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Design Improvement and performance Analysis of kocho, bulla and fiber production machine to achieve good product

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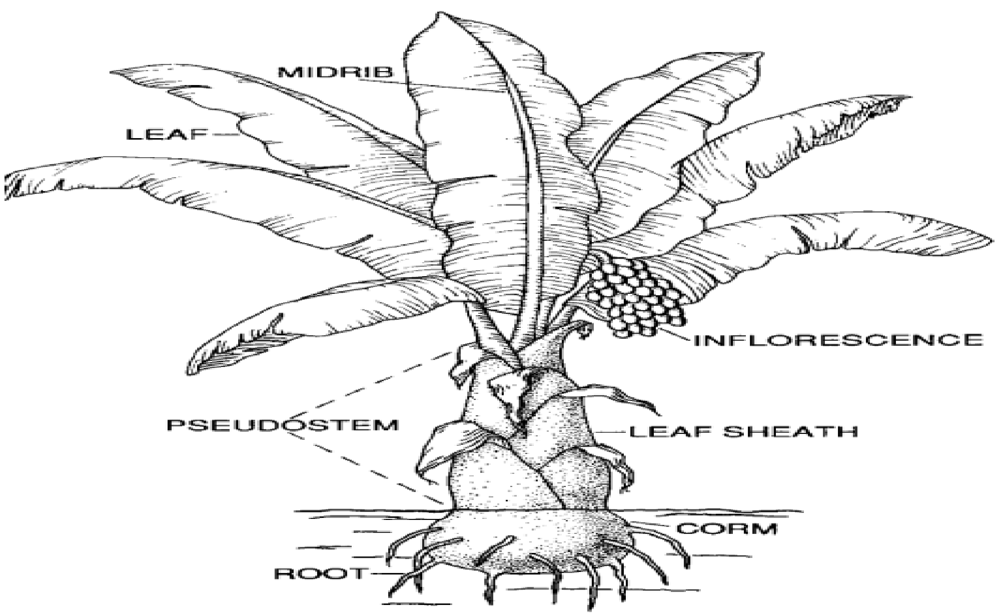
ABSTRACT

Among the total population of Ethiopia more than 85% 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. More than twenty percent of Ethiopia's population used Enset for human food, fiber, animal forage, construction materials, and medicines. In Ethiopia Enset were processed traditionally using a locally made karka scraper against a wooden plank inclined from the ground. This traditional method was hygienic problem, gender based, unproductive and time consuming. To solve this problem, the way aimed for developed low horse power motor driven Enset decorticator but it was limited function. The existed Enset sheave decorticating machine simply designed for Enset sheave decortication and the main short coming is the hardest and very important part said to be Hamacho (corm) is not decorticating. Therefore, this work intended to design improvement of the machine, performance analysis and increasing kocho, bulla and fiber product productivity. Generally the improved kocho, bulla and fiber production machine performs better work than the existed machine in the field with required feed rate, very low fiber damage.

***Key words**: Enset processing Machine, Re-design, Decorticating cylinder speed, decorticating clearance*

INTRODUCTION

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 Stat and western Oromia including West Shewa, Jimma, Ilubabora and Welega (Taye, 1984). 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



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). 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 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).

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). According to Atnafua et al., (2008), 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.

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).

Mechanizing 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, resulting in low yield due to poor growth or untimely harvesting or decorticating (MoA, 2014).

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 true stem was separated or stumped from the underground corm. The concave side of the leaf sheath was peeled and then cut into the pieces of about certain length and split lengthwise in order to shorten the leaf sheath to a available size to workable. Then the leaf sheath was decorticated using a locally made bamboo scraper while the leaf sheath was held on an incline (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, Areka Rural Technology jimma agricultural research center, and Melkassa Agricultural Research center tried to develop modern devices that enable easy decortication. Researchers at Adama Science and Technology University developed motor driven Enset Decorticaor and evaluated its performance. The new developed motor driven Enset decorticating machine that is developed from the local materials is better than the others.

This was a significant development over the traditional method which used the decorticators save time and reduces labor and increase hygienist. However, their work didn’t improve because the developed decorticators couldn’t decorticate the very crucial parts called hammicho (corm

The aim of this review was to improved 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. Dieselengine 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 contact with modern technology.

The developed three horsepower diesel engine motor driven Enset sheave 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 ϴ and the edges of the blade were sharp enough to peel of the sheaves of Enset. The decorticator could 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. Theoretically motor drive decorticator could maintain the rotation of drum in adjustable decorticating clearance. 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.

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 is296 km away from Addis Ababa.

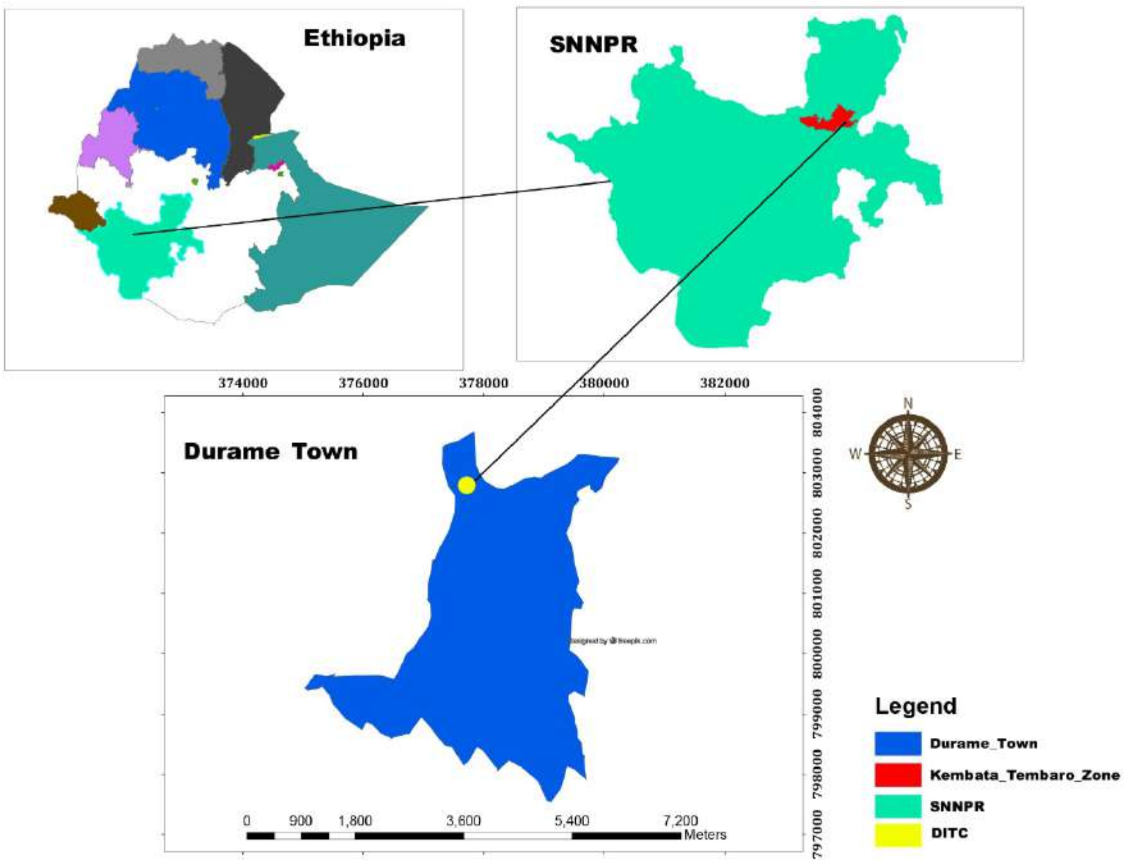


Figure 3.1. Study site map

3.2. Materials Selection

The materialsselection was based on durability, cost, availability, strength, rigidity, weight and friction. The material designed to Enset decorticator drum and blade must be free from iron and other heavy metal, but some parts like frame, main shaft, safety guard and pulley and belts were constructed from angled iron and any 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, digitalweight balance (0.1gm accuracy), digital caliper of 0.01 mm accuracy, measurement tape (millimeter graduation) and stop watch instruments, 30 kg of enset wereused 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 motor.
2	Blade	8	Made from Stainless steel and Sharp and blunted at the tip with 12 by 1mm cross sectional dimensions and equal lengths of 500mm
3	Drum or cylinder	1	Flat sheet metal rolled into circular diameter 300mm, length 500mm and 2 mm thickness 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 500mm in length and 50mm height with 3mm 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 Steel 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, 2mm thickness developed as per design drawings.
10	Pulley safety cover	1	Rolled iron sheet, 2mm thickness .developed as per design drawings
11	Bucket or bin	1	Made from aluminum sheet and 40x30x3mm in volume
12	Motor sitting	1	Angled iron of 320mm by 320mm by 3mm cross Sectional dimensions.

3.3. Physical Properties of Enset Leaf Sheave

The physical property of Enset sheave was important factor for the design of motor driven Enset decorticator. The Enset sheave 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 sheave.Three Enset sheave were selected randomly from sample and dimensions were measured. Therefore, sheave properties relevant to the design of Enset decorticator were identified and determined. Parameters like shape, dimension,weight, decortication resistance, diameter of Enset fiber was determined. Length, width and thickness of the sheave were taken using digital Vernier caliper.

3.3.1. Shape Determination of Enset Sheave

The shape of Enset sheave 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.

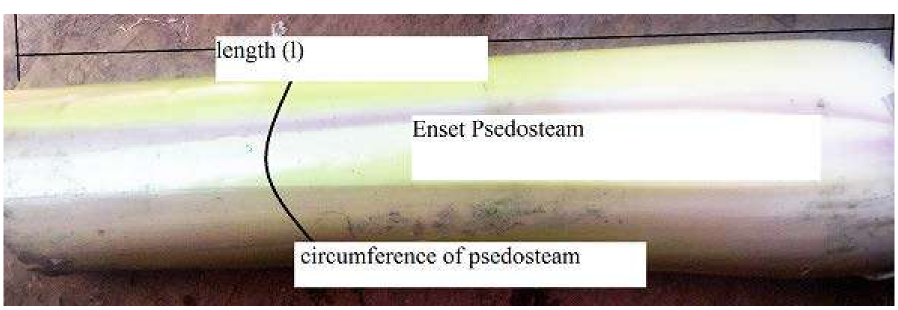


Figure 3.2. Pseudostem of Enset

3.3.2. Size Determinationof Enset sheave

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 sheave was determined by measuring the dimension of the principal axes; major, intermediate and minor of sheave.

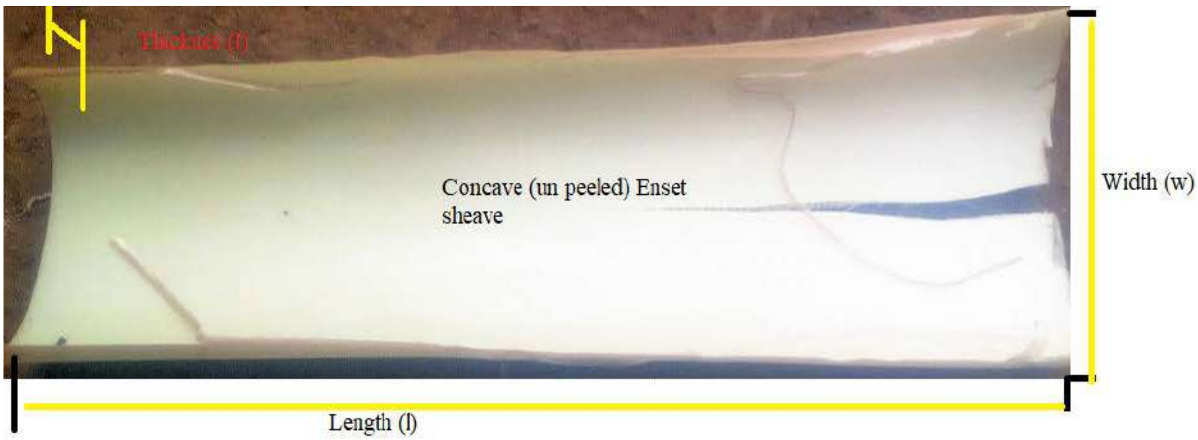


Figure 3.3. Enset leaf sheave

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

Size $= \sqrt[3]{(l \times b \times t)}$ ……………………………………………………………………….. 3.1

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

3.3.3. Weight of Enset Sheaves

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 sheave was determined by using digital weighting balance.

3.3.4. Local Variety of Enset and Decortications Resistance

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

According to this study the decortication resistance of the Enset sheave was determined by two ways. The first methods to determine the decorticating resistance of the Enset sheave was putting the decorticating blade tip on the sheave and recording the time by using stop watchas shown appendix (A).The decortication resistance was depending on the Enset local variety. 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

3.3.5. Enset FibreDiameter Determination

Diametersof 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).

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

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.

3.4.1. Functional Requirements of Enset Sheave Decorticator

The three horsepowerdiesel engine motor driven Enset sheave decorticator should fulfill the following functional requirements:

- It should scrap of the fleshy ventral side of the leaf sheath properly with respect to uniform feed rate.
- It should maintain the fiber cut or fiber breakage.
- It should minimize wastageand be safe to operate.

3.4.2. Economical Requirement of Enset Sheave Decorticating Machine

The economic requirements of decorticators were determined according to (Khurmi and Gupta, 2005).

- Decorticating gap of the required feed rate should be reliable and easy to adjust.
- Fiber should not be cut by the decorticating blade and fiber cut must not exceed 10 %.
- Decorticator should require minimum labor.
- Operating efficiency of the decorticator should not be dependent on the number of operators power but it may be depends on the operators skill.
- The output capacity of the machine was depending on the drum speed and decorticating gaps.

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 is designed in a cylindricalshape 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).

