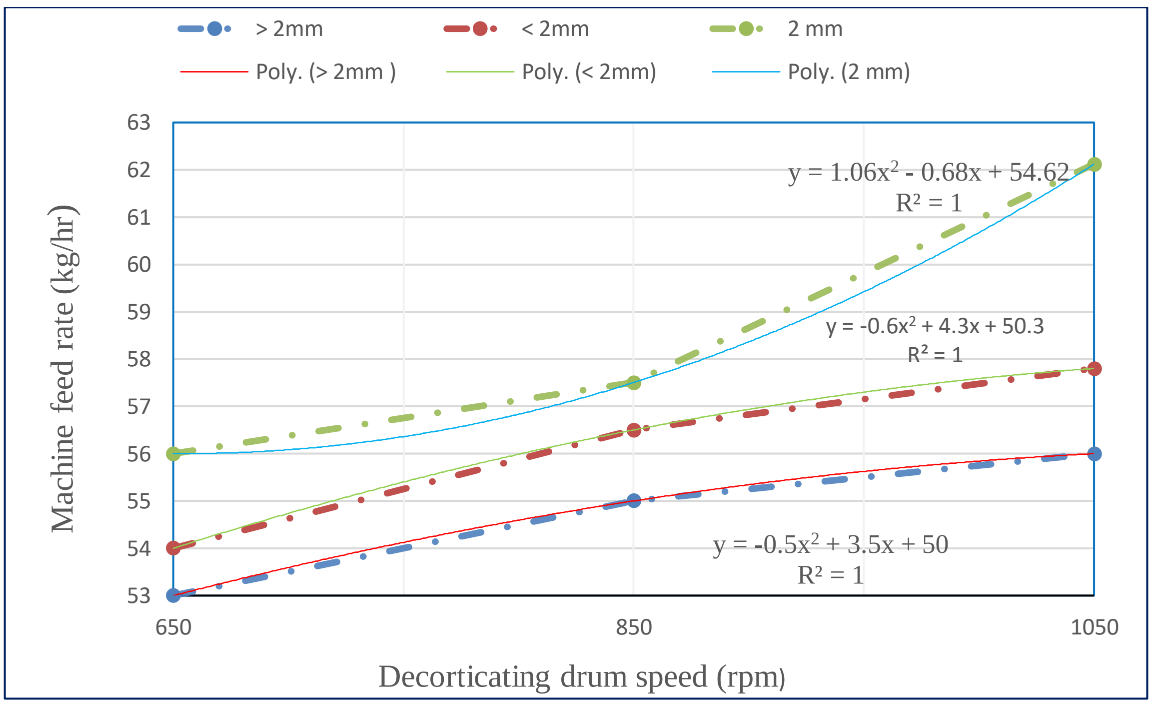


Figure 4.3. Average machine feed rate versus drum speeds at different clearance

The positive correlation between decorticator feed rate at different decorticating clearance and drum speed was shown in Fig. 4.3. The data obtained from the tested were analyzed and second-degree polynomial regression shows strong correlation between feed rate and drum speed in all trials, with a high coefficient of determination ($R^2 = 1$, $R^2 = 1$ and $R^2 = 1$) were observed with > 2mm, < 2mm and at 2 mm respectively.

Table 4.5. Un-decorticate sheath (%) at different drum speed and decorticating clearance

Speed	Average value in different Clearance		
	< 2 mm	At 2 mm	> 2 mm
650	20.01	25.05	48
850	24	29	50.07
1050	27.07	38	56.01
Mean	23.69	30.68	51.36
SD	3.54	6.63	4.15
CV	14.94	21.6	8.1

It was observed that the mean values of un-decorticated sheave (partially decorticated sheave) was 20.01 % to 27.07 % at < 2 mm decorticating clearance. In the same way the mean values of partial decorticated sheave varied from 48 % to 56.01 % and from 25 % to 38 % at > 2 mm and 2 mm decorticating clearances respectively. Here it can be noticed that decorticating clearance was basic factor of the incomplete decortication.

