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DESIGN AND PRODUCTION OF A VERTICAL PALM FRUIT DIGESTER

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Abstract

This work 'Design and Production of a Vertical Palm Fruit Digester' has been carefully carried out. The digester was initially conceived to meet design requirements like functionality, strength and robustness, corrosion resistance, capacity delivery, aesthetics, efficiency and others. To achieve the design requirements design software (AutoCAD) and laptop was used for the engineering drawing of detailed parts and assembly drawing, while design calculations and analysis of loads and forces acting on the vertical palm fruit digester was carried out to assist in the materials selection for the production of the digester. The detailed parts were produced according to the design and standard parts selected in line with design calculations. The digester was assembled using welding machine, bolts and nuts and the right fastening strength and technique was used to ensure rigidity and prevent leakages. The digester was then evaluated for performance and the results revealed that a vertical palm fruit digester was designed, produced and tested. The designed digestion machine was evaluated in regards to two major parameters, namely, the amount of oil produced (throughput and yield) and the quality of the oil produced (with the measures of moisture content, free fatty acid levels, viscosity, and retention of micronutrients). The findings confirm that operating conditions, including sterilisation time, storage time, shaft speed, and blade design, have a strong effect on machine performance. The machine digesting capacity remained high under different machine-set-ups with the highest conditions producing above 340 kg/h, and at 94% efficiency. Optimal sterilisation (120 minutes) and storage (3 days) resulted in oil that contained low amounts of water and low free fatty acids with 3 days maintaining its 0 -tocopherol and 0 -carotene. Long sterilisation or long storage however resulted in an increase in FFA, decrease in antioxidants, and colour decay, which are indicators of oxidative degradation. The total cost of producing the machine is ₦600,000 ($400) and the most expensive part of the machine is the gasoline motor which was ₦100, 000 ($66.67) whose value is approximately 16.7 percent of the total cost. The locally-developed machine is also much cheaper than imported palm fruit digestion machines, which can range between ₦2,000,000 ($1333.33) and ₦3,500,000 ($2333.33) depending on capacity and specifications. This affordability will make it available to rural cooperatives, small-scale processors, and community-based businesses, which is why it will support the local content policy in Nigeria and lessen reliance on imported equipment.

Keywords: *Palm oil; Design; Tenera fruit; Digester; Cost analysis; Testing; Production.*

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1. INTRODUCTION

The oil palm fruit (Elaesis guineensis) belongs to a family of (Arecaccae) that was found in tropical rain forest region of West Africa. The ripe fruits are drops, 60 to 70g in size, with fibrous and oily mesocarp and stony endocarp or shell, the shell containing one seed or kernel in the majority of cases. The fruit is normally red though the top could be black or brown. The oil palm produces bunches of fruits that usually have a range of between 10 and 40kg. Palm oil fruits are commonly found in three varieties called Dura, Tenera and Pisifera. The Dura fruits are thick-skinned (2-8mm), and their fruits are known to have large nuts and thin mesocarp (fleshy part of the fruit), whereas pisifera fruits never have a shell and are generally female sterile; that is, they do not bear so many fruits. A hybrid between Dura and Pisifera is called Tenera and it has a thin shell with more oil. The nut of the Tenera is readily shelled, and in clumps is commonly greater than the Dura bunch. The only variety suggested to be used in commercial production is Tenera. Pisifera are not a good breed in a commercial perspective because they produce a low percentage and are hard, but they are also crucial in breeding (Agbonkhese *et al*., 2018).

In order to underline the economic significance of the oil palm fruit, it is commonly called a crop of multiple values. Palm oil can be used to manufacture many products including edible and non-edible products, and medicinal products. Other edible products containing palm oil also contain palm oil cooking margarine and palm oil. Examples of non-edible palm oil include soaps, detergents, candles, lubricants, glycerol and cosmetics. Medical products synthesized with palm oil are also of the liniment diuretic and drugs used in the treatment of cancer (Adepoju *et al*., 2017). Palm fruit digestion is a major process in the production of palm oil. Palm fruit digestion; Aideloje *et al*., (2018) refer to the process of extracting palm oil through a combination of heat and mechanical shear to break the oil-bearing cells. It begins with sterilization, where the palm fruits are taken through high temperatures and this kills off enzymes and softens the fruit to make it easier to thresh. Threshing means increasing the distinction between the bunch and the individual fruits. Following the threshing, fusion is then introduced into the digesters that is the design of a cylindrical vessel with rotating beater arms. The oil-bearing cells are broken by mechanical action of the beater arms and the outer covering of the fruit is broken down. The highest quality palm oil is immediately released by this digestion process. But the greater part of the oil have already been absorbed in the digested mass, which will be relinquished, when digested, by the digester, and pumped into a press machine, when all the oil is fully extracted.

The old forms of processing were the most common way of producing palm oil in Nigeria, (Kudasko, 2002). This is normally time consuming, unhygienic, and labour intensive. To a large extent, this is what has contributed to the unbalanced demand and supply of palm oil produce in both the local and international market. The oil palm in Nigeria is found in small palm plantations and wild groove although recently few large scale plantations have been set up (Badumus, 1990). In this regard, small scale mills require the creation of machines. Due to its potential in high volume production of palm oil, the development and design of machines has been the focus of numerous researches. This has led to the production of advanced and complex foreign palm oil processing equipment that does not fit within our small scale production system (Udo *et al.,* 2015; Uzoma and Obo, 2024; Offiong, 2024). To address the above disadvantage, the project offers a solution by coming up with the design and development of a better mobile vertical palm fruit digestion machine. The machine is tailored to meet the tenera fruits.

The objective of this work is to Design, produce and optimize the process variables of a vertical palm fruit digester for best performance. The prototype of the developed digestion machine should be capable of small scale production and it must be a worthy substitute of foreign ones with the optimization of its performance metrics and variables.