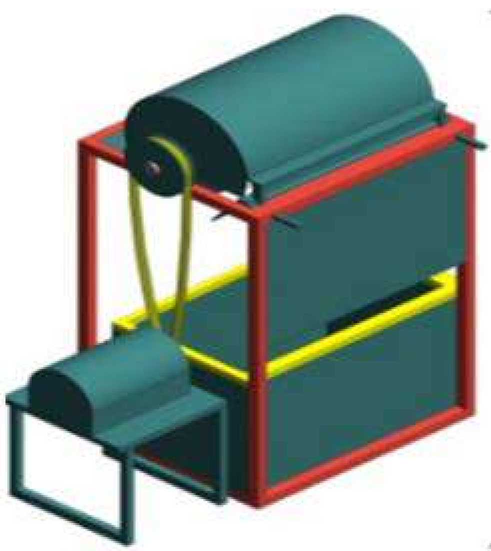


Figure 3.4. 3DMachine model

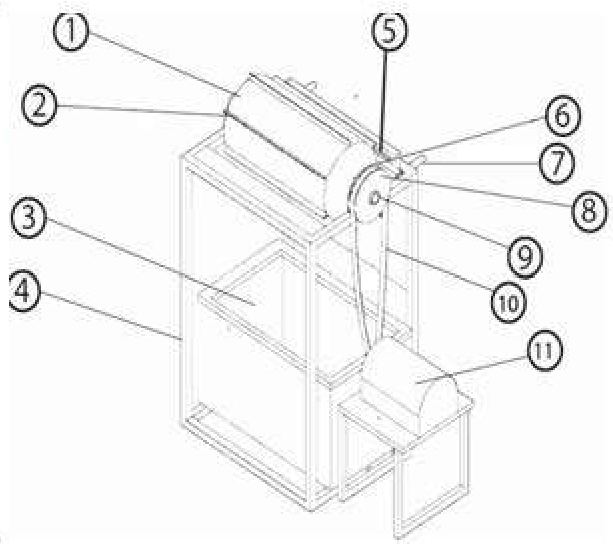


Figure3.5. Machine parts representati0n

Key

1. Decorticating drum 7. Dual rollers 10. Belt

2. Decorticating blade 8. Inclined plate 11. Diesel engine motor house
3. Bucket with filter 9. Clearance adjuster
4. Frame 10. Drum pulley

The roller was the feeding unit through which the Enset sheave were fed into the machine inclined plate which was the Enset sheave to be decorticated on it. The driving mechanism consist of a motor which is used to supply power for operating the machine by transmission units called pulley- belt system. The cost of the machine is 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. The dimensions of the shaft was 30 mm diameter and 700 mm length. Shaft design consists primarily of the determination of the correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading conditions.

3.5.2. Estimation of Weight the Decorticator by Using Cattie Software

The weight of each part designs 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. Solid work 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

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 metalas rolled of 300mm in diameter and coated 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

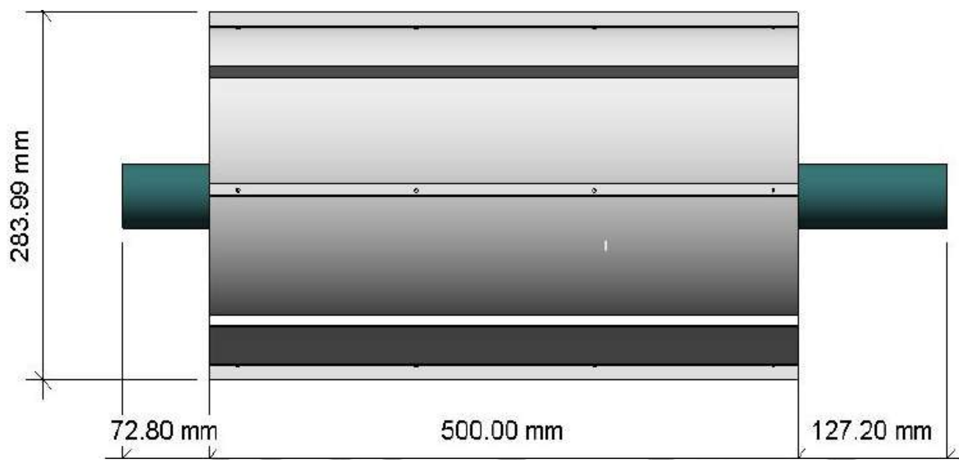


Figure 3.6. Decorticating drum with blade

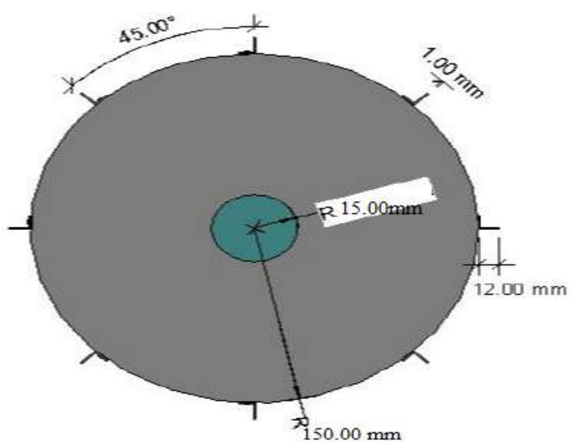


Figure 3.7. Decorticating drum side view

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

Figure 3.8. 3D Blade model

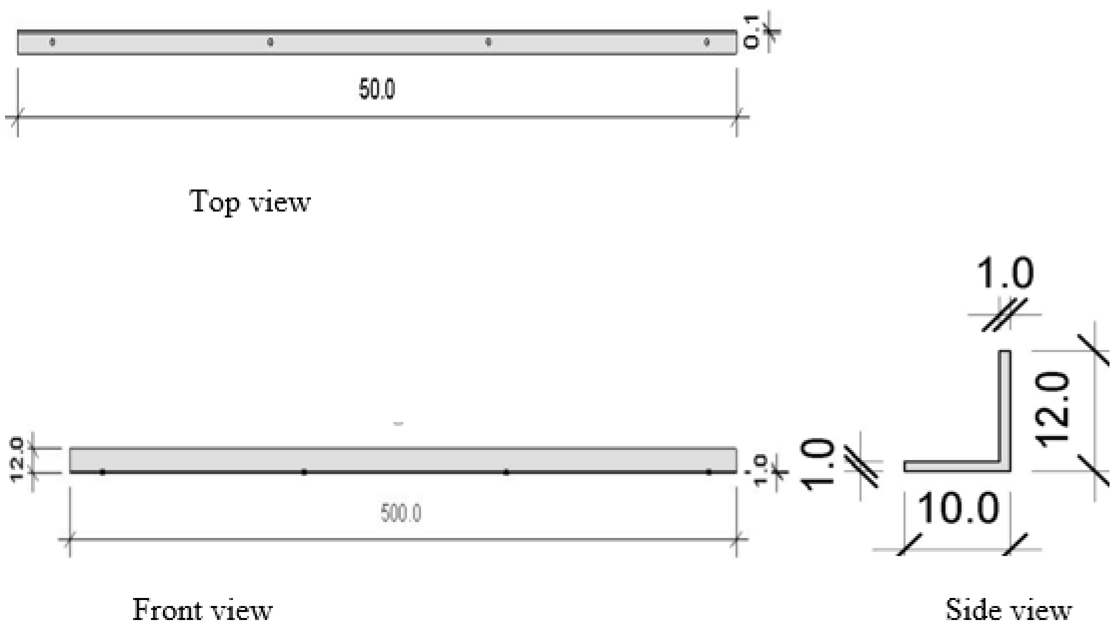


Figure 3.9. Detail blade view

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

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 (3.3) (Kanogu, et al., 2011)

$n = \frac{2\pi}{\theta}$ ……………………………………………………..…………..…...………… .3.3

Where.n = is the number of blades on the beater drum and = 8, ϴ = is angle between two successive blades and determined by protractor given, ϴ = 45^0

The number of blade on the drum was eightand therefore the angle between two successive blades was 45^0. This angle was said to be arc length between two successive blades.

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 wasfed 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 vertically duringoperation 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.

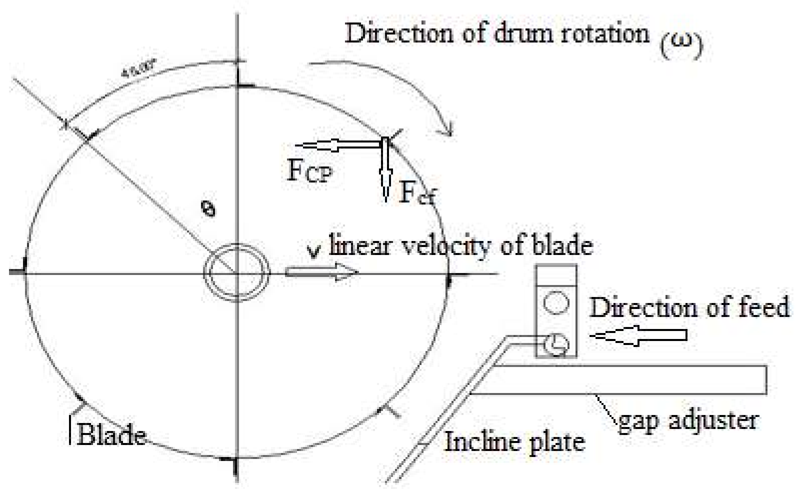


Figure 3.10. Layout of rotating drum with blade

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 by equation (3.4) (Kawongolo, et al,. 2002).

$M = m \times v \times r$…………………………………………………………………….....3.4

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 5.5m/s x 0.15m, = 3.04kgm2/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 (3.5) (Abdulkadir et al., 2009).

$$F_{CP} = \frac{mv^2}{r} \quad \text{......} 3.5$$

Where. F_{cp} = centripetal force

m = mass of decorticating drum with blade

v = linear velocity of blade

From the above equation 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 (3.6) (Abdulkadir et al., 2009).

$$F_{cf} = mv^2 \quad \text{......} 3.6$$

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

m = mass of decorticating drum with blade

v = linear velocity of blade, then the values was 111.62 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. 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 wastoo small the result, the fiber was cut(damaged). The pitch was determine using Equation (3.7) (Snyder et al., 2006).

$\mathrm{Pt} = \frac{2\pi vf}{N2 \times n}$ ……………………………………….…………………………………………3.7

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.

If fig 3.9 belowillustrated 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, was given by the following parametric equations.

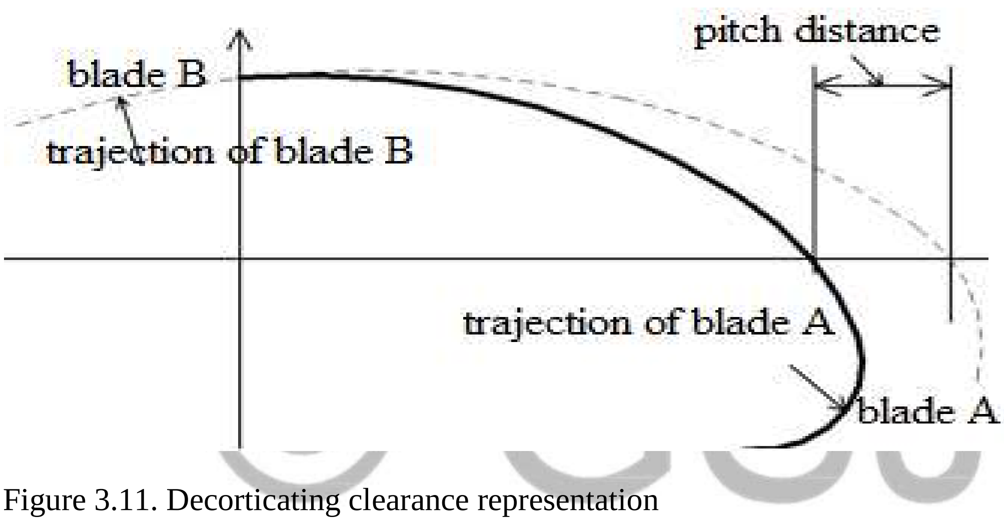


Figure 3.11. Decorticating clearance representation

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 (3.8 and 3.9) (Khurmi and Gupta, 2005).

$A_B(t) = vt + \frac{D}{2}\sin(\omega t)$ ……………….………..……......…………..…………………. .3.8

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 rpmthere fore

A_x (t)= $\frac{D}{2}$cos (ωt) …...3.9

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

B was be given by the following parametric equations (3.10 and 3.11)(Khurmi and Gupta, 2005).

$B_x(t) = vt + \frac{D}{2}\sin(\omega t - \Theta)$ ………………...……………………...…..……………..... ..3.10

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.

$B_B(t) = \frac{D}{2}\cos(\omega t - \Theta)$ ……………………………………………………………......3.11

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

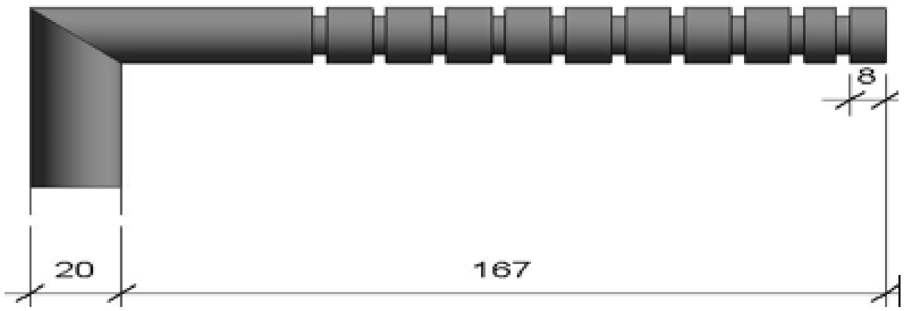


Figure 3.12. Decorticating gap adjuster

3.5.6.Inclined Plate Design

An adjustable inclined breast plate of about 500 mm long and 50 mm width and 5mm 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.