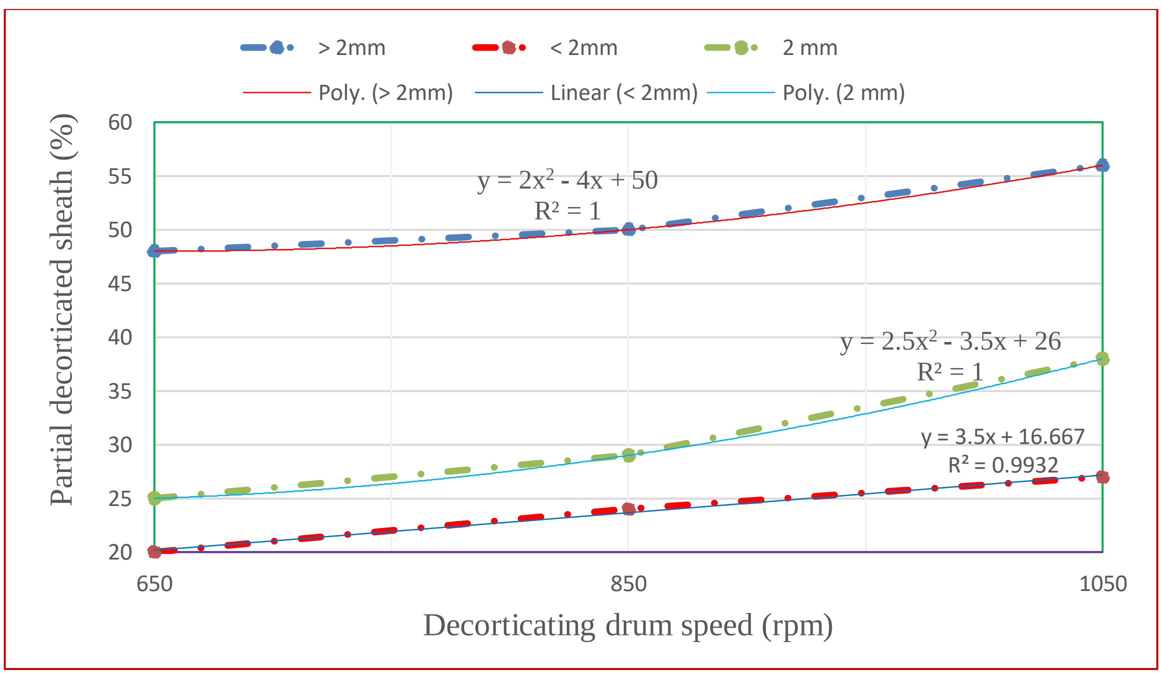


Figure 4.4. Average un-decorticated sheave versus drum speeds at different clearance

The data showed in Fig.4.4 strong correlation between un-decorticated sheave and drum speed in all trials, with a high coefficient of determination (R^2 = 1, R^2 = 0.9932 and R^2 = 1) were observed with > 2mm, < 2mm and 2 mm respectively.

Table 4.6. Fibber breakage (%) at different drum speed and decorticating clearance

Speed	Average value in different Clearance		
	< 2 mm	At 2 mm	> 2 mm
650	45.72	26.02	17
850	49.81	28	18.83
1050	57	32.08	23
Mean	50.84	32.03	19.61
SD	5.7	3.05	3.1
CV	11.2	9.52	15.68

Fiber breakage increases with increase in drum speed as shown in ANOVA Table 4.7. The test result showed that the mean values of fiber breakage varied from 45.72 % to 57 % at < 2 mm decorticating clearance. In the same way the mean value of fiber breakage varied from 17 % to 23 % and from 26.02 % to 32.08 % at > 2 mm and 2 mm decorticating Clearances respectively. Additionally, it was noticed that the increased in drum speeds increased the amount of cut fiber increases. With maximum mean values were at 1050 rpm for all decorticating clearances but the maximum value registered was at lower decorticating clearance.

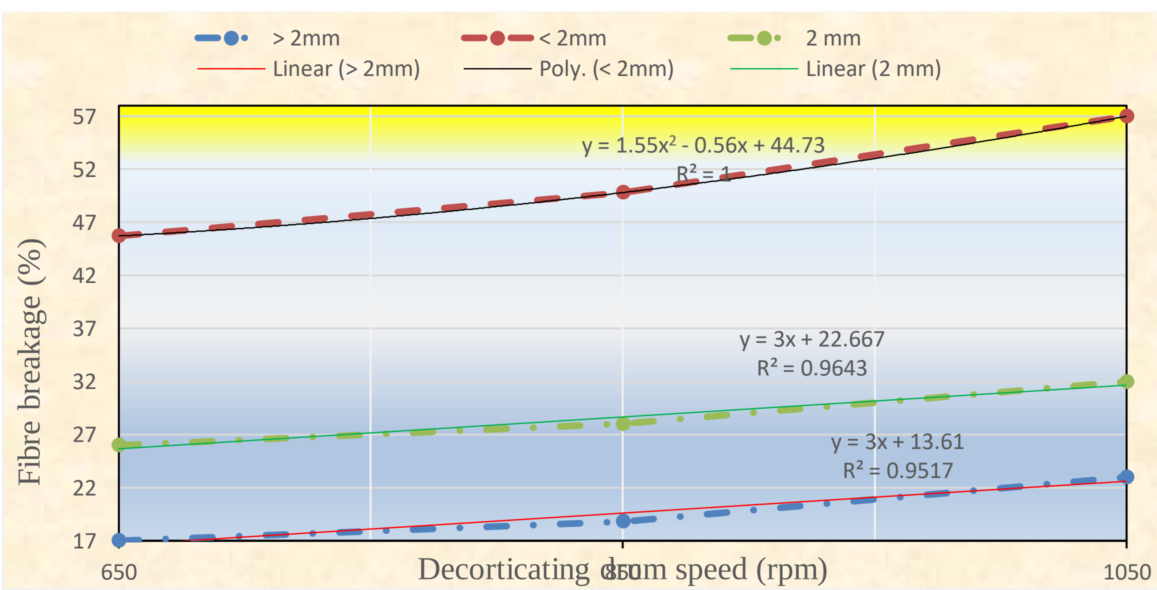


Figure 4.5. Average fiber break versus drum speeds at different clearance

The data showed in Fig.4.5 strong correlation between fiber break and drum speed in trial, with a high coefficient of determination (R^2 = 0.9517, R^2 = 1 and R^2 =0.9643) were observed with > 2mm, < 2mm and 2 mm respectively. From linear and polynomial regression, the fiber breaking (cut) was high at clearance of < 2mm. Some fibres were broken due to force of scraper on leaves and due to narrow gap between the inclined plate and rotating blades (Naik et al. 2013).