2. MATERIALS AND METHOD

2.1 Materials

2.1.1 The Palm Fruit Digestion Machine

This project will have an aim of coming up with a portable mechanical method of digestion machine which will be mobile and viable to use in any part of the palm oil-producing rural areas where small scale production is the order of the day. Design and construction is made easy in order to make available to small scale farmers the design and construction. This is aimed at achieving high weight/rigidity, easy installation like assembly, dis- assembly and operation and reduction of costs and also to achieve an efficient extraction with high throughput. The design methodology is after Onyenanu and Okiemute (2023).

The materials employed mostly were mild steel that can be found in the local market. This is ensured by making the power requirement of the machine minimal, such that it can be powered on the same petrol engine as utilized in Taofik *et al.,* 2019 and Offiong *et al.,* (2024) a, b and e. It had been assumed that the commercial farm tenera species will be the only one processed by this machine. It was also assumed that the machine will also serve small scale industry whose amount of palm frits to be digested does not surpass 1000kg per day. It was believed that the fruits which needed to be digested had been boiled 100 percent during an hour (Babatunde *et al.,* 1988; Erhimona *et al.,* 2023).

2.1.2 Palm Fruit Digestion Machine Functional Component Description

The key characteristics of the oil palm fruit digestion machine are: frame, hammers, stirrer shaft, digestion chamber, bevel gear, vee-belt and petrol engine.

Frame: The frame are composed of 2 inches angle bar. The frame offers stern and considerable support to the entire construction. The frame is made up of 2 compartments and they are the support of the digestion chamber and the tap of the petrol engine. The frame is built in a way that allows easy movement of tyres. Besides the four-corner support of the main frame, there is a handle at one end. The length of the frame is 700mm, length is 700m and height 500mm.

Hammers: The palm fruit digestion machine has four different configurations of hammers: (i) three arm configuration at angle 1200; four arm configuration at angle 900; five arm configuration at angle 720; and six arm configuration at angle 600. See Figure 3.2. Hammers: The hammers consist of mild steel of 16mm diameter and a length of 170mm between the bottom and top of the stir shaft. The bottom hammer and top hammer have a clearance of 30mm and 70mm respectively before the welding process takes place. The hammers are welded onto the shaft which is used to rotate the stirrer at a distance of 150mm, 100mm, 75mm and 60mm to the three, four, five and six arm setups respectively. The beaters in the digestion process are the hammer.

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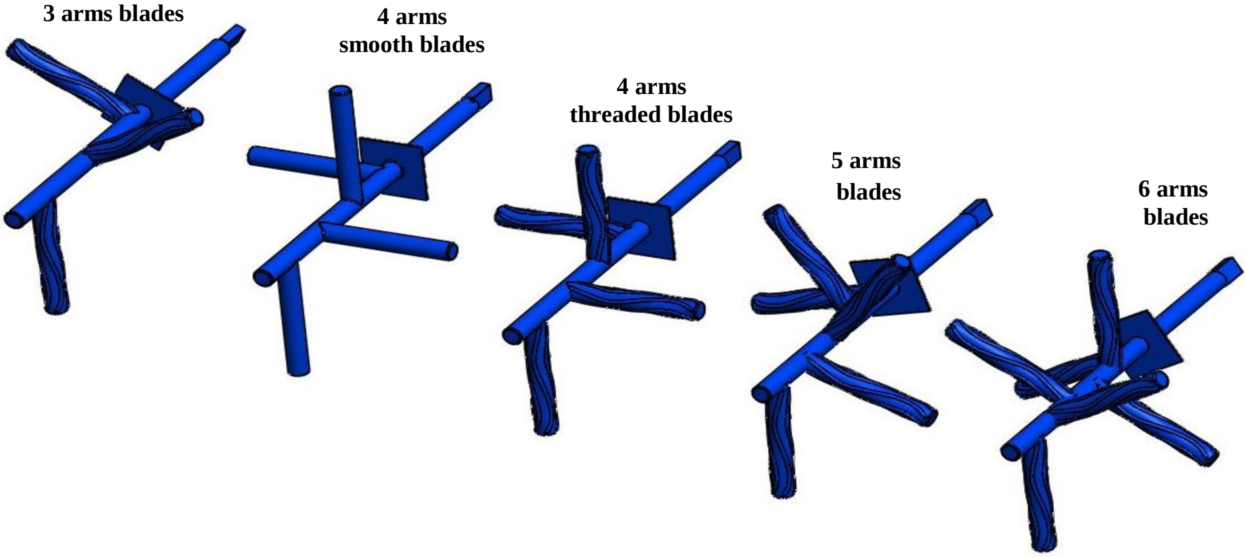

Figure 2.1: Hammer design of the developed palm fruit digestion machine by Researcher (2025).

Stirrer Shaft: The stirrer shaft is comprised of steel shaft with inner diameter of 300mm and length of 400mm placed in the centre of the digesting chamber. A scaled 40mm diameter ball bearing is used to carry either end of the stirrer shaft. The stirrer shaft is mounted vertically with this being welded to four configurations using the hammers. See Figure 2.2. Survey conducted by researcher made on market and in the industry indicates that threads stirring mechanism have high throughput and efficiency compared to smooth stirring mechanism. Therefore, most of the experiment will involve the threaded stirring mechanism. Nonetheless, an experiment shall be carried out to show the superiority of smooth stirring mechanism over threaded stirring mechanism in a sense of quantity and quality of oil produced by digestion mechanisms.

Digesting Chamber: This is the digestion chamber, which is a vertical cylindrical drum. The chamber will create a place where the hammers can rest during the working process. The chamber is composed of 3.5mm stainless steel sheet and has a diameter of 455mm and a height of 380mm. It will possess a palm oil center opening in the digestion chamber of 25mm diameter and will facilitate the collection of oil as the food digests. At the base of the digestion chamber, there is also the discharge end of a fibre/nut outlet, which flows the fully macerated oil palm fruit of the digestion chamber to a receptacle. The fibre and nut outlet is a square hole measuring 150mm.

Hopper: Four 3.5mm sheet of stainless steel are used to form the hopper. The hopper is a trapezoid form mounted on top of the digesting chamber. The shape is semi-circular at the throat to allow smooth passage of palm fruits. A hopper gives an entrance to the digestion chamber.