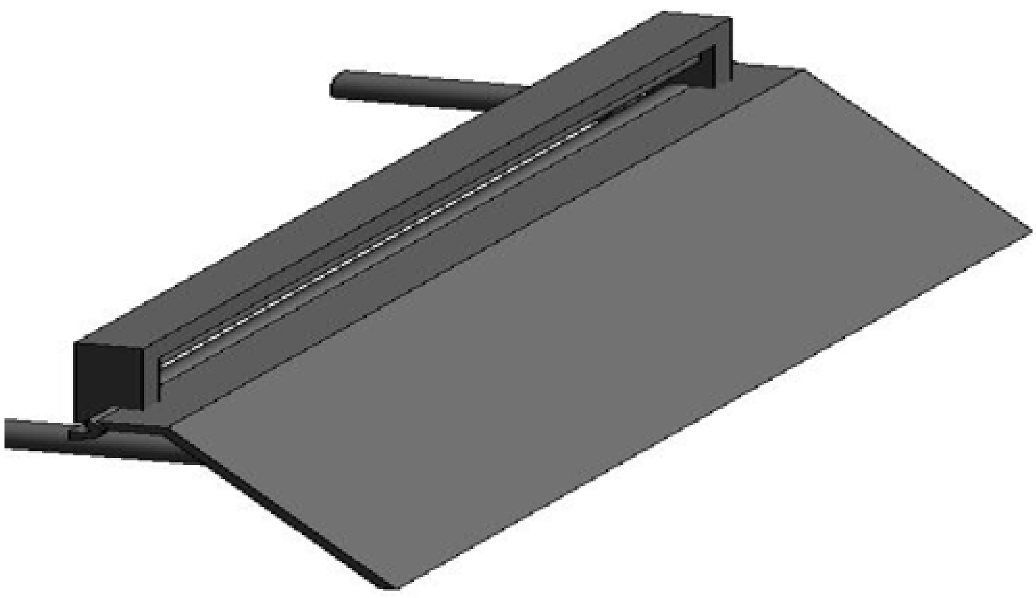


Figure 3.13. 3D model of inclined plate

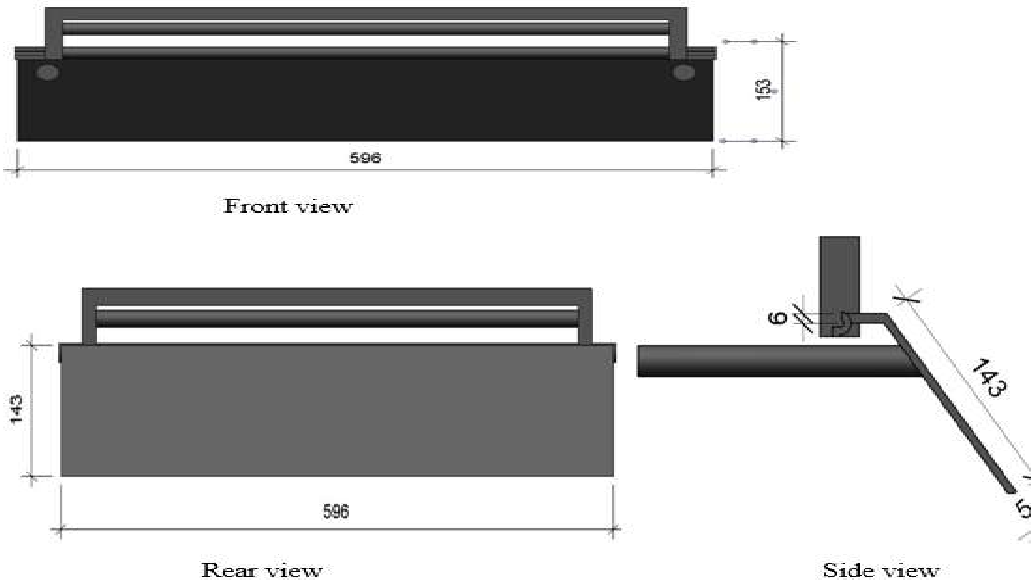


Figure 3.14. Detail view of inclined plate.

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, angle of cutting and that of the power available from worker to resist the load.

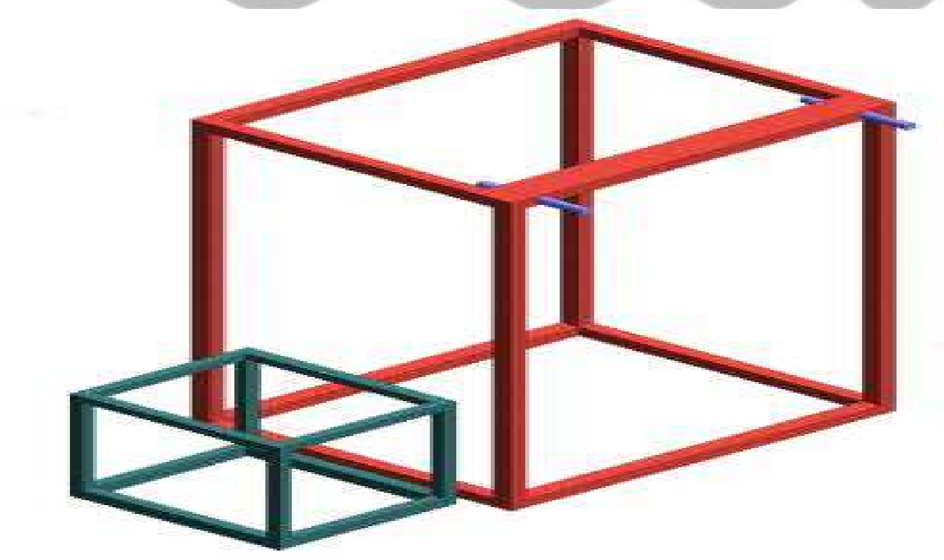


Figure 3.15. Frame

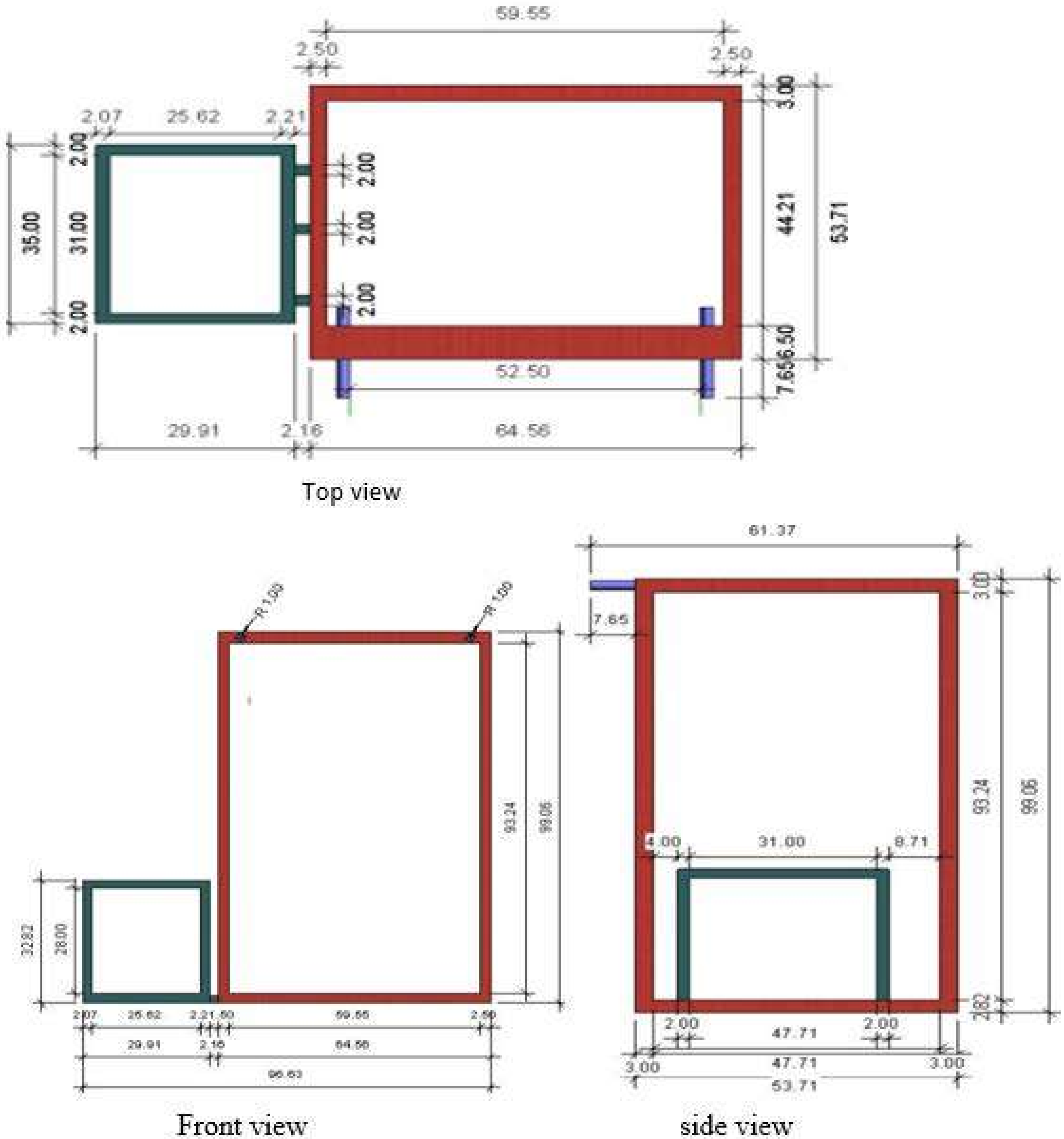


Figure 3.16. Detail view of frame

3.5.8. Bucket Design

Bucketwas 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 without any wastage.

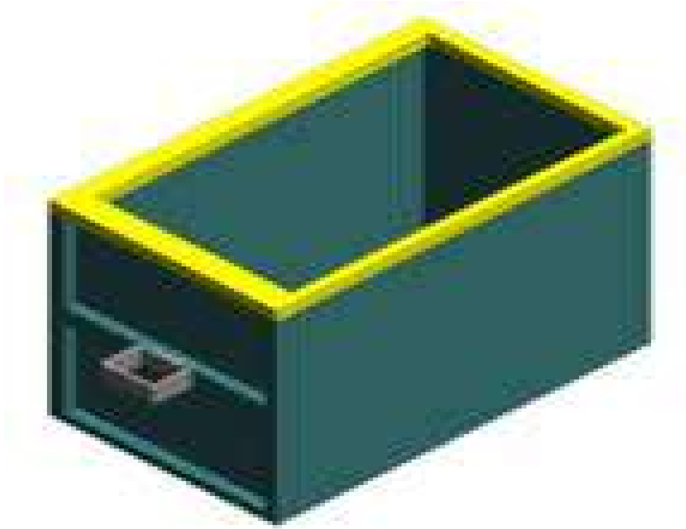


Figure 3.17. Bucket model

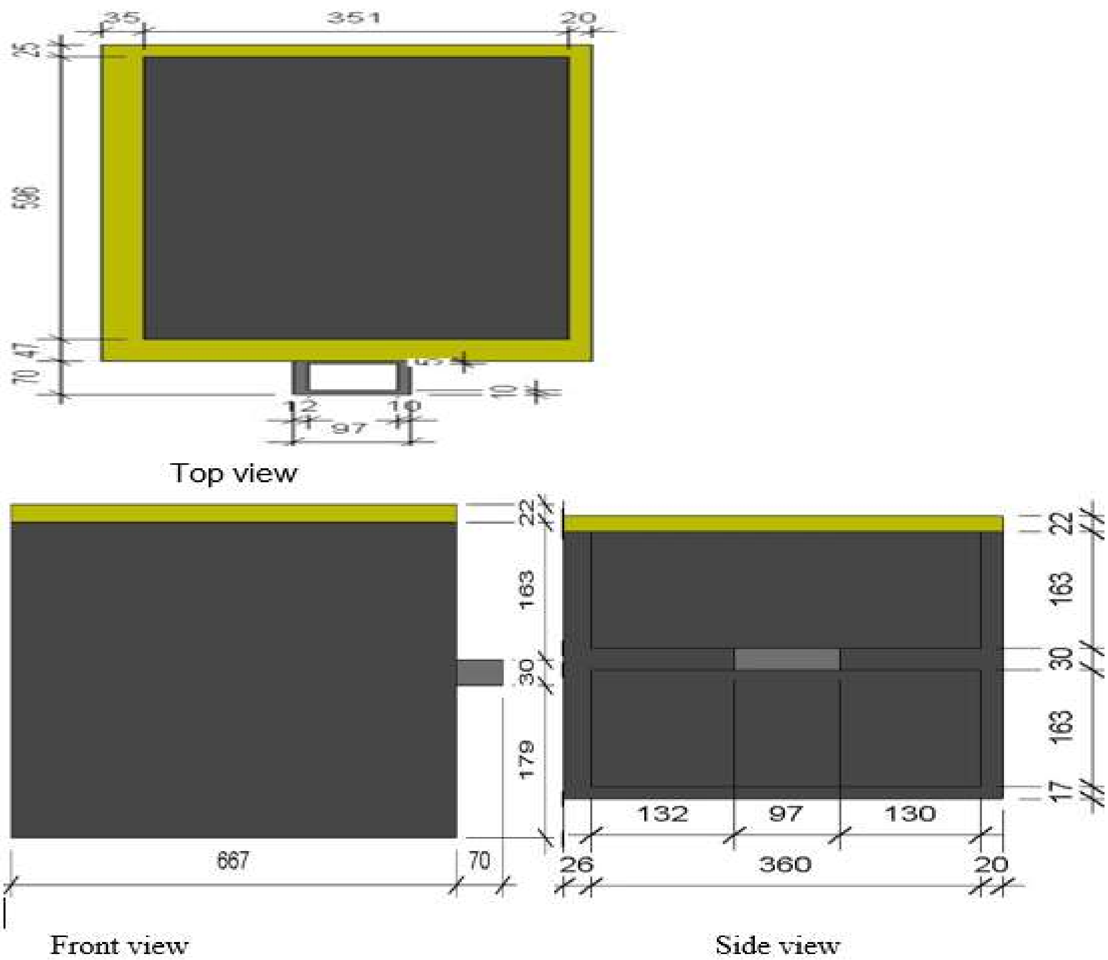


Figure 3.18. Detail drawing of bucket

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 internal three horse power diesel engine as the source ofpower because most of the areas where Enset grown do not have access toelectricity. The power required for decortications process was determined using Equation (3.12) (Kanogu, 2011).

$P_d = \frac{2\pi N2T}{60}$ ……………………………………………...……………………………3.12

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

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

= 1703.45 W reference equation 3.18

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.

3.5.9.1. Design of Pulleys

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).

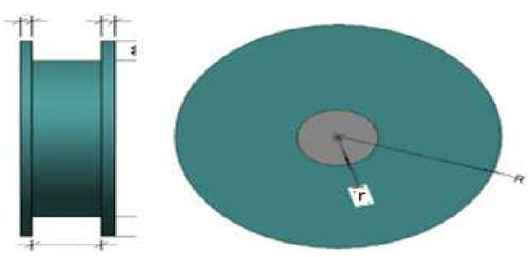
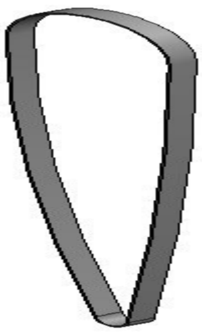


Figure 3.19.Pulley

3.5.9.2. Belt Design

It 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.