Table 4.7. Fibber cleaning efficiency at different drum speed and decorticating clearance

Speed	Average value in different Clearance		
	≤ 2 mm	At 2 mm	≥ 2 mm
650	82	77.07	56
850	76.12	69.01	50.01
1050	74.05	65	48
Mean	77.39	70.36	51.33
SD	4.12	6.14	4.16
CV	5.32	8.72	8.10

It was observed that the mean values of fiber cleaning efficiency of Enset sheave decorticator were 82 %, to 74.05 % at < 2 mm decorticating clearance. In the same way the mean values of fiber cleaning efficiency of Enset sheave decorticator varied from 56 % to48 % and from 77.07 % to 65 % at > 2 mm and 2 mm decorticating clearances respectively.

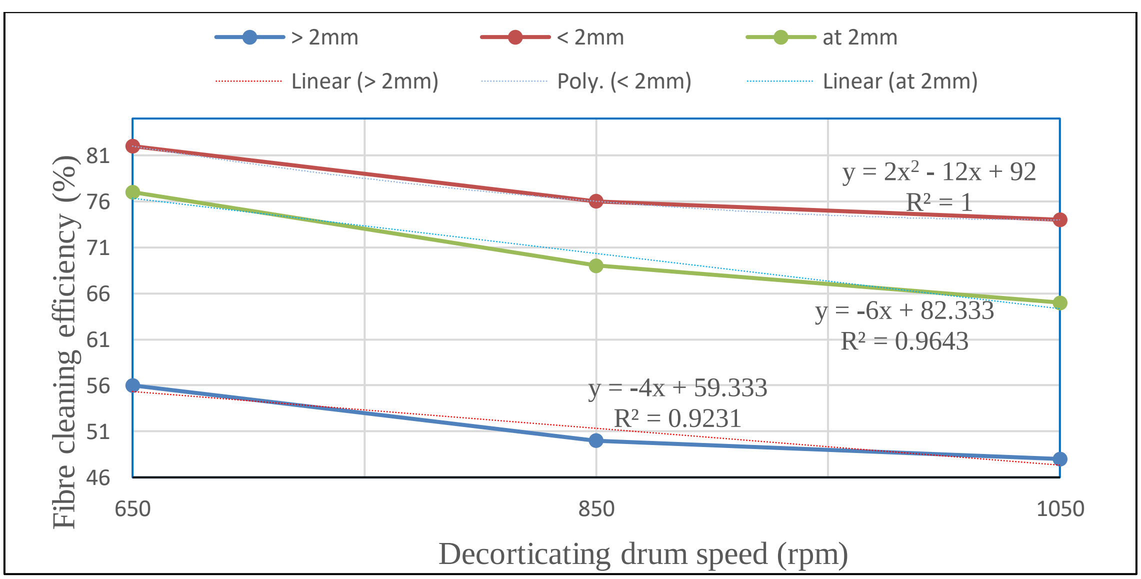


Figure 4.6. Average fiber cleaning efficiency versus drum speeds at different clearance

The data showed in Fig.4.8 good negative association between fiber cleaning efficiency and drum speed with negative in all trials, with a high coefficient of determination (R^2 = 1, R^2 = 0.9231 and R^2 = 0.9643) were observed with < 2mm, > 2mm and 2 mm respectively. It tells us the fiber cleaning efficiency of Enset decorticator did affected by drum speed but highly affected by decorticating gap (clearance). Weight lost during decorticated of Enset sheath in different decorticating clearance and different decorticating drum speed was determined were 1.28 kg, 1.06 kg and 0.87 kg in decorticating clearance of > 2 mm, < 2 mm and at 2 mm respectively at three different decorticating drum speed.

From the above result, the optimum clearance between cylinder blades and inclined plate was determined as 2 mm with drum speed of 1050 rpm. Therefore from the above three decortication clearance, decorticating Enset at clearance of 2mm was more productive, highly efficient with drum speed of 1050 rpm than the rest and it is a similar with the result was observed with (Cantalino et al., (2015), the fiber producing machines in Pakistan are recommended at decorticating gap of 2.1 mm with drum speed of 1500 rpm is more effective.

4.5. Performance Analysis of decorticator with Traditional Decortication.

Table 4.8. Major strengths and weakness of traditional enset processing

Sr.No.	Particulars	No. of respondent Percentage	
	Total number of questioners (N = 16)	Yes	No
1	Unhygienic	75	25
2	Time and energy consuming	87.5	12.5
3	Increased household income (productivity)	37.5	62.5
4	Locally available	93.75	6.27
5	Decortication is gender requirement	81.25	18.75
6	Fiber clearing efficiency.	87.5	12.5
7	Fiber breakage	37.5	62.5