Bevel Gear: To attach the rotating stirrer shaft that has hammers, the palm fruit machine is configured in such a way that the hammers are attached to the bevel gear. The role of the bevel gear palm fruit digestion machine is to transform the horizontal movement to vertical movement. The equipment is fitted with a 125mm diameter pulley. The driver has 11 teeth and the driven gear has 42 teeth. The bevels provide shaft power at low speed and high torque.

Vee-belt: A vee belt is one that transmits the power and rotation between the petrol engine and the gear via; the pulley on the petrol engine and the gear.

Petrol Engine: The petrol engine is mounted to the frame with bolts/nuts and is used to power the palm fruit digestion machine.

2.1.3 Working Principle of the Digestion Machine

The palm fruit digestion machine is driven by the petrol engine which serves as the prime mover. The petrol engine motion is been transferred to the stirrer shaft by means of the V-belt. The bevel gear setup converts vertical motion to horizontal motion. When the hammers welded to the stirring shaft rotate they complete the digestion process. The boiled palm fruits meet with rotational hammers and walls of the digestion chambers, the fruits are pounded hence destroying the oil containing cells in the fruits. The product of the digestion of fruits is now in the form of a pulp, and the product of the digestion of the mass is in the form of a fibre/nut outlet. The process being what it is, some amount of oil are being emptied out of chamber via the oil chute on the bottom of the digestion chamber. The stirrer is in the clockwise direction.

2.1.4 The Production of the Digestion Machine Materials use.

The power, hardiness and reliability of a machine is largely determined by the type and quality of materials that are employed in its production. The working of farm machines has a tendency towards avoiding as many castings as possible and to use formed materials. Forming involves a set of operations that are used to shape material through deformation. Bending, rolling and forging are examples of forming process. The choice of materials required to manufacture this machine was done according to: the availability of the material in the local markets, the cost of the material, material strength, material durability, material machinability, material corrosion, material hygienicity, the policy of Nigeria of the local content initiative. The chosen materials are predominantly mild steel material with the exception of the pulleys and tyres which are made of aluminum and rubber respectively. The machine welding was fabricated through electric arc welding. The materials of the palm fruit digester are indicated in Table 2.1.

2.2 Methods

2.2.1 Processes in the Work of the Digestion Machine

The process of developing the palm fruit digesting machine started with the computer aided design (CAD). AutoCAD was utilized to

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create a virtual design of the digestion machine. The design functional parameters and parts that were taken into consideration when developing the digesting machine were the density of boiled palm fruit, selection of petrol engine, machine torque, machine pulley speed, size of the belt, size of shaft, tension on the v-belt, speed of the stirrer, speed reduction of the gear pulley, and centrifugal force generated in the system.

The step by step process that will be utilized in the completion of this work consists of: description of the functional component of the digestion machine, the working principle of the digestion machine, design analysis of the digestion machine, design of the palm fruit digestion machine, creation of the digestion machine, establishment of the evaluation parameters of the machine, experimental procedure involved in the evaluation of the machine, design of the experiment that will be applied in the optimization of the machine as well as development of the machine learning algorithms to the machine.

2.2.2 Analysis of the Design of the Digestion Machine

Conducting the design analysis of the palm fruit digestion machine involved determining the belt length, speed of the stirrer, gear to stirrer speed reduction, centrifugal force produced in the system, torque produced, power demanded, v-belt tension and shaft diameter.

Belt Length Calculation. The distance length of the belt of the digestion machine was obtained using Kurmi and Gupta (2005) formula below..

$$L = \frac{\pi}{2}(D_1 + D_2) \text{ at } 2x + \frac{(D_1 - D_2)^2}{4x} \qquad \text{Equation 2.1}$$

L is the entire length of belt, D_1 radius of driving pulley, D2 radius of driven pulley, and X is the distance between centres of two pulleys. The Belt length is 1200mm.

Maximum speed of stirrer = 90 rpm.

The stirrer was calculated by the following formular on the theory that the product of diameter and speed of one pulley equals that of the other.

$$D_1 N^1 = D_2 N_2 \qquad \text{Equation 2.2}$$

Where N_1 is the petrol engine speed (rpm), N_2 is the speed of the bevel gear, D_1 is the size of the pulley on the petrol engine and D_2 is the size of the pulley coupled with the bevel gear. Therefore in optimum operating condition, the bevel gear goes 1600rpm.

Calculation of the speed change between gear and the stirring shaft.

Derived gear speed was calculated based on the Kurmi and Gupta (2005) formula below.

$$N_1T_1 = N^2+T_2 \qquad \text{Equation 2.3}$$

Where N_1 is the driver gear speed (rpm), N_2 is the driven gear speed (rpm), T_1 is the number of teeth of the driver gear, T_2 is the number of teeth of the driven gear. The driven gear is connected to the stirrer, and the speed of the stirrer was the same as the speed of the driven gear.

Calculation centrifugal force generated in the system.

The formula derived by Badmus 2002 below was used to determine the centrifugal force created in the system.

$$F_c = M \left[\frac{2\pi N_2}{60}\right]^2_{r_1} \qquad \text{Equation 2.4}$$

A centrifugal force Fc is centrifugal, radius of the pulley on the gear r_1, speed of the driven gear N_2, and mass of the inertia of the hammer prior to attaching to shaft M.

The centrifugal force generated in stirrer was 64N based on equation 2.4.

Torque developed determined

Torque generated on the shaft of the stirrer was calculated by the formula whereby Kurmi and Gupta (2005) converted the identified hardware to a formula below.

$$T = F_c r_2 \qquad \text{Equation 2.5}$$

Where F_c is the centrifugal force generated in the digestion chamber and T is the shaft of torque. In such a way, the worth of the torque generated within the system would be 1.6Nm. Torque is defined here in such a way that the notion of the ability of the petrol engine to be exploited can be identified.

Calculation of power demand.