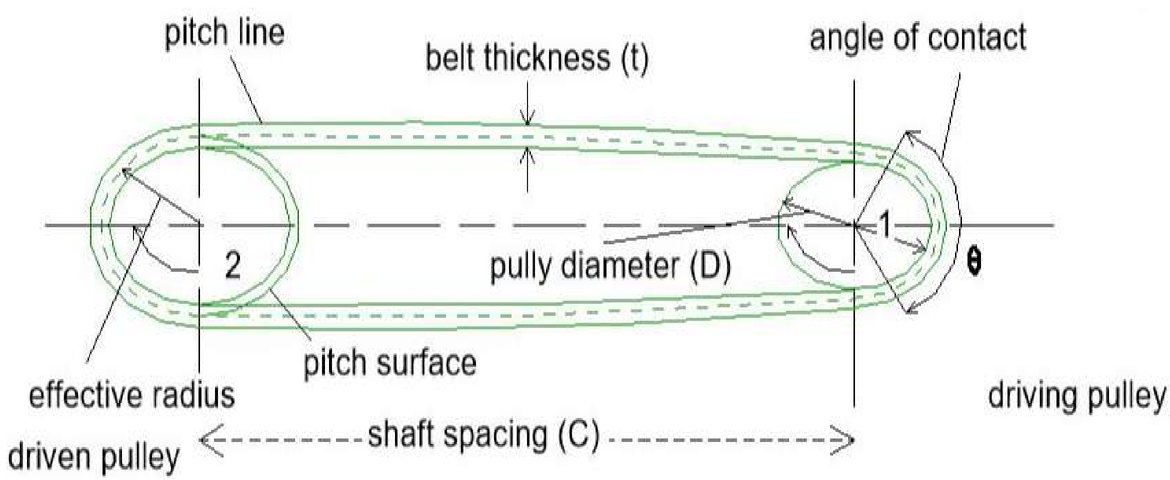


Figure 3.20.Belt design

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 (3.13) (Khurmi and Gupta, 2005).

$$L = 2C + \pi \frac{Pd1+Pd2}{2} \quad \ldots\ldots\ldots 3.13$$

Where. L = Length of belt

Pd_1 = pitch diameter of big pulley: = 100mm

Pd_2 = Pitch diameter of small pulley: =75 mm

C = Center distance between the pulleys: = 500mm, therefore the overall length of the belt was 1.3 m.

From the speed ratio of the drum shaft to motor shaft, the speed of the shaft was obtained by the following equation (3.14) (Khurmi and Gupta, 2005).

$N_1D_1 = N_2D_2$..3.14

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

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 (3.15) (Khurmi and Gupta, 2005).

$V = \frac{\pi D1N1}{60}$……………………………………………………...………………………………3.15

V = 5.5m/s

The tension force on the pulley must be calculated according to the following equations (3.16) (Khurmi and Gupta, 2005).

$F_{cf} = T_c = mv^2$……………………………………………………………………………......3.16

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

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

Therefore the value of the T_c was given by 3.69 x $(5.5m/s)^2$ = 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 (3.17) (Bashir et al., 2013).

$P_{in} = \frac{2\pi N1T}{60}$……………………………...…………………………………………………3.17

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 (3.18) (Bashir et al., 2013).

$P_d = \frac{2\pi N2T}{60}$ ………………………………………………...……………………………3.18

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

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

= 1703.45 W or 1703.45 kW.

And the linear speed (velocity) of drum was determined from the output power and total force required to drive the machine = 7.33 m/s

The belt efficiency to transmit power from the power source to drum rotating shaft was determined as the equation (3.19) (Bashir et al., 2013)

$\text{Efficiency} = \frac{\text{output power}}{\text{input power}}$ ……………………………………………………………..3.19

Efficiency = 76.12% therefore the belt can transmitted power effectively

The total driving force of the decorticator was determined by the equation as (3.20 and 3.21) (Khurmi and Gupta, 1984)**.**

$F = (T_1 - T_2)$………………………………………………………………………………3.20

$F = (3T_c - T_2)$…………………………………………………………………..………3.21

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 (3.22) (Bashir et al., 2013) below.

$P = Fv$ …………………………………………………………………………………………… 3.22

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

F = force required to drive

v = velocity of the belt

$$F = \frac{1703.45w}{7.33m/s} = 309.71 \text{ N}$$

$T_1 = 3T_C$ ……………………………………………………………………………………………. 3.23

$T_1 = 3(198.25) = 594.75$ 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 andbending 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. According to Theodre (1985) 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 (3.24) (Khurmi and Gupta, 2005).

$$d^3 = \frac{16}{Ss}\sqrt{(Kb.Mb)^2 + (Kt.Mt)^2} \quad \text{………………………………………………… 3.24}$$

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

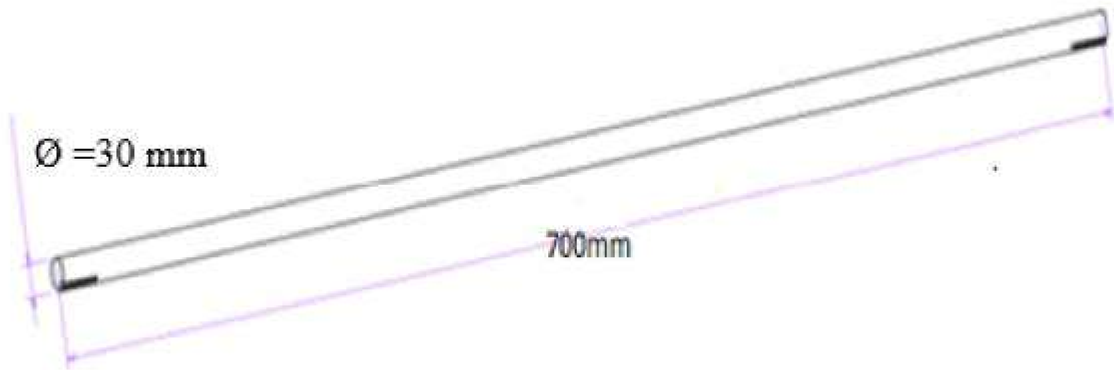


Figure 3.21. Shaft

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 (3.25) (Richard et.al, 2011).

$$Mb = \frac{\pi fb \times d^3}{32} \quad \text{……3.25}$$

Where. Mb = maximum bending moment (Nm)

Fb. = bending stress of shaft material

d = diameter of drum shaft

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

$$d^3 = \frac{16}{Ss}\sqrt{(Kb.Mb)^2 + (Kt.Mt)^2} \quad \text{…… 3.26}$$

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.

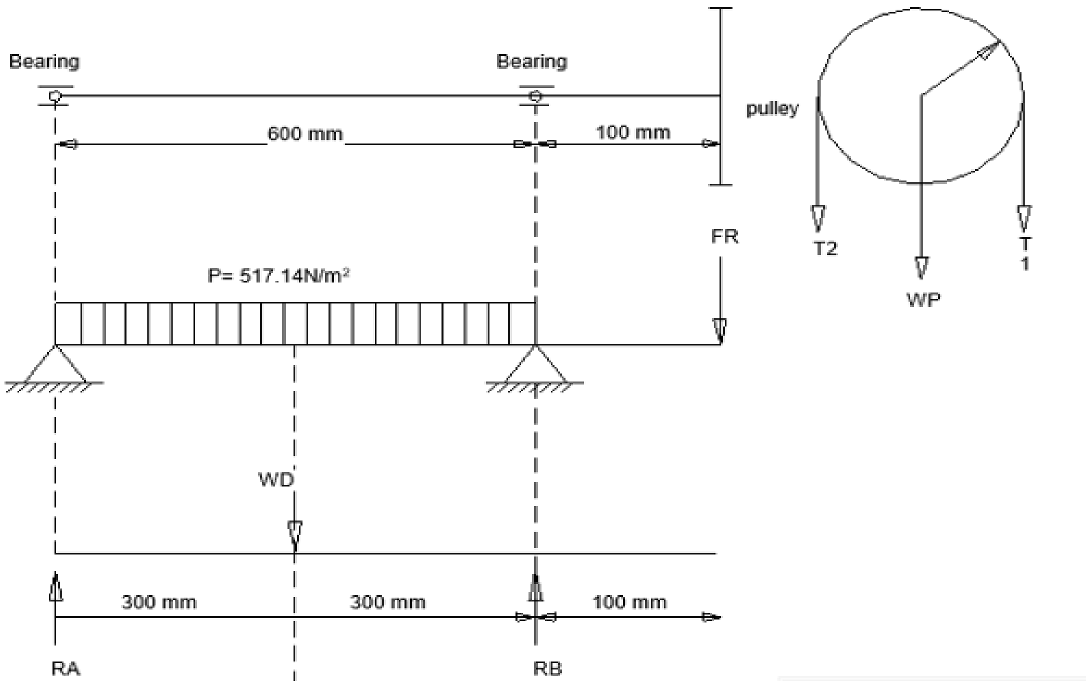


Figure 3.22. Vertical forces distribution on the shaft

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

$\Sigma MA = 0$ ……………………………………………………………………………….. 3.27

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

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

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

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

$R_A = 228\ N$

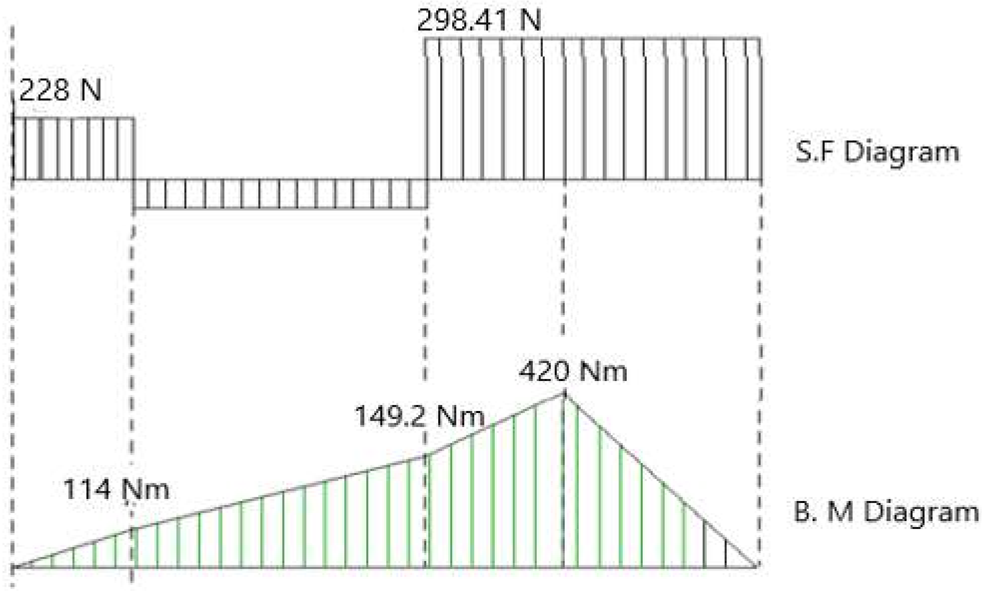


Figure 3.23. Shear force and bending moment diagram

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 smash the plant leave sheave in order to minimize the thickness (Kanogu et al., 2011).

Figure 3.24. 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 Design

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).

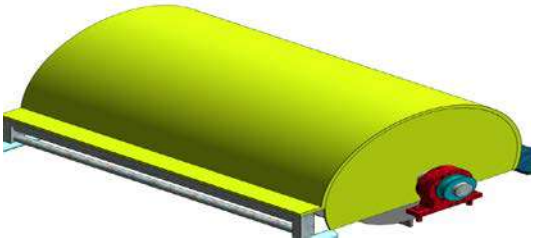


Figure 3.25. Drum cover

The same to other machine parts drum cover was also made from the 2mm thick mild steel with external radius of 160mm and internal radius of 156mm with the overall length of 500mm.

3.5.13. Bolts

Key parts in the design to be welded were: the main beater cylinder and shaft, the towing frame and the decorticator box. Parts that were bolted in place include the inclined plate, beater cylinder bearings, engine, beater blades, wheels and sheet metal protective cover. As previously designed, the cylinder blades were made removable by using M8×1.5 bolts and spring washers Property class of the bolt was 9.8 tensile strength of 900Mpa and yield stress of 720Mpa.

3.5.14. Bearings

Bearing is a device that is used to fix an axle in position in the wheel or gear. Generally, it allows for constrained relative motion between two or more parts, typically rotation or rotational motion. Essentially, a bearing can reduce friction by virtue of its shape, its material or by introducing a containing fluid between surfaces or by separating the surfaces by an electromagnetic field. Bearings vary greatly over the size and directions of forces that they support. Forces can predominantly be radial, axial, thrust bearings or forces perpendicular to the main axis. Different bearing types have different operating speeds. Generally, there is considerable speed range overlap between bearing types. Plain bearing, typically handle only lower speeds.

3.6. Fabrication of Three Horsepower Motor Driven Enset Decorticator

Cattie drawing (fig.3.24) was designed, fabricatedand the three horse power diesel engine motor driven Enset decorticator (3.25) 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 stainless steel 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.

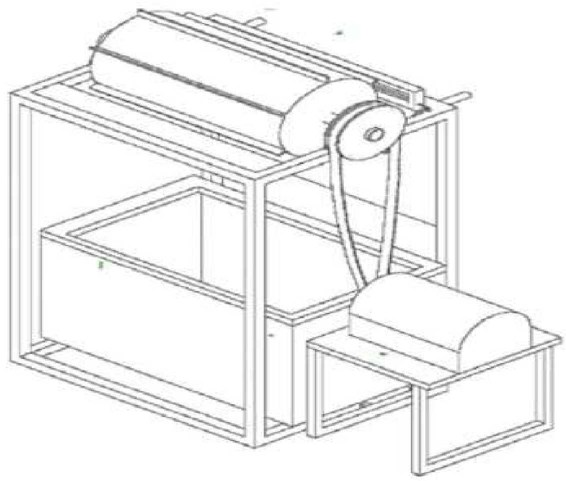


Figure 3.26.ModeledmachineFigure 3.27.Developed machine

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 with filter. Two pulleys one having 100mm diameter and other having 75mm 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 research, 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
6	No un-decorticated kocho (quality fiber)	14	2
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 sheave decorticator was tested in the laboratory (with ought 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. It was done to determine the uniform rotation of decorticator drum with blade, belt slip, correct power transmission from engine motor to drum shaft through belt and pulley. 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 sheave 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 sheave decorticating machine was evaluated at DITC.The Enset 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. The concave side of the leaf sheath was peeled and cut into pieces of about one meter length and split length wise in order to shorten the leaf sheath to a workable size.