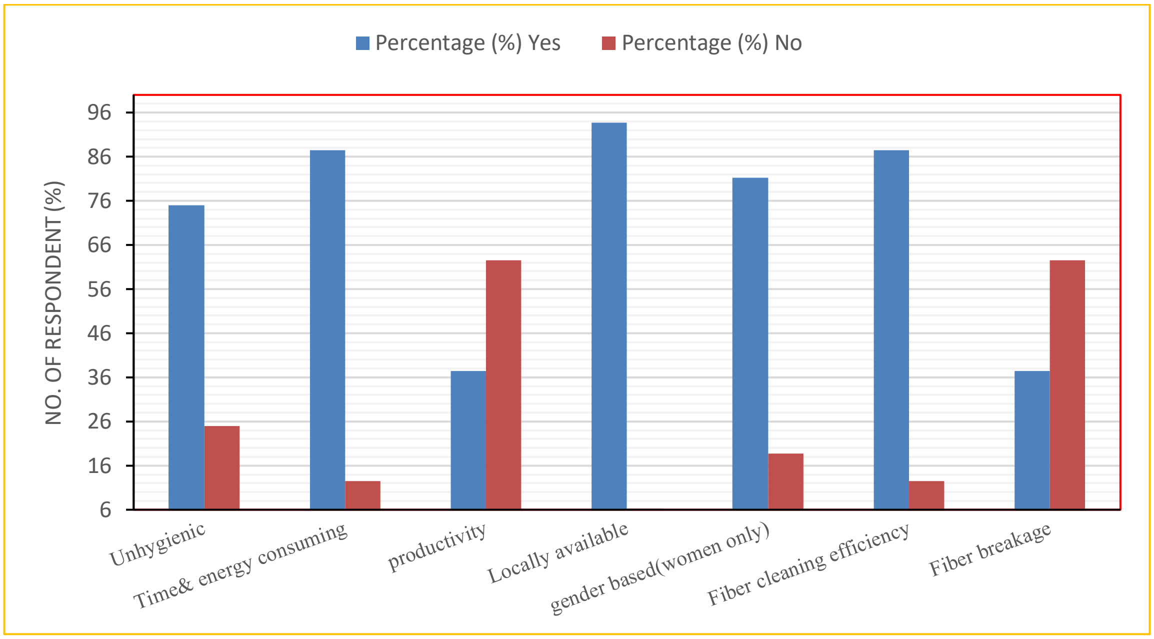


Figure 4.7. Analysis of major strengths and weakness of traditional enset processing

In generally the traditional decorticating technique was:- difficult to work during pregnancy, because of they have put their legs on the steam of Enset, old age and health complication, does not attract men to be involved in Enset processing, consumes much time and energy, poor sanitation and difficult to decorticating. The major good future of the traditional method involves availability of the material at local level, farmers are well experienced low fibre breakage and can use their indigenous knowledge

The main activity of in enset processing includes the following: - decision to process matured Enset plant, cutting the Enset plant, peeling, decorticating, squeezing to produce bulla, and transporting the extracted product, digging a pit, and fermentation of the kocho. Before starting all the Enset processing activity, the number of matured Enset plant should be decided either by men or women or both. However in both methods the decision to process the matured Enset plant is made jointly by men or women. The main functional difference between traditional and new introduced technology was decorticating activity. In generally the new introduced machine was expected to perform decorticating activity more efficient, effective, hygienic, productive, improve product quality, save time, reduce labor, (save energy) and there was no gender requirement (both boy and girls can participate equally). But under traditional method nearly all activities, especially decorticating performed by women.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The following conclusions were made from the study of developed motor driven Enset decorticator.

- Motor driven Enset decorticator works better efficiency in the field with required feed rate and output capacity with minimum damage to fibre.
- The operating belt speed of drum of 5.5 m/s. Therefore there was suitable for decorticating without belt slip.
- Therefore, it was expected that the improved Enset decorticator was many socio-economic important likely to bring income change, it allows women to spend less time providing basic needs and more time on their preferred productive activities, improves women's businesses, leading to increases in production or to products of higher quality, Women's health improves due to a trend toward less strenuous. For- the last decades the work was given only for women and girls but now this technology had some green light to involve for Enset users.

5.2. Recommendation

The following suggestions were explored to improve the performance of three horsepower diesel engine motor driven Enset decorticator.

- The developed machine was for only Enset sheave decortication purpose, it was possible to redesign for Enset sheave and amicho decortication purpose.
- The machine may be tested for similar crop (banana plant) and feedback received may be used for further design requirement for decorticating clearance.
- Bulla squeezing machine existed was not efficient in wanted level. Therefore it was possible to redesign the developed machine for bulla squeezing purpose.

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APPENDICES

Appendix A

Determination decortications resistance by pressing the blade tip on the decorticating enset sheave and reading how much time taken to cut in minute was by using stop watch as shown below.

Figure 1. Decortication resistance determination

Appendix B

Table. b1. Result obtain from short duration tests of enset Decorticator gap < 2mm

Speed (rpm)	Decorticating efficiency (%)	Output capacity (kg/h)	Federate (kg/hr)	Un-decorticated sheave (%)	Fibre breakage (%)	Fibber cleaning efficiency (%)	Weight lost by during decortication (kg/hr.)
650	80	36.4	55.1	20	46	79	0.82
	81	39.33	50.66	19.1	46.3	80	0.89
	80	43.2	56.48	20.93	47.3	87	0.79
Aver	**80.15**	**44.64**	**54.08**	**20.01**	**45.72**	**82**	**0.85**
850	83.46	45.3	54.25	21.78	47.9	79.5	0.83
	86.37	44.9	53.32	24.89	48.9	68.66	0.91
	79.23	46.88	61.93	25.33	52.63	80.2	0.76
Aver	**83.02**	**46.69**	**56.5**	**24**	**49.81**	**76.12**	**0.98**
1050	88.47	52.14	58.06	25.36	49.52	76	0.82
	88.87	50.94	56.25	26.82	48.64	73.8	0.9
	89.66	56.07	59.07	30.89	72.84	72.35	0.77
Aver	**89**	**53.05**	**57.8**	**27.69**	**57**	**74.05**	**1.35**