The power requirement of the digestion machine was calculated with the use of formula presented in Kurmi and Gupta (2005) below.

$$P = \frac{2\pi N_2 T}{60} \qquad \text{Equation 2.6}$$

Where P represents the power (watt), T is the force necessary to rotate the shaft (Nm) and N_2 is the rotation speed of shaft (rpm). Therefore 5.5 horsepower petrol engine has been selected to provide the necessary torque in the digestion machine.

Calculation of tension in the V-belt.

The tensions of the V-belt were calculated by the following formula:

$$T_2 = \frac{F_c}{3} \qquad \text{Equation 2.7}$$

Where Fc is centrifugal force applied in the barrel, Fc = T_1 -the tension on tight side of the belt; T_2 -the tension on the slack side of the belt; and 3 is a constant in V-belt.

Selection of shaft diameter.

The size of the shaft was established by using the equation in Kurmi and Gupta (2005) as shown below.

$$d^3 = \frac{16}{\pi T_s}\left[(k_b M_b)^2 + (K_t T_t)^2\right]^{½} \qquad \text{Equation 2.8}$$

Where d is shaft diameter (mm); Ts is torsional shear stress (Mpa); Mb is bending moment (Nm); Kb shock t fatigue factor on bending moment; Tt is torque and Kt shock and fatigue factor on torsional moment.

2.2.3 Designing the Palm Fruit Digestion Machine.

The palm oil digestion machine design will consider an approach relying on the Agbonkhese *et al.,* (2018) but the difference with that design being that depending on the desired parameter to be analyzed, the machine will take a two, three, four, five or even six arms centrifugal mild steel harm design on the axle depending on the desired parameter to be measured as compared to the fix four arm design that was used in Agbonkhese *et al.,* (2018). As demonstrated in Figure 2.3, isometric drawing of the palm fruit digestion machine will be created with the use of AutoCAD. Figure 2.4 illustrates the orthographic representation of the palm fruit digestion machine that will be created in AutoCAD. Figure

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2.5 -2.12 indicates the isometric sketch of the constituent components of the palm fruit digestion machine to be designed. The three dimensional model of the palm fruit digestion machine to be developed is illustrated in Figure 2.13. Figure 2.14 depicts the investigated perspective of model parts of the d palm fruit digestion machine to be produced.

2.2.4 Digestion Machine

Finishing between the welding phase and the painting phase is a special consideration in the production of the palm fruit digester machine, and poor finishing in a single step is seen as one of the causes that makes the products manufactured in Nigeria to face marketability issues at international markets (Allen *et al.,* 2002; Offiong 2024). The entire construction will be carried out at the Department of Mechanical and Aerospace Engineering, University of Uyo, Nigeria. It is estimated that two palm kernel nut cracking machine can be constructed at a cost of Three Hundred thousand Naira only (₦300,000.00). The diagrammed view of the developed palm fruit digestion machine appears in Figure 2.15. The pictorial view of the parts components of the developed palm fruit digestion machine appears in Figure 2.16.

Table 2.1 presents the material, which is utilized in each component part of the machine. The manufacturing process of each of the sub-assembly part is presented in Table 2.2. Table 2.3 indicates equipment and tools employed in the production of the palm fruit digestion machine. The technical specification of voltage digitizer palm fruit digestion machine, which is locally manufactured, is presented in Table 2.4.

Table 2.1Materials: Palm Fruit Digester.

S/N	Parts	MATERIAL	DESCRIPTION
1.	Hopper unit	Stainless steel	2mm thickness
2.	Digestion chamber	Stainless steel	2mm thickness
3.	Shaft	Stainless steel	Circular pipe (dia 30mm)
4.	Blades	Mild steel	Flat bur
5.	Frame	Mild steel	45x45x5 angle iron
6.	Bearing	Stainless steel	4 holes flange bearing unit 25mm ID
7.	Gasoline motor	Cast iron	YL7124
8.	Bolts	Stainless steel	Hex bolts, M10 x 35mm
9.	Bearing cover	Stainless steel	2mm thickness

Table 2.2: The manufacture of the parts of each Sub-assembly.

S/N	Sub-part	Manufacturing process
1.	Digesting chamber	• cutting • Folding • Welding
2.	Frame	• Making • Cutting • Welding
3.	Shaft	• Cutting • Shaping • Forging • Boring
4.	Blade	• Cutting • Welding
5.	Outlet cover	• Cutting • Welding
6.	Sieve	• Cutting • Folding • Welding

Table 2.3: Tools and equipment used in Manufacturing.

S/N	Manufacturing process	Equipment	Tools	Consumables
1.	Measurement		Tape rule, steel rule, vennier	

DOI: 10.5281/zenodo.18647850

			calipers	
2.	Marking		Centre punch, divided, try square, hammer	Engineering chalk
3.	Cutting	Oxy-acetylene set, hand cutting machine	Cutting disc, cutting blades	Saw blades, Oxy-acetylene, cutting disc
4.	Drilling	Vertical drilling machine, lathe machine	Drill bits, coolants	
5.	Folding	Folding machine stakes, anvil, mallet, hammer	Stakes, anvil, mallet, hammer	
6.	Rolling	Cylindrical rolling machine	Hammer, mallet	
7.	Welding	Arc welding machine	Hand gloves, welding shield, chipping hammer	Stainless steel electrodes, carbon steel electrodes