Three different decorticating clearance were found out at different drum rotational speed. Rotation speed of cylinder shaft was selected for decorticating operation and feed rate uniformity. At each decorticating clearance three replications were taken. The decorticating of different variety of Enset was carried out in field.

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 (3.28) (Cantalino et al., 2015).

$Dc = \frac{W}{t}$ ………………………………………………………………………………..……3.28

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 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 3.28. Enset sheave product balance.

Note: Bulla was extracted from kocho after fermentation therefore assumption made her was the mass of kocho consist of the bulla and kocho itself. The output capacity or material capacity was determine using Equation (3.29) (Cantalino et al., 2015).

$O/P \text{ capacity} = \frac{W_k+W_f}{t}$ …………………………………………………………….....3.29

Where: O / P = output capacity

W_k = weight of decorticated kocho (bulla)

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 (3.30) (Snyder et al., 2006).

$\% \text{ Us} = \frac{wUs}{W} \times 100$……………………..…………………...………………………………3.30

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 (3.31)(Cantalino et al., 2015).

$$\eta = \frac{WK+Wf}{W} \times 100 \quad \text{......} 3.31$$

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 (3.32)(Cantalino et al., 2015).

$$\eta f = \frac{Wf}{Ft} \times 100 \quad \text{......} 3.32$$

Where.ηf = fiber cleaning efficiency

Wf = weight of clear (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 (3.33) (Naik et al. (2013).

$$\%\, Fb = \frac{Fb}{Ft} \times 100 \quad \text{......} 3.33$$

Where. Fb = broken or cut fiber.

Ft = total fiber (clean un-broken fiber + broke) 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 etal., 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.

$$D = \frac{C - S}{L \times H} \quad \text{......3.34}$$

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).

$$I = \frac{C \times S}{2} \times \frac{i}{H} \quad \text{...... 3.35}$$

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 etal., 2012).

RM = 2.5 % × purchase price or capital investment per year………………………………...3.36

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 (3.37) below.

Total Cost/hr. = Fixed Cost per hour + variable Cost per hour…………………………….... 3.37

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.

The general form of the empirical equation developed to relate decorticator performance at three different decorticating clearance and drum speed was represented by a general linear regression equation (3.39) (Narany and Varshnery,2006).

Y = mX + b…………………………………………………………………………...……. 3.38

Where.Y = dependent variable.

X = independent variable.

m= and b are constant

CHAPTER FOUR

RESULTS and DISCUSSION

The three horse power diesel engine motor driven Enset decorticator was designed and fabricated. In this section, Enset sheave engineering properties related to the design and fabrication of Enset sheave decorticator were studied. The performance evaluation of the designed motor 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 toscrape 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 and it was 45degree. The inclinedplate 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. 2mm 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 Sheave 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. The decorticator can be stoppedoff 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 Leaf Sheave

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, weightand decortication resistance were measured using the standard procedure. The shape of the Enset sheave of randomly selected Enset variety were concave (shape of pseudostem). Which is similar result with the shape of banana sheave (Mohsenin, 1970). 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. andit 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 male than female. During decortication the male Enset sheave needs more power and take long time than female.

Table 4.1.Local variety of Enset and decorticating resistance

Ro.no	Male enset variety	Decortication resistance	Female enset variety	Decortication resistance
1	Geshera	Higher	Ungame	Lower
2	Sisikela	Higher	Tebare	Lower
3	Dirbo	Higher	Moche	Lower
4	Abatmerza	Higher	Sheleke	Lower
5	Gembewa	Higher	Sebere	Lower
6	Dego	Higher	Etene	Lower

From the above table 4.1 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 (Rao K, 2007). According to Rao K. (2007), 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 they conclude that the male Enset variety can resist decortication than female Enset variety.

4.4. Performance Evaluation of Enset Sheave 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 TestResult

Table 4.2. Specifications sheet for enset decorticator

Particulars	Specifications
Type of machine	Diesel engine motor driven Enset decorticator.

Overall dimension of machine	Length = 1500mm, Width = 100mm
	Overall height of machine = 1400mm
	Working height of machine 1200mm
Decorticating drum	Circular hollow stainless with diameter 300mm, length 500 mm
Overall width of blade	L = 500mm, w = 12mm and t = 1mm
Power transmission system	Belt – pulley system
	100 mm on main shaft (Cast Iron)
Pulley	75mm mm on engine shaft (Cast Iron)
V belt	Average length of V belt 1300 mm
Number of blades	8
Rotation speed of drum	Average 1050rpm rpm
Linear velocity of blades	5.5m/s
Weight of machine	49.85 kg
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 two persons, Mr.meskelo and Mr. Deneke were operating the machine and the results indicated that

- The machine was most stable.
- The bearings were not getting heated
- 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 are 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 Enset sheave decorticator performance was studied with different drum speed, and varying decortication clearance between the inclined plate and blade tip. For a specific decortication clearance, three replications were taken on drum speed of 650 rpm, 850rpm and 1050 rpm to study the machine performance. Result obtained from the short duration test of Enset decorticator in different decorticating clearance and three decorticating drum speed was reported in table 4.1, 4.2 and 4.3 in appendix C. The all directly observed data was difficult to report because of its bulkiness. To show how the data was observed when the machine was operating was reported in table 4.4 and appendix C for the decorticating clearance of 2 mm and decorticating drum speed of 1050 rpm.

The machine was operated at drum rotation 650 rpm, 850 rpm and 1050 rpm 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 of kocho and fiber was shown in the tables and figures below.

Table 4.3. Decorticating efficiency based on drum speed and decorticating clearance

Speed	Average value in different Clearance		
	≤ 2 mm	≥ 2 mm	At 2 mm
650	81	72.67	86.5
850	84.5	78.3	89.5
1050	89	86	93.12
Mean	84.8	78.99	89.5
SD	1.54	0.81	1.73

Machine efficiency increased with the increase in drum speed as shown in Table 4.3.The test result showed that the mean values of decorticating efficiency varied from 81 % to 89 % at < 2 mm decorticating clearance. In the same way the mean value of decorticating efficiency varied from 72.67 % to 86 % and from 86.5 % to 93.12 % at > 2 mm and 2 mm decorticating Clearances respectively. Additionally, it was noticed that the increased in drum speeds increased the decorticating efficiency of the Enset sheave decorticator with maximum mean values were at 1050 rpm for all decorticating clearances. Kawongolo, et al. (2002) stated that decorticating efficiency of sisal leaf increased as drum speed increased.

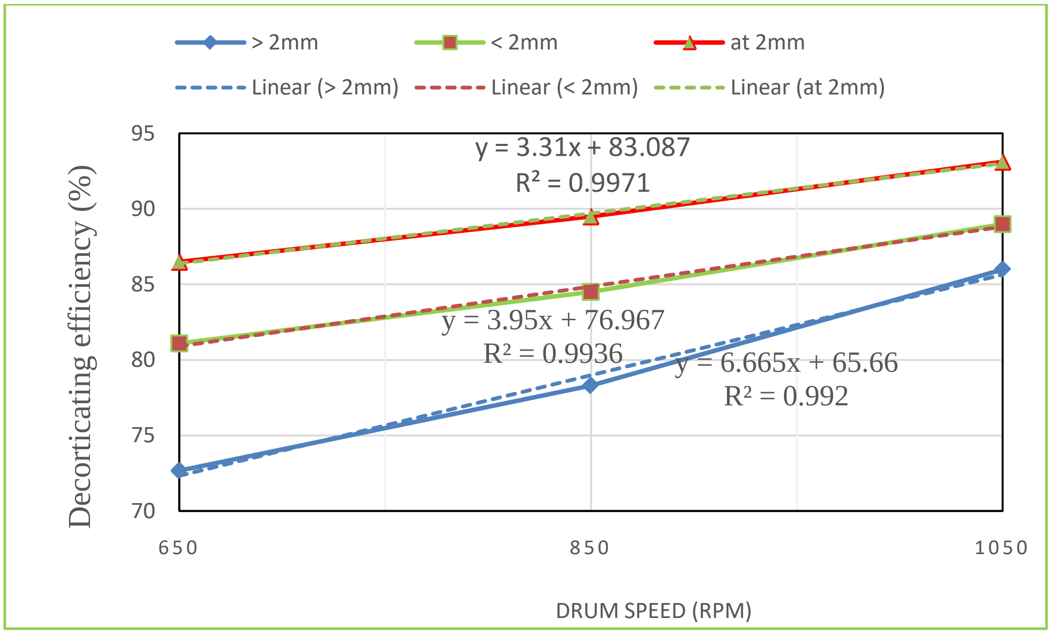


Figure 4.1. Average decorticating efficiency versus drum speeds at different clearance

The positive correlation between decorticating efficiency at different decorticating clearance and drum speed was shown in Fig. 4.1. The data obtained from the tested were analyzed and first-degree polynomial regression shown strong correlation between decorticating efficiency and drum speed in all trials, with a high coefficient of determination (R^2= 0.992, R^2 = 0.9936 and R^2= 0. 9971) were observed with> 2mm, < 2mm and at 2 mm respectively.Linear regression indicated that the Enset decorticating machine efficiency increases with increasing drum speed in different decorticating clearance.

4.4. Machine output capacity per hour based on drum speed and decorticating clearance

Speed	Average value in different Clearance		
	$\leq$ 2 mm	$\geq$ 2 mm	At 2 mm
650	44.64	42.97	51.9
850	46.69	43.5	53.93
1050	53.05	45.46	57.2
Mean	48.13	43.98	54.48
SD	4.65	1.25	1.25

The test result shown 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 at 2mm decorticating clearances respectively. Additionally, 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.

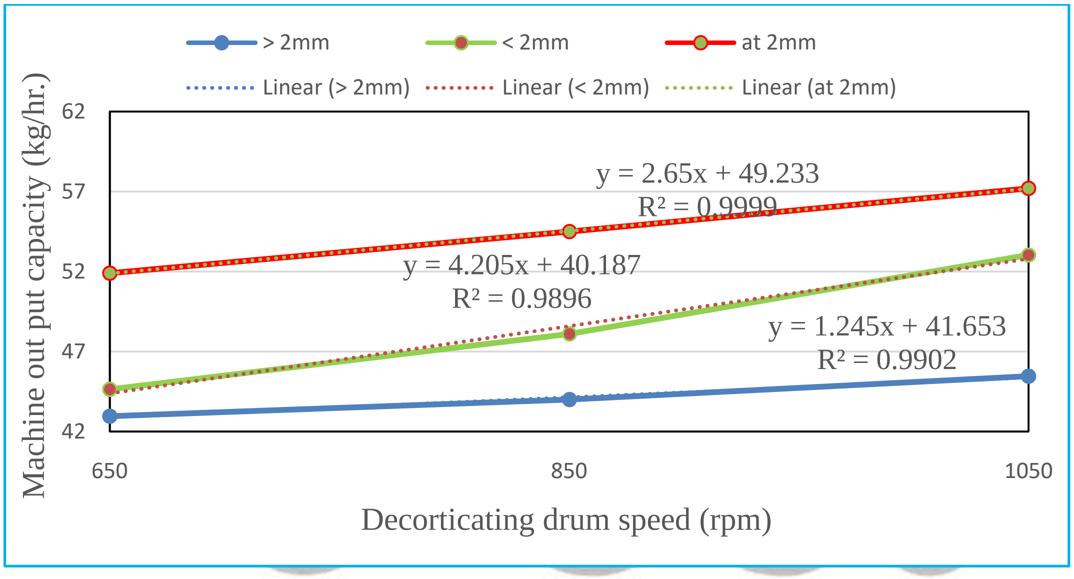


Figure 4.2. Average decorticating capacity versus drum speeds at different clearance

The positive correlation between decorticator output capacity at different decorticating clearance and drum speed was showed in Fig. 4.2. The data obtained from the testing were analyzed and first-degree polynomial regression shown strong correlation between decorticator output capacity and drum speed in all trials, with a high coefficient of determination (R^2 = 0.9902, R^2 = 0.9896 and R^2= 0. 9999) were observed with> 2mm, < 2mm and at 2 mm respectively.

Table 4.5. Feed rate per hour based on drum speed and decorticating clearance

Speed	Average value in different Clearance		
	$\leq$ 2 mm	$\geq$ 2 mm	At 2 mm
650	54.48	54.43	53.6
850	55.69	56.17	57.17
1050	57.46	56.85	62.12
Mean	56.54	56.67	56.74

SD	2.59	2.53	2.95

The test result showed that the mean values of feed rate varied from 54.43 kg/hr. to 56.85 kg/hr. at >2 mm decorticating clearance. In the same way the mean value of decorticator feed rate varied from 54.48 kg/hr. to 57.46 kg/hr. and from 53.6 kg/hr.to 62.12 kg/hr. at <2 mm and at 2mm decorticating clearances respectively. Additionally, it was noticed that the increased in drum speeds increased the feed rate of Enset sheave decorticator with maximum mean values were at 1050 rpm for all concave clearances.

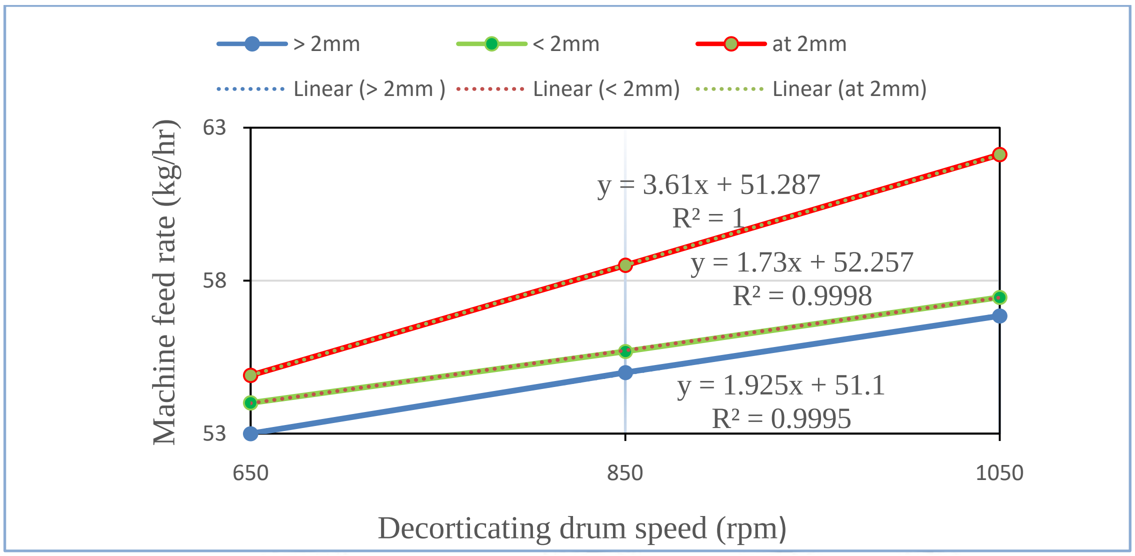


Figure 4.3. Average decorticating capacity versus drum speeds at different clearance

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 first-degree polynomial regression shows strong correlation between feed rate and drum speed in all trials, with a high coefficient of determination (R^2 = 0.9995, R^2 = 0.9998 and R^2= 1) were observed with> 2mm, < 2mm and at 2 mm respectively.