Table. b2. Result obtain from short duration tests of enset Decorticator gap >2mm

Speed (rpm)	Decorticating efficiency (%)	Output capacity (kg/h)	Federate (kg/hr)	Un-decorticated sheave (%)	Fibre breakage (%)	Fibber cleaning efficiency (%)	Weight lost by during decortication (kg/hr.)
650	71.5	41	55.7	43	18.4	59.31	0.65
	72.5	41.9	54.6	50.8	17.5	52.34	0.8
	74	46	48.7	50.2	15.1	56.34	0.79
Aver	**72.67**	**42.97**	**53**	**48**	**17**	**56**	**98**
850	72	45	54.98	49.87	17.8	50.96	0.86
	88.7	42.1	54.8	50.07	18.49	50.53	0.67
	74.1	44	55.28	50.1	20.2	48.55	0.7
Aver	**78.3**	**43.5**	**55.02**	**50.07**	**18.83**	**50.01**	**1.04**
1050	78.3	44.06	56.25	49.47	6.25	46.75	0.64
	90.01	42.1	58.06	52.33	14.8	49.62	0.88
	80.1	50.22	53.84	66.14	8.8	47.63	0.79
Aver	**83**	**45.46**	**56.05**	**56.01**	**23**	**48**	**95.2**

Table. b3. Result obtain from short duration tests of enset Decorticator gap at 2mm

Speed (rpm)	Decorticating efficiency (%)	Output capacity (kg/h)	Federate (kg/hr)	Un-decorticated sheave (%)	Fibre breakage (%)	Fibber cleaning efficiency (%)	Weight lost by during decortication (kg/hr.)
650	85	50	54.8	24.55	22.38	74	0.75
	86.5	52	58.2	23.78	28.87	78.6	0.78
	86.5	53.7	55.05	26.82	26.98	78.56	0.88
Aver	**86**	**51.9**	**56**	**25.05**	**26.02**	**77.07**	**0.82**
850	89	55	57.2	27.22	24.56	77	0.8
	87.3	54	56.3	26.1	30.2	75	0.91
	92.2	52.8	59	33.68	29.24	55.03	0.9
aver	**89.5**	**53.93**	**57.5**	**29**	**28**	**69.01**	**0,87**
1050	93.3	56	60	32.2	31.11	62.56	0.91
	93.3	57.96	64.3	43.15	33.06	62.56	0.95
	92.87	57.64	62.07	38.33	32.15	69.88	0.83
aver	**93.12**	**57.2**	**62.12**	**38**	**32.08**	**65**	**0.81**

Appendix C

Production and Operational Cost of the decorticator.

Table. c.1. Materials for constructions of the decorticator and its cost

No	Materials type	Standard size	Total Quantity	Rate	Total price
1	Stainless steel 1mm thick	1 x12x500mm	4000 mm	150	600.00
2	Flate sheet metal 2 mm thick	2 x 600x500mm	300000 mm^2	1000	300.00
3	Sheet metal 2mm thick	2 x400x600	240000 mm^2	1000	240.00
4	Mild steel angle iron 3 mm	3 x1000x500mm	500000 mm^2	1200	600.00
5	Plate 5 mm thick	5 x50x500mm	25000 mm^2	2000	50.00
6	Round bar	Ø25x700mm	700 mm	500	350.00
7	Sheet metal 3 mm	3 x600 x400mm	2400000 mm^2	1000	240.00
8	Plate 3mm thick	3 x300x400mm	400000 mm^2	1000	400.00
9	Metal bolt and nut	M-12x100	10 pcs.	25	250.00
10	Metal bolt and nut	M-16x80	1 pcs.	35	35
11	Electrode	Ø 2.5	2 package.	250	600.00
12	Pulley	Ø = 100mm	1 no.	130	130.00
		Ø = 75mm	1 no.	110	120
13	V – belt	B – 72	1300 mm	400	400.00
14	Bearing(pcs)	P204	2 pcs	100	200.00
15	Bearing(pcs)	P207	2 pcs	110	220.00
16	Paint		1 liter	200	200.00
17	3 hp IC engine motor		1 no.	8000	8000.00
18			Subtotal = 12935 ETB		

Appendix D

Table: d1: Machine and labor costs

No.	Type of machine	Machine cost/hr.	Working hour	Cost	Labor Cost/hr.	Labor price/hr.	Total Price
1	Universal metal cutting	11	2:30	270	6.25	20:30	150.62
2	Welding machine	60	15:00	900	6.25	15:00	930.75
3	Power hack saw	40	2:00	80	6.25	20:00	120.50
4	Lathe machine	150	3:00	450	6.25	30:00	180.75
5	Rolling machine	30	3:00	90	6.25	30:00	180.75
6	Bending machine	30.5	6:30	220	6.25	60:30	400.62
7	Radial drill machine	30	9:00	270	6.25	90:00	560.25
8	Grinding machine	20	3:00	60	6.25	30:00	180.75
Subtotal				2340			2740
Machine and labor cost sub total						5080 ETB	