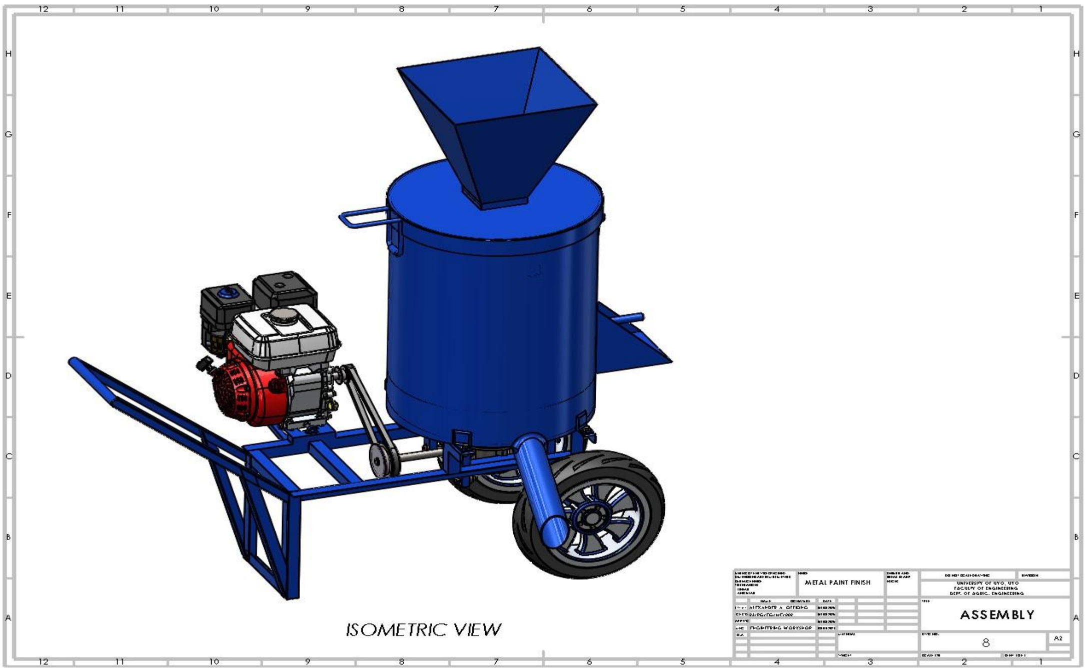

Figure 2.2: Isometric coloured drawing of the vertical palm fruit digestion machine by Reseracher (2025)

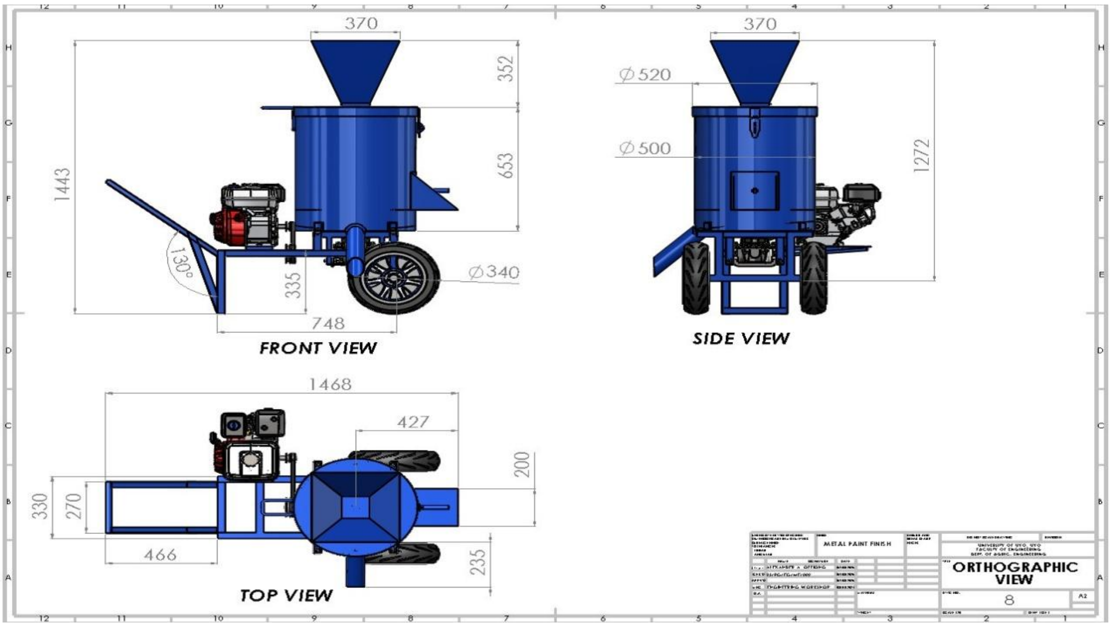

Figure 2.3: Orthographic coloured drawing of the vertical palm fruit digestion machine by Reseracher (2025)

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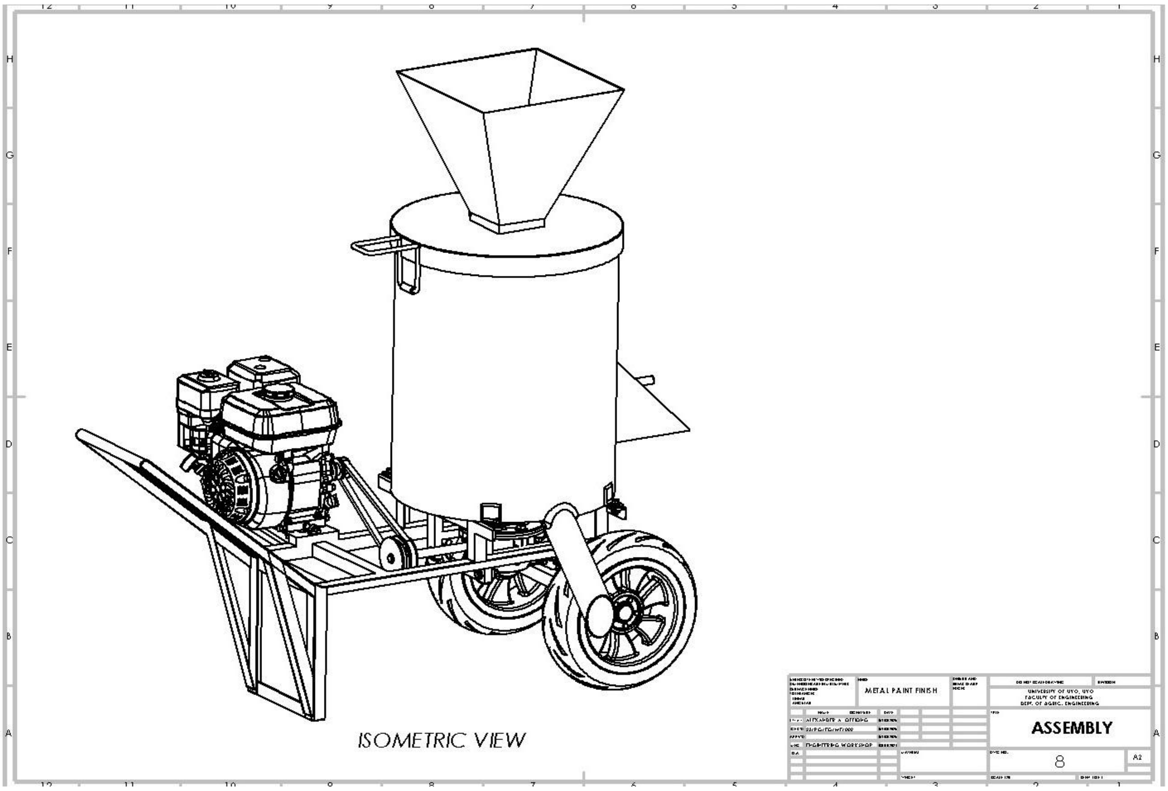