Table 4.6. Un-decorticate sheave (%) based on drum speed and decorticating clearance

Speed	Average value in different Clearance		
	≤ 2 mm	≥ 2 mm	At 2 mm
650	0.45	21.27	1.95
850	0.35	20.57	1.83
1050	0.47	21.52	1.99
Mean	0.42	21.12	1.92
SD	0.17	0.49	0.08

It was observed that the mean values of un-decorticated sheave (partially decorticated sheave) was 0.45%, 0.35%, and 0.47% at < 2 mm decorticating clearance. In the same way the mean values of partial decorticated sheave varied from 21.27 %, 20.57%, and 21.52% and from 1.95%, 1.83% and 1.99% at > 2mm and 2 mm decorticating clearances respectively. Here it can be noticed that drum speed is not basic factor of the partial decortication in all concave clearances

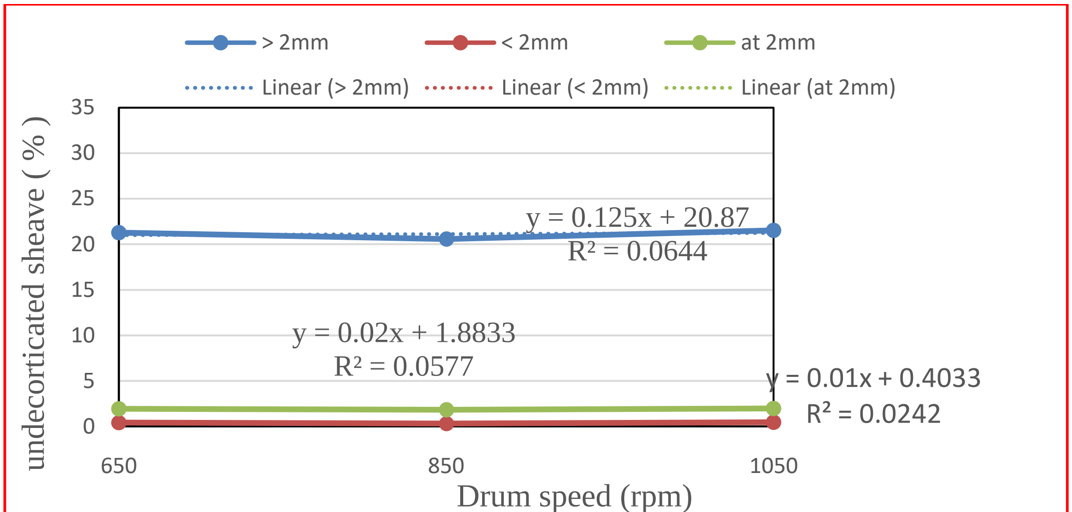


Figure 4.4. Average un-decorticated sheave versus drum speeds at different clearance

The data showed in Fig.4.4not good correlation between un-decorticated sheave and drum speed in all trials, with a low coefficient of determination (R^2 = 0.0242, R^2 = 0.0577 and R^2= 0. 0644) were observed with> 2mm, < 2mm and at 2 mm respectively.Linear regression indicated that the partial decorticating Enset sheave based on the decorticating clearance and at clearance of > 2mm was highest un-decorticated sheave occurs.

Table 4.7. Fibber breakage (%) based on drum speed and decorticating clearance

Speed	Average value in different Clearance		
	≤ 2 mm	≥ 2 mm	At 2 mm
650	47.77	7.97	9.57
850	48.97	9.2	10.33
1050	50.32	9.95	10.57
Mean	49.02	9.04	10.16
SD	1.28	1.00	0.52

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Fiber breakage increases with increase in drum speed as shown in Table 4.7.The test result showed that the mean values of fiber breakage varied from 47.77 % to 50.32% at < 2 mm decorticating clearance. In the same way the mean value of fiber breakagevaried from 7.97 % to 9.95% and from 9.57 % to 10.57 % 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.

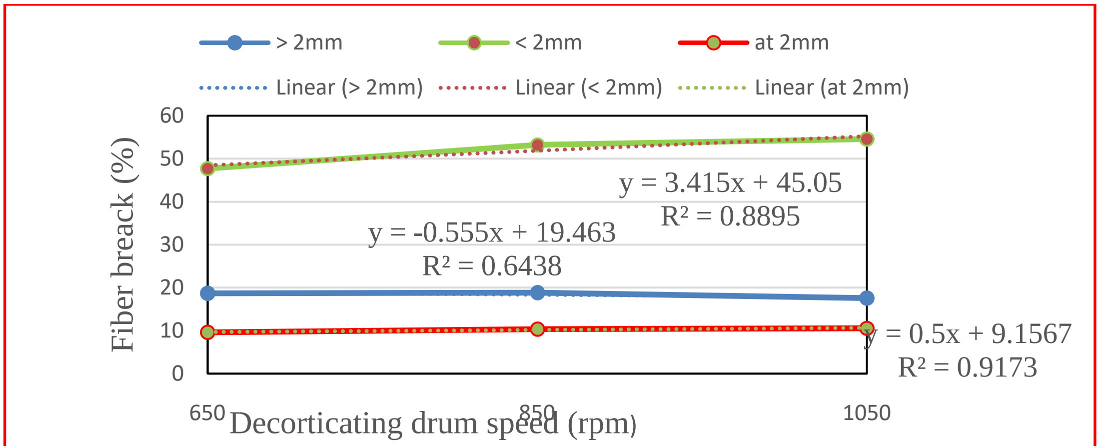

Figure 4.5. Average fiber break versus drum speeds at different clearance

The data showed in Fig.4.5not good correlation between fiber break and drum speed in trial, with a low coefficient of determination (R^2 = 0.057) was observed with> 2mm, and good correlation between fiber break and drum speed with a high coefficient of determination(R^2 = 0.9988 and R^2= 0. 9173) were observed with < 2mm and at 2 mm respectively. From Linear regression, the fiber breaking (cut) was high at clearance of < 2mm.

Some fibres were also broken due to force of scraper on leaves and due to narrow gap between the inclined plate and rotating blades. Naik et al. (2013) reported fibre losses up to 10 % in drum or raspador decorticators. In this study, the fibre loss was about 10.57 % at recommended decortication clearance.

Table 4.8. Fibber cleaning efficiency (%) based on drum speed and decorticating clearance

Speed	Average value in different Clearance		
	$\leq$ 2 mm	$\geq$ 2 mm	At 2 mm
650	79	18.67	77.27
850	80.12	18.83	77.28
1050	80.5	17.56	78.37

Mean	79.8	18.35	77.64
SD	0.78	0.69	0.56

It was observed that the mean values of fiber cleaning efficiency of Enset sheave decorticator was 53.27%, 53.27% and 54.6% at < 2 mm decorticating clearance. In the same way the mean values of fiber cleaning efficiency of Enset sheave decorticator varied from 18.67 %, 18.83% and 17.56% and from 77.67%, 77.27% and 78.37% at > 2mm and 2 mm decorticating clearances respectively.

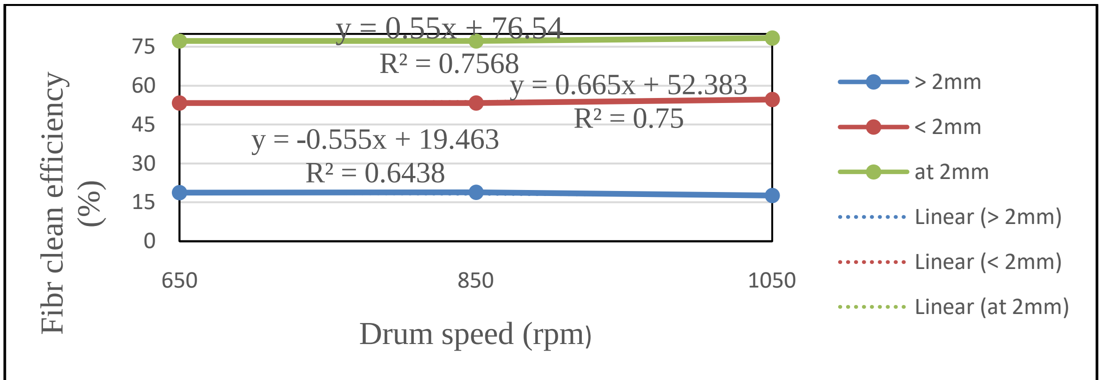

Figure 4.6. Average fiber cleaning efficiency versus drum speeds at different clearance

The data showed in Fig.4.8 not good correlation between fiber cleaning efficiency and drum speed in all trials, with a low coefficient of determination (R^2 = 0.75, R^2 = 0.6438 and R^2= 0.7568) were observed with < 2mm, > 2mm and at 2 mm respectively.it tells us the fiber cleaning efficiency of Enset sheave decorticator did not affected by drum speed but highly affected by decorticating gap (clearance). Here it can be noticed that drum speed is not basic factor of the cleaning fiber efficiently in all concave clearances.

Weight lost during decorticated of Enset sheath in different decorticating clearance and different decorticating drum speed was determined as 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 was 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 (Kawongolo, et al. 2002) the fiber producing machines in Kenya are recommended at decorticating gap of 2mm with drum speed of 1500 rpm is more effective.

4.5. Performance Analysis of decorticator with Traditional Decortication.

Table 4.9. Major strengths and weakness of traditional enset processing

Sr.No.	Particulars	No. of respondent		Percentage	
	Total number of questioners (N = 16)	Yes	No	Yes	No
1	Unhygienic	12	3	75	25
2	Time and energy consuming	14	2	87.5	12.5
3	Increased household income (productivity)	6	9	37.5	62.5
4	Locally available	15	1	93.75	6.27
5	Decortication is gender requirement	13	3	81.25	18.75
6	Fiber clearing efficiency.	14	2	87.5	12.5
7	Fiber breakage	6	9	37.5	62.5

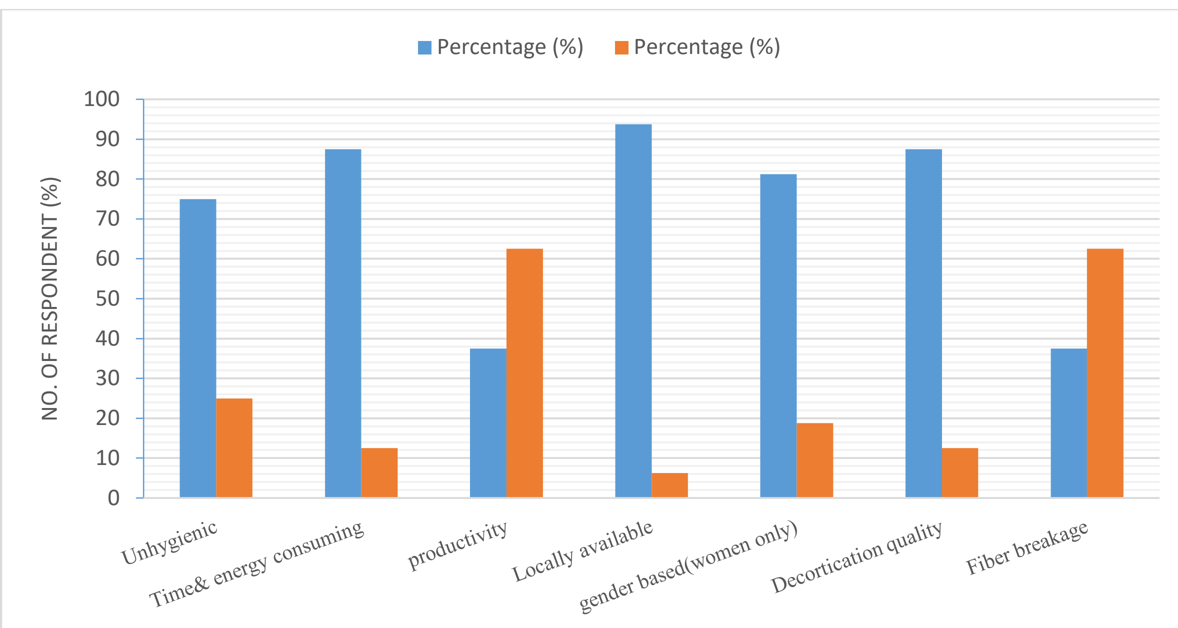

Figure 4.7. Analysis of major strengths and weakness of traditional enset processing

With regard to the traditional method major difficulties were: - It 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 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 technology was expected to perform decorticating activity more efficient and effective, hygienic, productive, improve product quality, save time, reduce labor, (save energy consumption), 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

SUMMARY,CONCLUSION and RECOMMENDATION

5.1. Summary

This work was conducted to design and development of a diesel engine motor driven Enset sheave decorticator for decorticating operation suitable for farmers and to evaluate its performance. The machine was powered by three horsepower diesel engine motor. Decorticating drum was cylindrical shaped device with stainless steel blades attached at a to-be-determined distance apart from each other around the cylinder.

Each of the blades should be approximately equal in length and equal spaced between the blades. One designed of drum had been described mainly as a strong stainless steel rolled of

300mm in diameter. The drum was fastened onto a horizontal shaft which was mounted on the bearings that were in turn fixed onto a firm base.

The capacity of bucket was 30kg for temporary storage and filter used to separate bulla from kocho. The feeding mechanism of the rotating decorticator blades, fitted on circumference of the drum was, gets the drive power from engine motor. The 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. The already rotating decorticator blades then come into contacted with the leaves thus stripped the soft part of sheave against the inclined plate and pulled through to the collection bucket. An adjustable inclined plate of about 500 mm long and 50 mm width and 5mm thick was attached to the framework about 800 mm from the ground. The distance between the breast plate and the blade was regulated so as to give clean decortication without undue strain on the fibers. In Ethiopia the existed traditional decorticating technique was done totally by women in most ethnic groups and the process was laborious, boring, unhygienic and less productive.

The present investigation was carried out with the following objectives.