Table. d2: Cost summary

No	Cost Variables	Summary
A	Raw Material Cost	12935 ETB
B	Material Wastage 2.5%	323.375 ETB
C	Machine Cost	2340 ETB
D	Labor Cost	2740 ETB
E	Overhead Cost 5%(C+D)	254 ETB
F	Profit 10 %(A+B+C+D+E)	1859.24 ETB
G	Sells Tax 15 %(A+B+C+D+E +F)	3067.74 ETB
	Selling Price	23,519.36 ETB

E.3. Cost of operation of 3 hp motor drive Enset decorticator

Table. d3: Calculation of cost of operation of decorticator per hour

Cost of machine (c)	23,519.36 ETB
Assumption	
Life of machine (L), years	10
Annual working hours (H), hr.	1200
Salvage Value (S)	10% of capital cost
Interest rate	10 % percent per annum
Fuel cost	1 liter = 15 birr, used 1 liter for testing
Wage per day of 8hr	50 birr
A. Fixed cost	
Depreciation (D) , ETB/hr.	$D = \frac{C-S}{L \times H}$
	$\frac{23519.36\ ETB - 2351.936\ ETB}{10\ year \times 1200\ hr/year}$ 17.63 ETB/hr.
Interest	$\frac{C+S}{2} \times \frac{i}{H} \frac{23519.36\ ETB + 2351.936\ ETB}{2} \times \frac{\frac{0.1}{year}}{1000 \frac{hr}{year}},$
	I =1.29 ETB/hr.
Taxes and insurance	TI = 1% of the initial cost of the machine per year
	= 0.01 × 45000 ETB × 1/1000/hr. TI = 0.24 ETB/hr.
Total fixed cost, ETB/hr.	17.63 ETB/hr. +1.29 ETB/hr. + 0.24 ETB/hr.
	TFC = 19.16 ETB/hr.
B. Variable Cost	
(a) Fuel cost at l/h, ETB/hr.	Fc= 1 liter per hour , = 16 ETB/hr.
(b)Lubrication cost at 1.5 % of fuel cost, ETB/hr.	Lc = 1.5 % of fuel cost 0.24 ETB/hr.
(C). Repair and maintenance cost at 2.5 % of initial cost of machine, ETB/hr.	RM = 2.5 % × 23519.36 × 0.001 RM = 0.59 ETB/hr.
Wages of the operator, ETB/hr.	6.25 ETB /hr.
Total Variable cost per hour	16 ETB/hr. + 0.24 ETB/hr. + 0.59 ETB/hr. +6.25 ETB /hr. VC =23.08 ETB/hr.
Total cost of machine, ETB/hr.	19.16 ETB/hr. + 23.08 ETB/hr. TC = 42.24 ETB/hr.

Therefore, the cost of operation of Enset decorticator was 42.24 ETB/hr.