Figure 2.4: Isometric drawing of the vertical palm fruit digestion machine by Reseracher (2025)

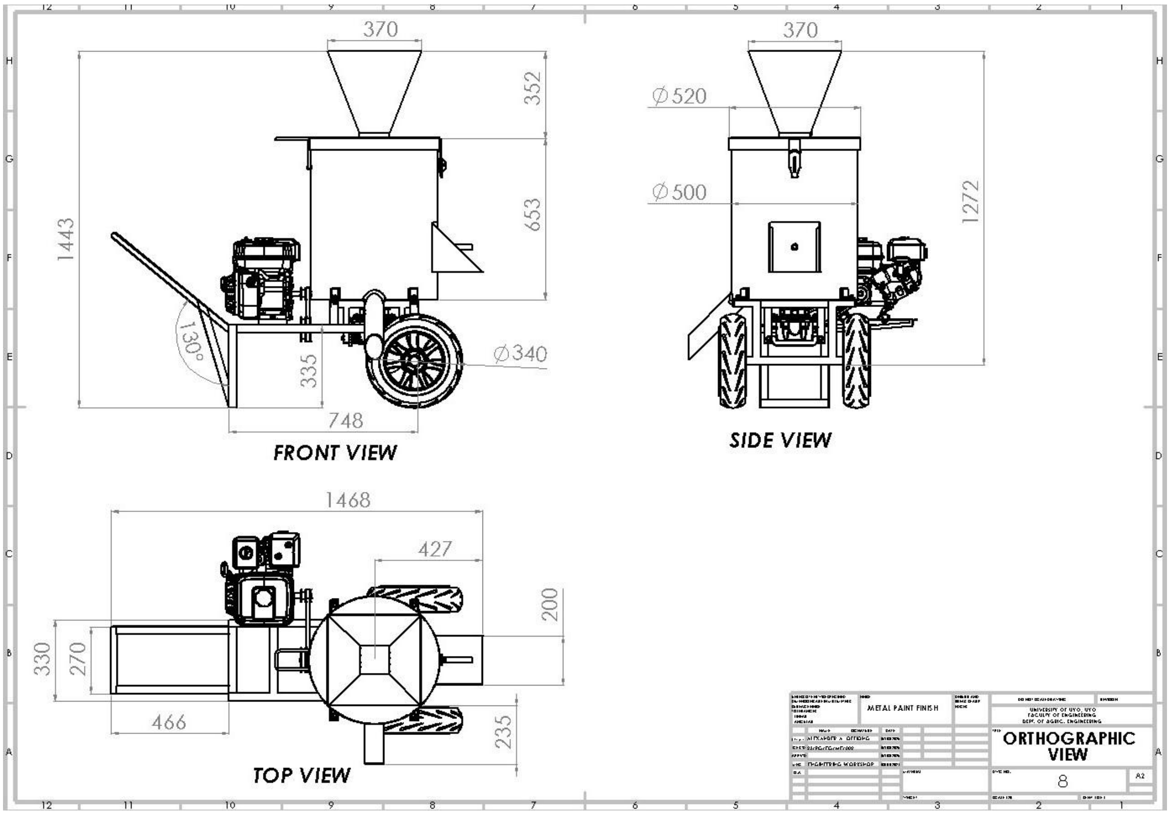

Figure 2.5: Orthographic drawing of the vertical palm fruit digestion machine by Reseracher (2025)