- Identified the physical properties of Enset sheave and fiber related to Enset decorticator.
- Designed and manufactured component parts of Enset decorticator.
- Assembled and conducted performance evaluation of the Enset sheave decorticator in laboratory and on field test.
- Compared the performance of decorticator with existed traditional decorticating methods.

Motor driven Enset sheave decorticator has the following benefit:

- Enset sheave decorticator was a low cost machine, which can be afforded by small and marginal farmer.
- The maintenance of Enset sheave decorticator was easy.
- Enset sheave decorticating machine can easily be manufactured by local material.
- Enset sheave decorticating machine can be operated even by unskilled operator.
- Reduces human drudgery, un-hygienic, increase productivity and reduce labor requirement compared to traditional decorticating system.

The physical properties of Enset with parameters of different varieties of Enset which prevalent some common variety in the country were selected. The mean length (L), width (w), thickness (T), size (S), shapes and decorticating resistance was studied.

These properties were considered and accordingly a motor drive Enset sheave decorticator was developed. The developed accordingly a motor drive Enset sheave decorticator was consisting of drum, blade, inclined plate, decorticating gap adjusting device or screw, frame, double rollers, bucket, and others elementary component. Blade was sharp enough to scrape 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 Ɵ and it was determined by protractor.

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 collection bucket.

The decortication clearance or pitch distance could be varied above 2mm or below 2mm depending on the diameter of the Enset fiber. Data gathered from informal communication from research experts, the average diameter of the false banana fiber was less than 2mm but determining exact value is difficult. The decorticating gap adjusting device was used to increase or decrease the pitch distance in order to control fiber breakage or cut.

The power transmission system consist of pulley and belt drive mechanism to efficiently transmit power. The developed motor drive 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, the bearings were not getting heated, and the machine was easy to start, operate and stop at load. The field test conducted at decorticating clearance of < 2mm at 2 mm and >2mm with three drum speed 650 rpm, 850 rpm and 1050 rpm and analyzed by Microsoft excel. The result obtained shown better decorticating performance of machine at each decorticating clearance with three decorticating drum speed but at 2mm decorticating clearance with 1050 rpm gave best operation result than others.

5.2. Conclusion

The following conclusions are made from the study of developed motor drive enset sheave decorticator.

- Motor drive Enset sheave decorticator works betterefficiency in the field with required feed rate and output capacity with minimum damage to fibre.
- The operating belt speed of drum of 5.5m/s. Therefore there was suitable for decorticating without belt slip.
- The preliminary test conducted at decorticating gap of < 2mm at 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.
- The average decorticating, capacity of machine was 57.63 kg/hr., the machine output capacity was 54.48 kg/hr. of kocho and fibre per hour, 10.16 % broken fiber and 1.92% un decorticated kocho (un-cleaned fiber), machine decorticating efficiency of 89.5% with fiber cleaning efficiency of 77.64% and total weight lost 0.83kg.
- 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.
- Researchers at Ethiopian jimma agricultural mechanization research canter and Melkassa Agricultural Research canter, try to develop the clamping mechanism Enset decorticating machine. However, the performance of this machine was not analyzed and thoroughly compared with other machines, which is the limitation of this study.

5.3. 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 is possible to redesign for Enset sheave and amichodecortication purpose.

- The machine may be tested for similar crop (banana plant) and feedback received may be used for further design requirement.
- Bulla squeezing machine existed was not efficient in wanted level. Therefore it is pebble to redesign the developed machine for bulla squeezing purpose.
- The developed machine can be used for banana fiber extraction.

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APPENDICES

Appendix A

A. Physical properties of enset sheave Sample and same calculations.

1. Size (mm) = $\sqrt[3]{\text{length} \times \text{width x thickness}}$

$\sqrt[3]{2.5\text{m x}0.35\text{m x }0.03\text{m}}$ = 300 mm

2. Size (mm) = $\sqrt[3]{\text{length} \times \text{width x thickness}}$

$\sqrt[3]{2.3\text{m x}0.28\text{m x }0.028\text{m}}$ = 262 mm

3. Size (mm) = $\sqrt[3]{\text{length} \times \text{width x thickness}}$

$\sqrt[3]{1.8\text{m x}0.32\text{m x }0.025\text{m}}$ = 243.3 mm and average size was 268.4 mm

B**. Determination decortications resistance**by pressing the blade tip on the decorticating ensetsheave and reading how much time taken to cut in minute wasby using stop watch as shown below.

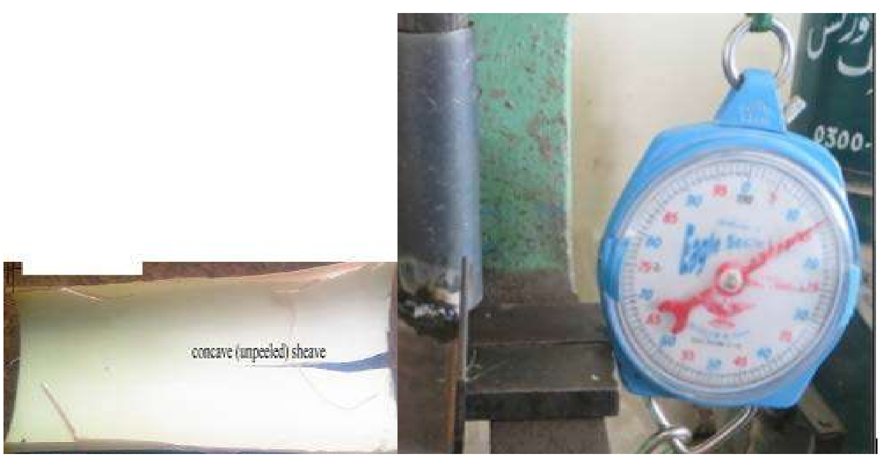


Figure 1. Decortication resistance determination

Appendix B

1. Sample Calculation for decorticating capacity for decortication gap of at 2 mm and for first test($R_{1)}$ and total tame taken was 30 minute.

$$\text{Deco capacity} = \frac{\text{weight of enset sheave fed in to the blade}}{\text{time requared for decortication}}$$

Deco capacity $= \frac{30\text{ kg}}{30}$ X 60 = 60 kg/hr

2. Machine Output Capacity: $\text{O /P capacity} = \frac{\text{Weight of kocho +Weight of fiber}}{\text{total time in minut}}$

$\text{O /P capacity} = \frac{22.41\text{kg} + 5.5\text{ kg}}{30}$ X 60 = 56 kg/hr

3. Percent Un-decorticate Sheave

$\% \text{ US} = \frac{\text{WUS}}{\text{W}}$ X 100, $\% \text{ US} = \frac{0.54\text{ kg}}{30\text{ kg}}$ x 100 = 1.8%

Decorticating Efficiency

$\eta = \frac{WK+Wf}{W}$ X 100, $\eta = \frac{22.41\ kg+5\ kg}{30\ kg}$ x 100 = 93.3%

Percentage of broken (Cut) fibre

$$\%\text{ Fb} = \frac{broken\ or\ cut\ fiber}{Total\ fiber\ obained}\ x100$$

$\%\text{ Fb} = \frac{0.55\ kg}{0.55kg+5kg}\ x100$ = 9.9%

4. Labor Requirement

Labor requirement in man hours/ 100kg of kocho and fibre = $\frac{number\ \ of\ \ labor}{Output\ \ capacity\ \ (\frac{kg}{hr})}$x 100,

$= \frac{2}{56\ kg/hr}$x 100, = 3.57 man hour/quintal of kocho, bulla and fiber.

Appendix C

Table. C1. 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	0.43	46	79	0.82
	81	39.33	50.66	0.46	47.3	80	0.89
	82	43.2	57.67	0.45	50	78	0.79
Aver	**81**	**44.64**	**54**	**0.45**	**47.77**	**79**	**0.83**
850	83.46	45.3	54.25	0.44	47.9	81	0.83
	86.37	44.9	53.32	0.46	48.9	79.5	0.91
	90.13	46.88	59.51	0.48	50.1	80.2	0.76
Aver	**84.5**	**46.69**	**55.69**	**0.35**	**48.97**	**80.12**	**0.83**
1050	88.47	52.14	58.06	0.47	49.52	76	0.82
	90.23	50.94	56.25	0.45	48.64	83	0.9
	89.66	56.07	62.06	0.5	52.8	82.6	0.77
Aver	**89**	**53.05**	**57.46**	**0.47**	**50.32**	**80.5**	**0.83**

Table. C2.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	22	8.4	24	0.65
	72.5	41.9	54.6	21	7.5	15	0.8
	74	46	53	20.8	8	17	0.79
Aver	**72.67**	**42.97**	**53**	**21.27**	**7.97**	**18.67**	**0.75**
850	72	45	54	19.9	7.8	20.1	0.86
	78.3	42.1	54.8	21	9.6	19.4	0.67
	75.9	44	59.7	20.8	10.2	17	0.7
Aver	**74**	**43.5**	**55**	**20.57**	**9.2**	**18.83**	**0.74**

1050	78.3	44.06	56.25	22.23	6.25	18.11	0.64
	75	42.1	58.06	20.67	14.8	16.93	0.88
	75.1	42.26	56.25	21.67	8.8	17.65	0.79
Aver	**86**	**43.47**	**56.85**	**21.52**	**9.95**	**17.56**	**0.77**

Table. C3.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	1.97	9	74	0.75
	86.5	52	51	1.88	8.7	80	0.78
	88	53.8	55	2	11	79	0.88
aver	**86.5**	**51.9**	**53.6**	**1.95**	**9.57**	**77.27**	**0.80**
850	89	55	57.2	1.8	9	77	0.8
	87.3	54	56.3	1.9	12	75	0.91
	90.1	52.8	58	1.78	10	79.8	0.9
aver	**89.5**	**53.93**	**57.17**	**1.83**	**10.33**	**77.28**	**0,87**
1050	93.3	57.96	64.3	1.8	9.9	73.8	0.91
	93.3	56	60	2	11.43	80.8	0.95
	92.87	57.64	62.07	2.17	10.39	80.5	0.83
aver	**93.12**	**57.2**	**62.12**	**1.99**	**10.57**	**78.37**	**0.81**

Table. C4.Observations of short duration tests of Decorticator gap at 2mm for 1050 rpm

Sr. No.	Particulars	R1	R2	R3
1	Date of test	28/06/2018	29/06/2018	30/06/2018
2	Place of test	DITC	DITC	DITC
3	Duration of test (min)	28	30	29

4	Variety of enset	local	Local	Local
5	Weight of enset sheave (kg)	30	30	30
6	Weight of decorticated kocho (kg)	23	22.5	22.41
7	Weight of cleaned un broken fibre (kg)	4.05	5.5	5.45
8	Weight of broken(cut) fiber (kg)	0.95	0.71	0.67
9	Weight of un-decorticated kocho	0.54	0.6	0.65
10	Weight lost by different means	0.91	0.89	0.82

Appendix D

Production and Operational Cost of the decorticator.

Table. D.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 E

Table: E.1. 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. E.2. 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. E.3. **Calculation** of cost of operation of decorticator per hour

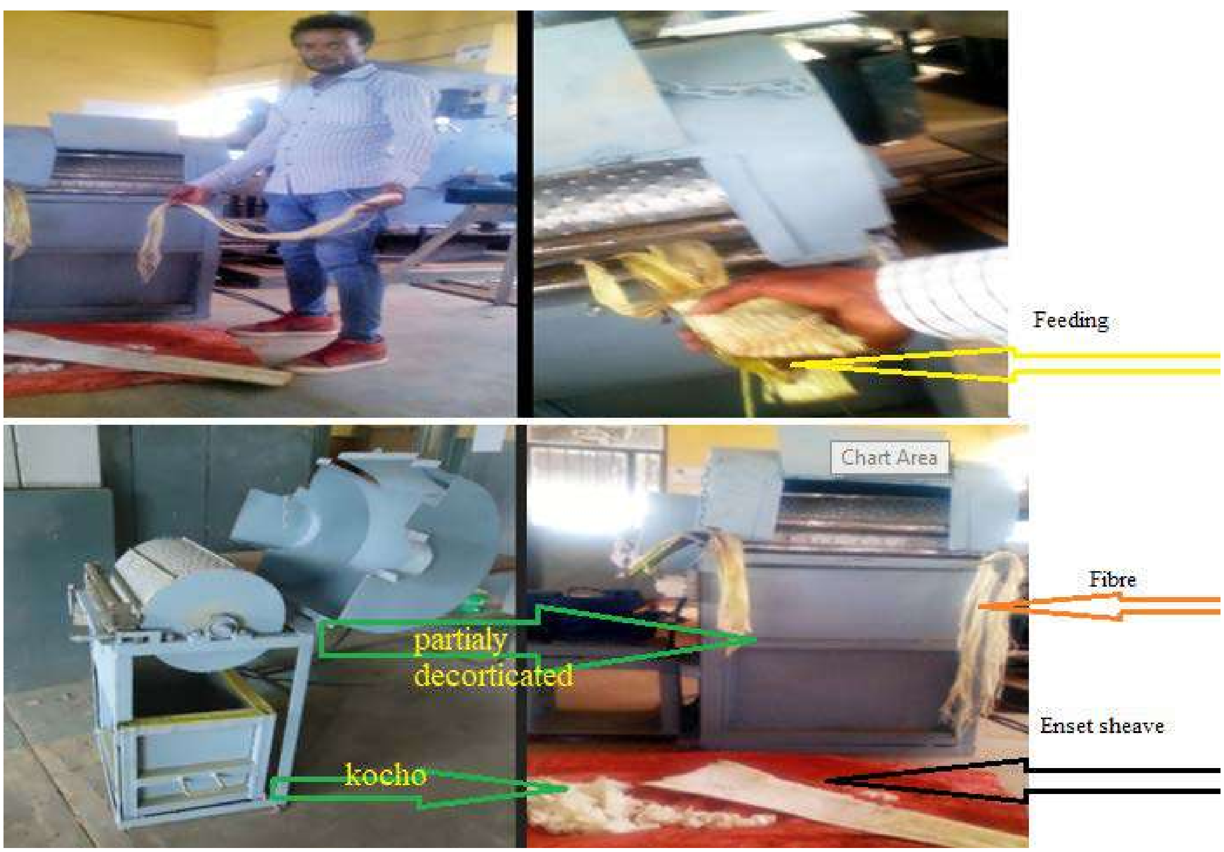
Cost of machine (c)	23,519.36 ETB
Assumption	
Life of machine (L), years	10
Annual working hours (H), hr.	1200
Salvage Value (S)	10% of capital cost
Interest rate	10 % percent per annum
Fuel cost	1 litre = 15 birr, used 1 litre for testing
Wage per day of 8hr	50 birr
A. Fixed cost	
Depreciation (D) , ETB/hr.	$D = \frac{C - S}{L \times H}$
	$\frac{23519.36\ \text{ETB} - 2351.936\ \text{ETB}}{10\ \text{year} \times 1200\ \text{hr/year}}$ 17.63 ETB/hr.
Interest	$\frac{C+S}{2} \times \frac{i}{H} \frac{23519.36\ \text{ETB} + 2351.936\ \text{ETB}}{2} \times \frac{\frac{0.1}{\text{year}}}{1000\frac{\text{hr}}{\text{year}}}$,
	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 litre 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 sheave decorticator is42.24 ETB/hr.