Appendix E

Photograph of Enset decorticator field test

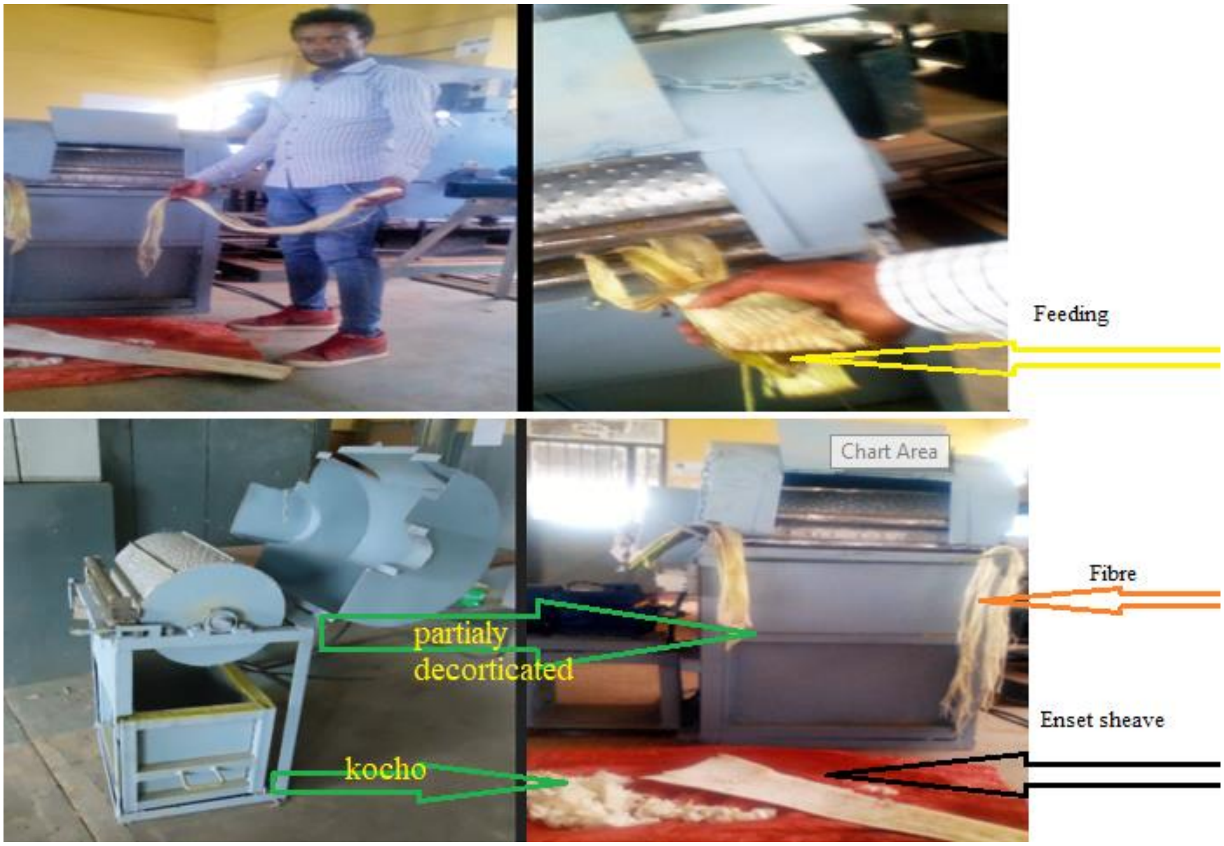

Figure. 2. Photograph of Enset decorticator during field test

Appendix F

Developed machine model and its detail views

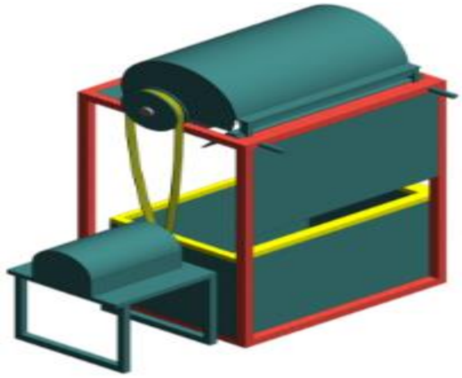