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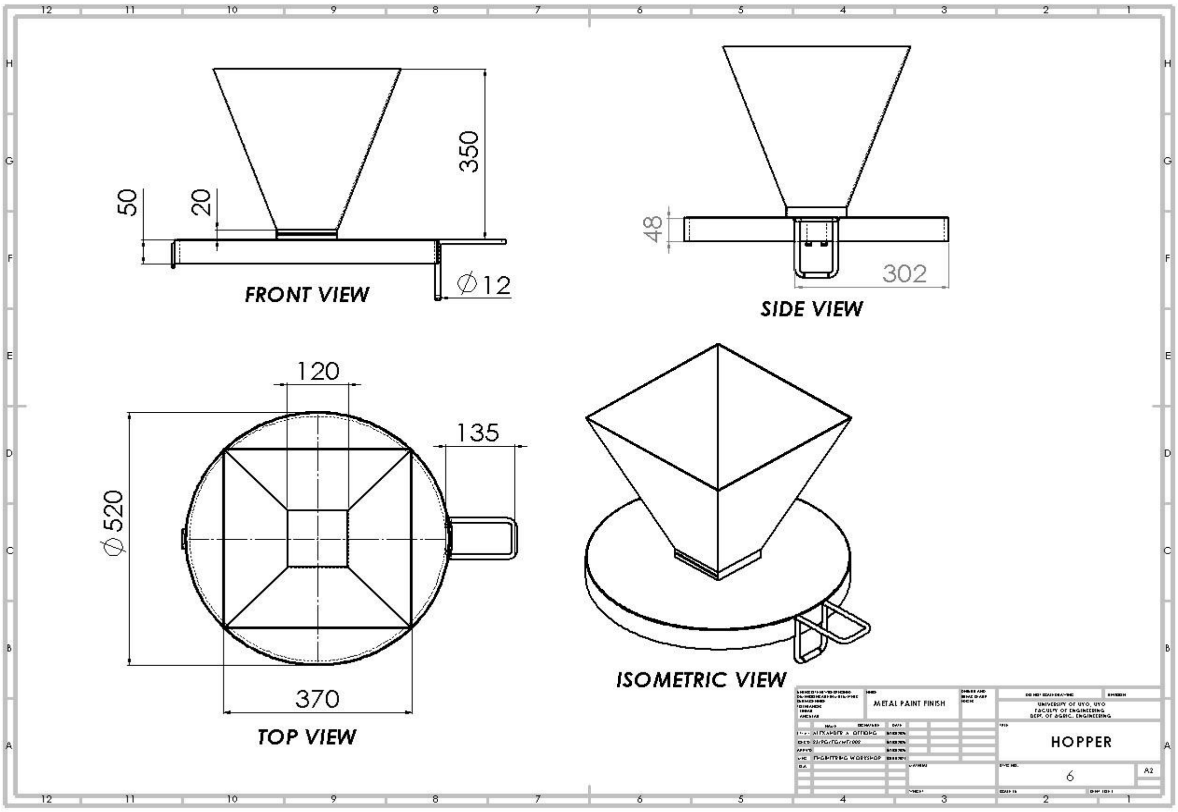

Figure 2.6: Component drawing of the vertical palm fruit digestion machine (Hopper) by Reseracher (2025)

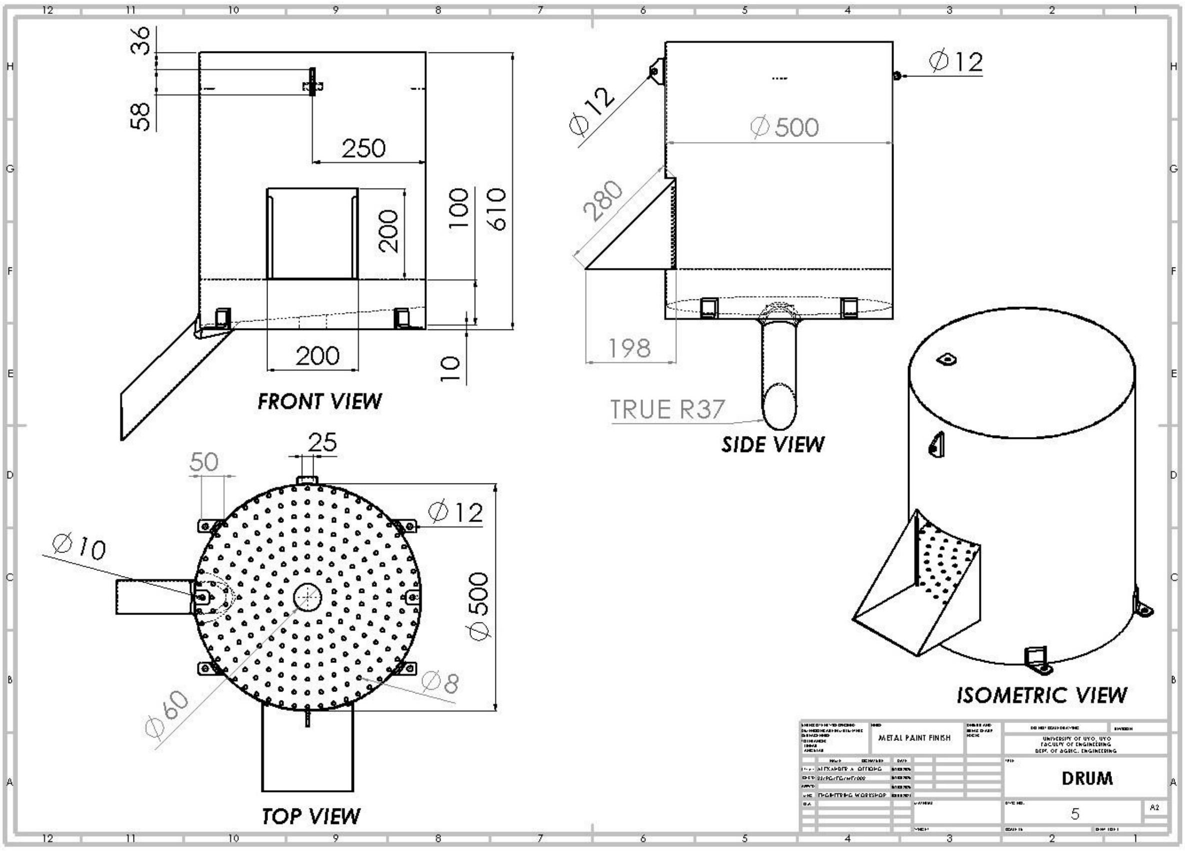

Figure 2.7: Component drawing of the vertical palm fruit digestion machine (Drum) by Reseracher (2025)