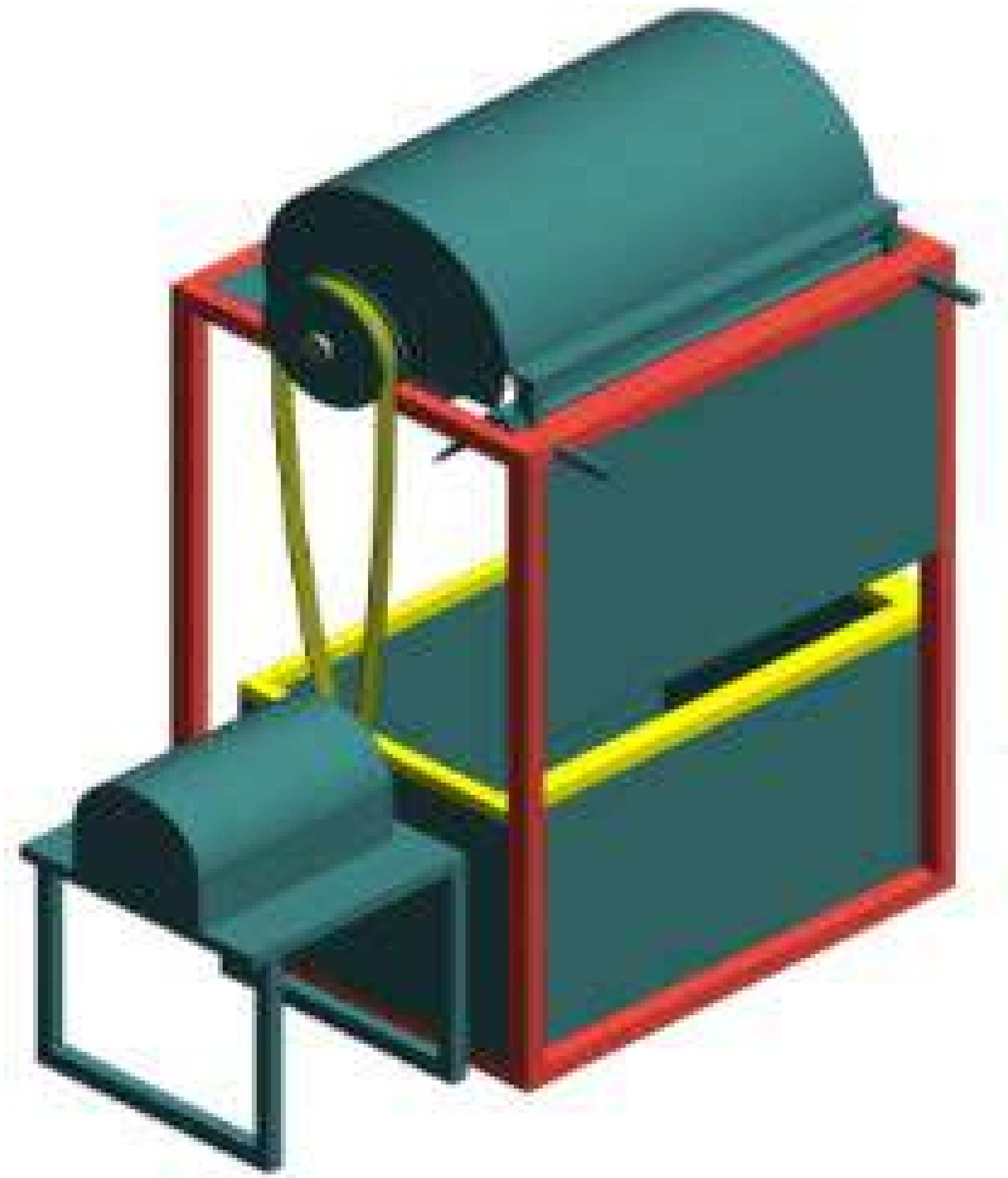
Appendix F

Photographic view of Enset decorticator and decorticated results

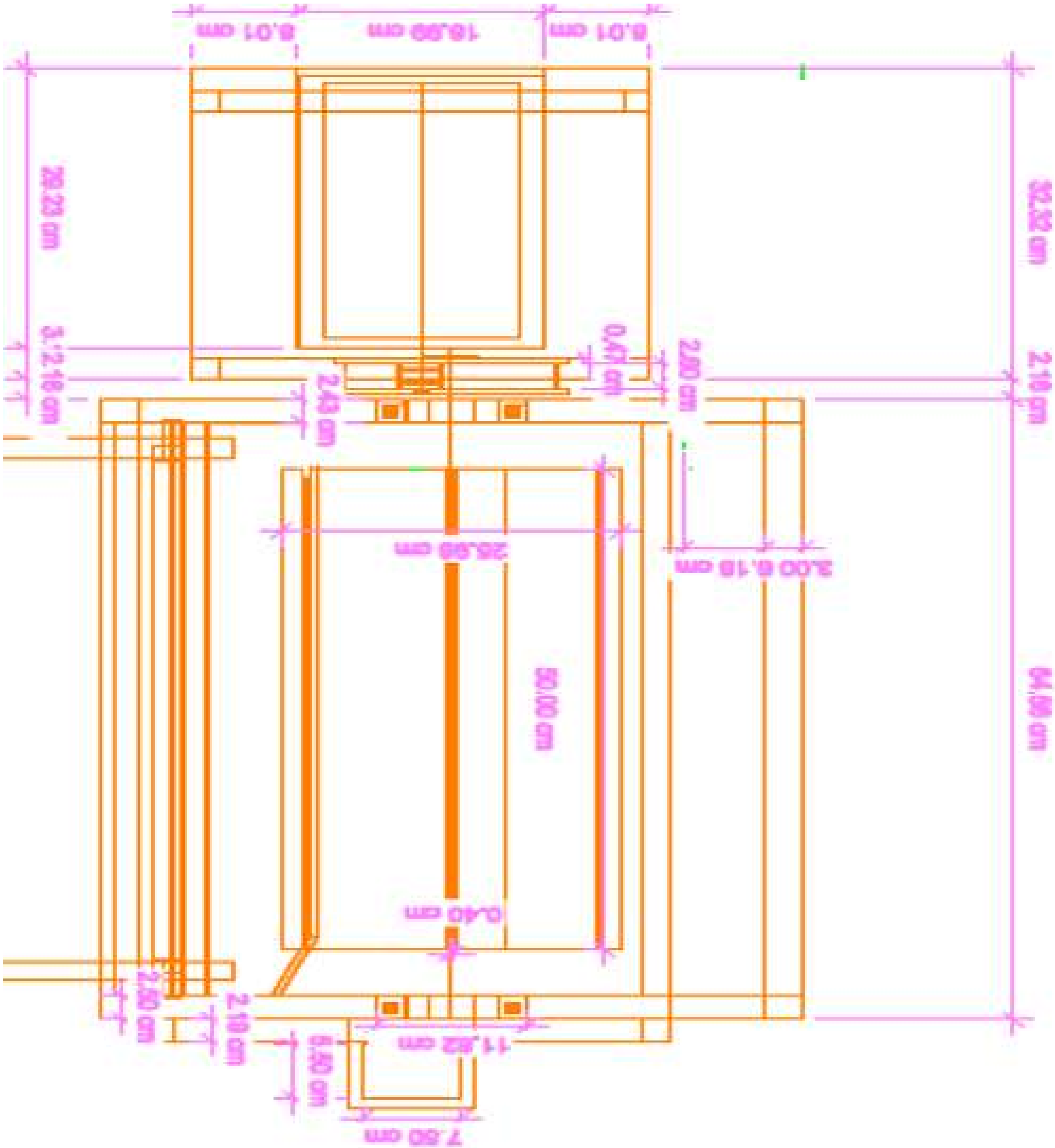


Appendix G

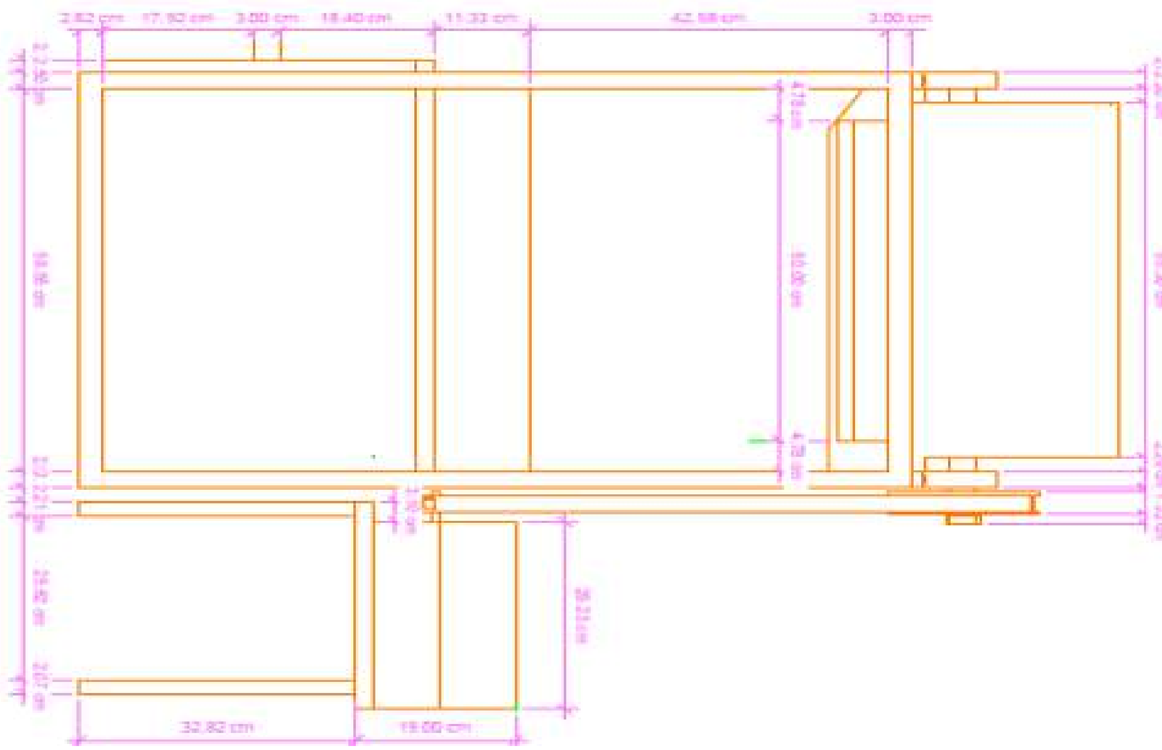
Developed machine model and its detail views



Machine model



3D view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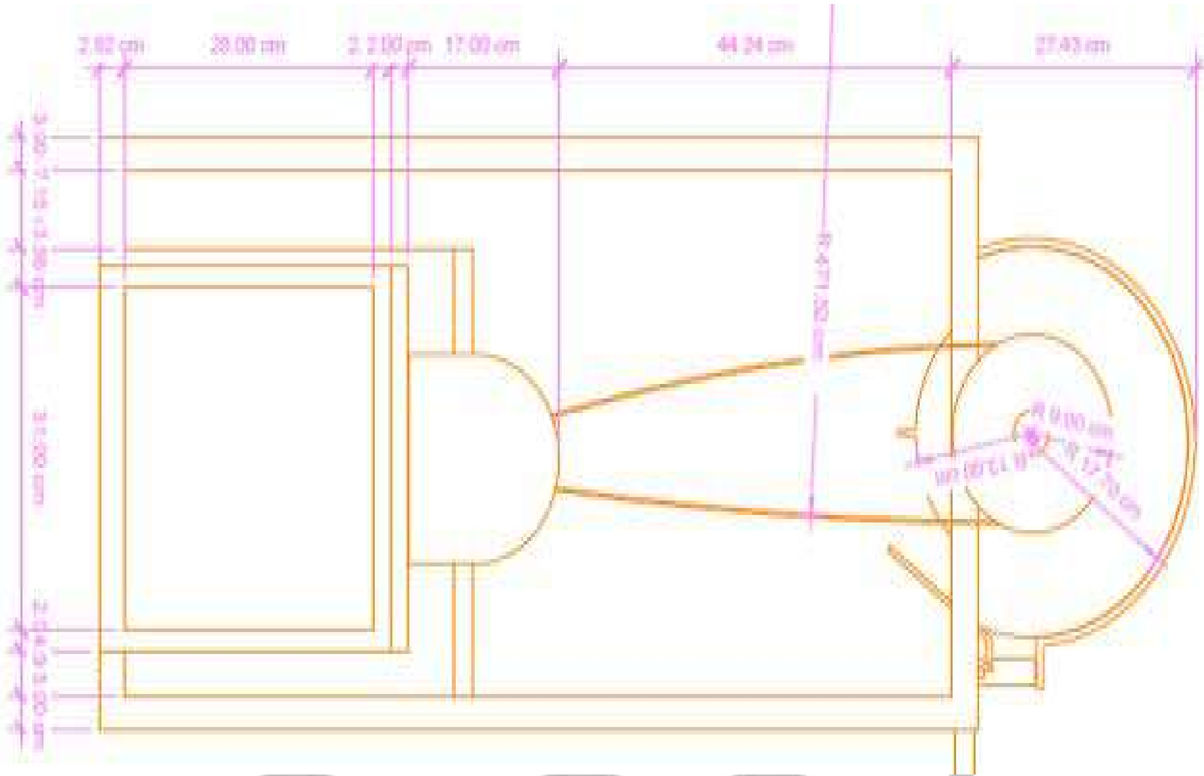
17.50 cm
3.00 cm
18.40 cm
11.33 cm
42.58 cm
3.00 cm
32.82 cm
19.00 cm

Side view



Front view