Figure. 3. Enset decorticatind machine model

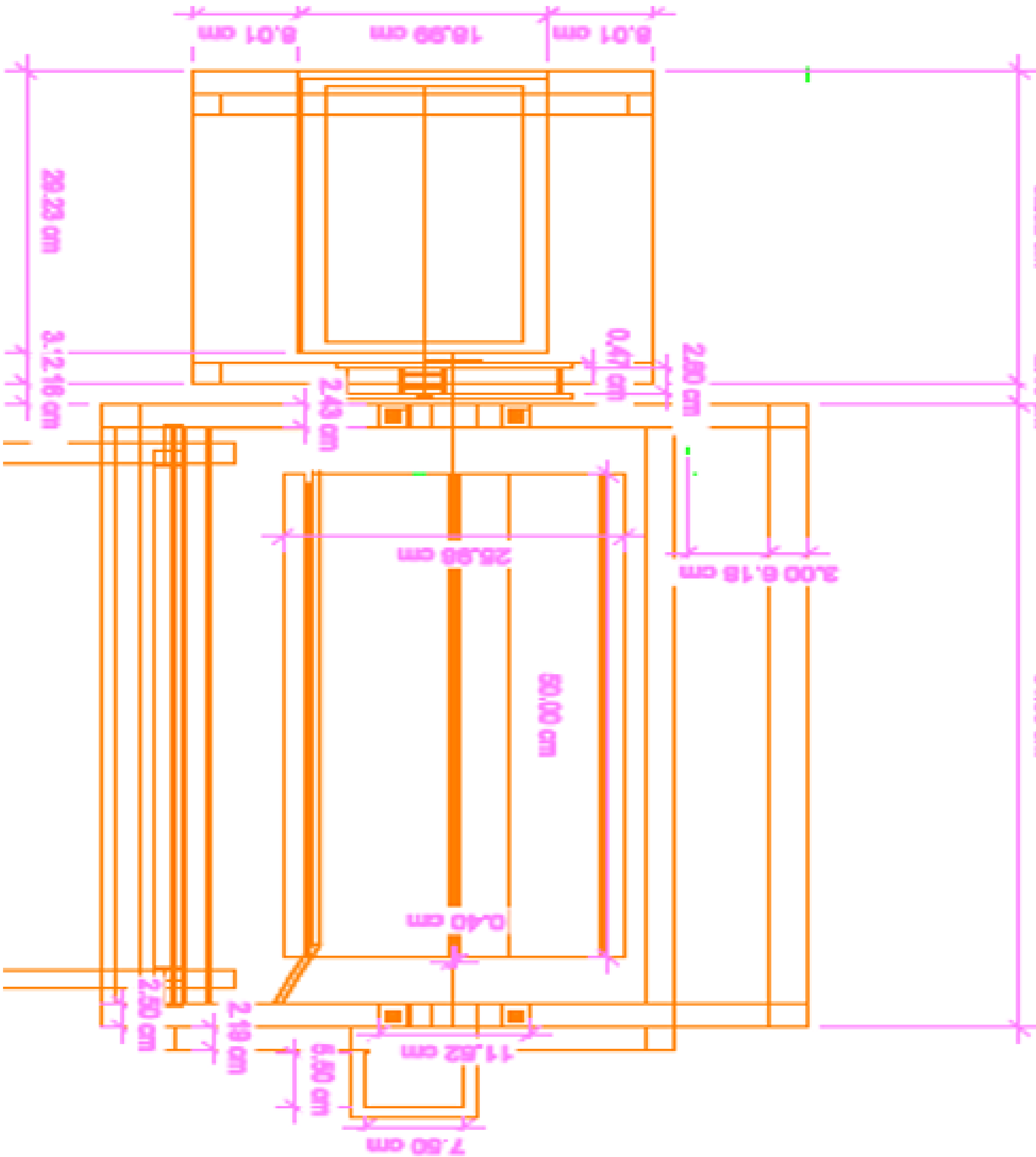

Figure. 4. 3D view

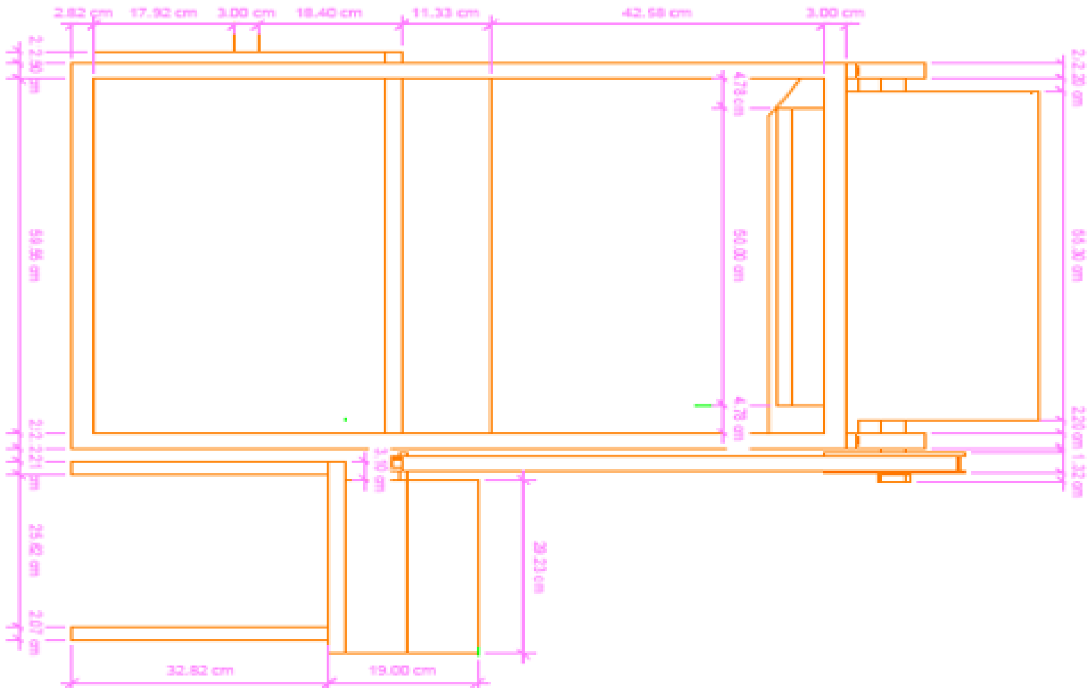

Figure. 5. Side view

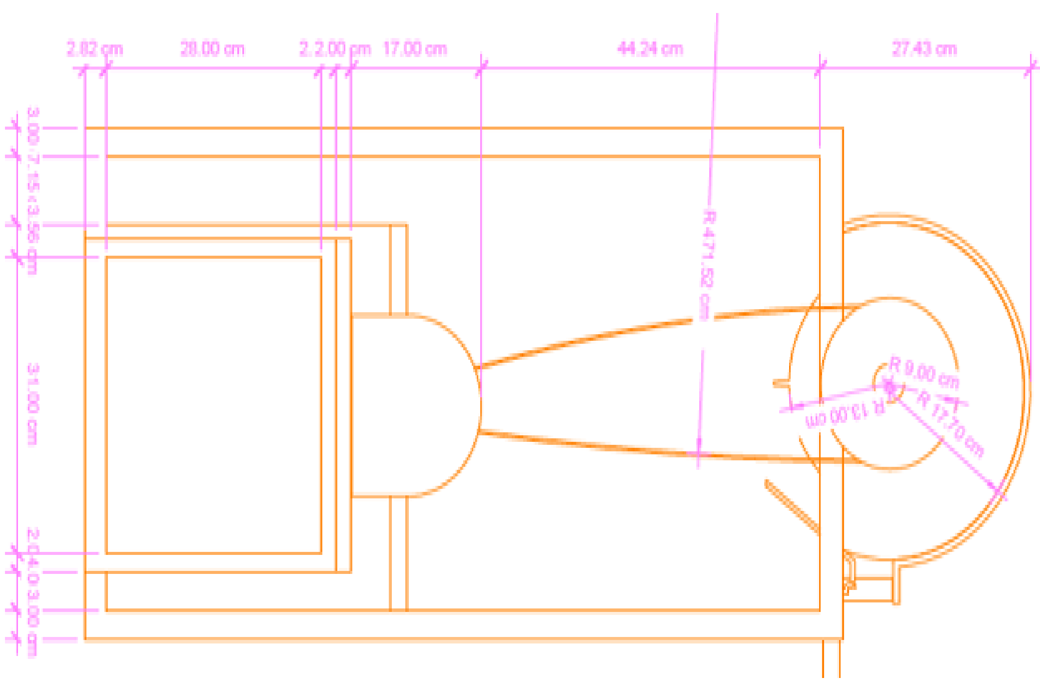

Figure. 6. Front view