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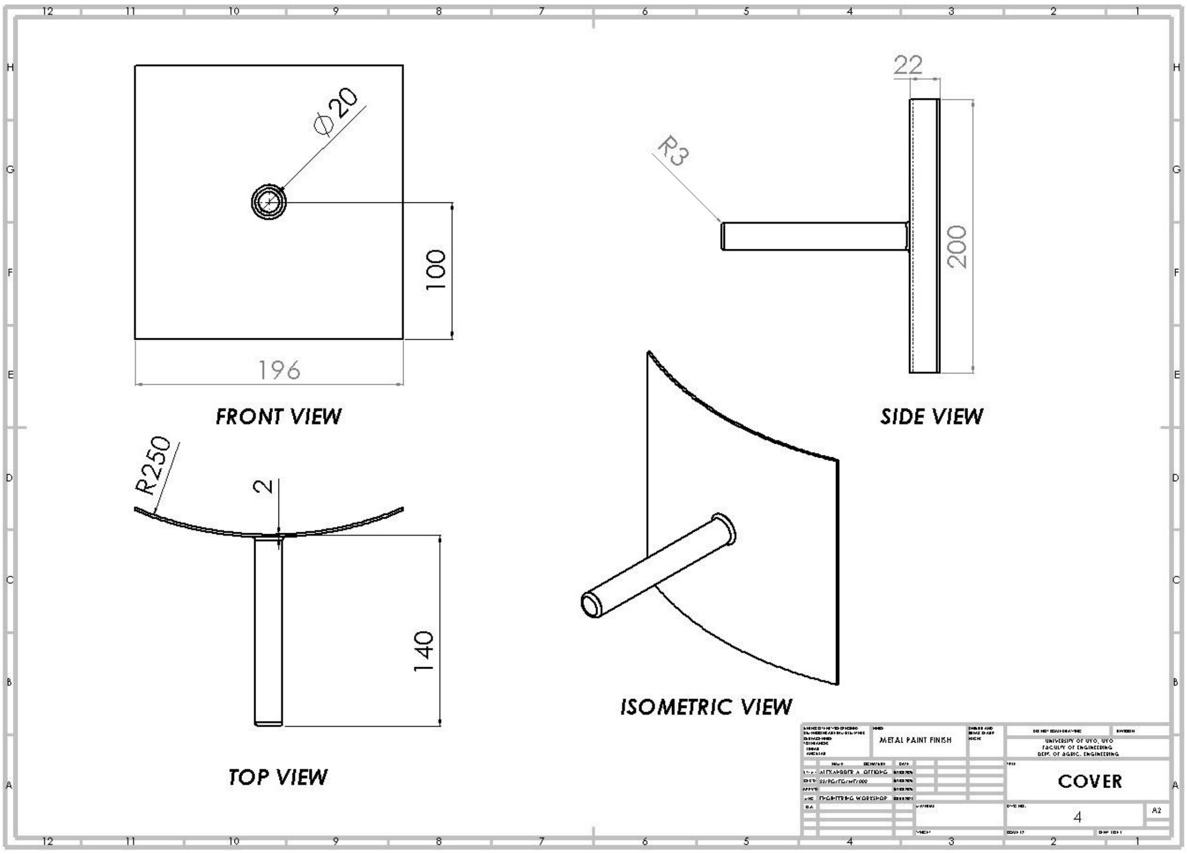

Figure 2.8: Component drawing of the vertical palm fruit digestion machine (Cover) by Reseracher (2025)

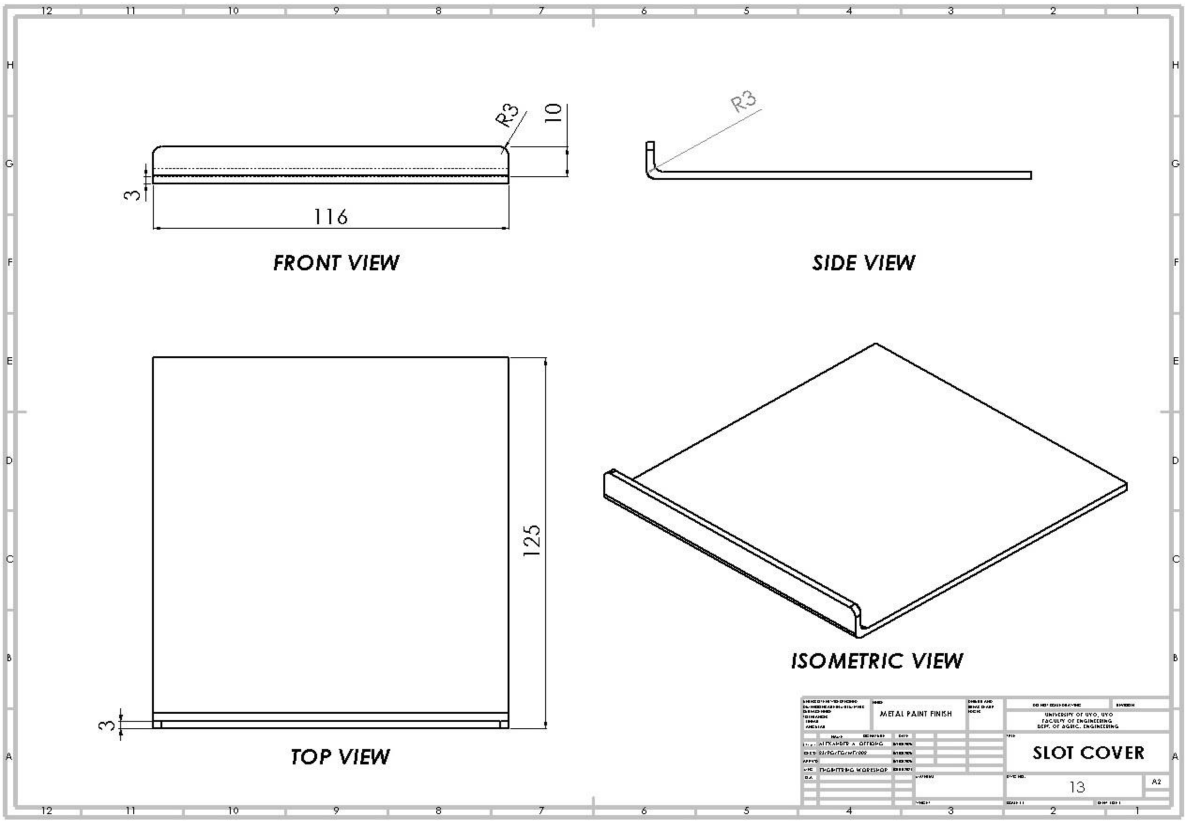

Figure 2.9: Component drawing of the vertical palm fruit digestion machine (Slot cover) by Reseracher (2025)

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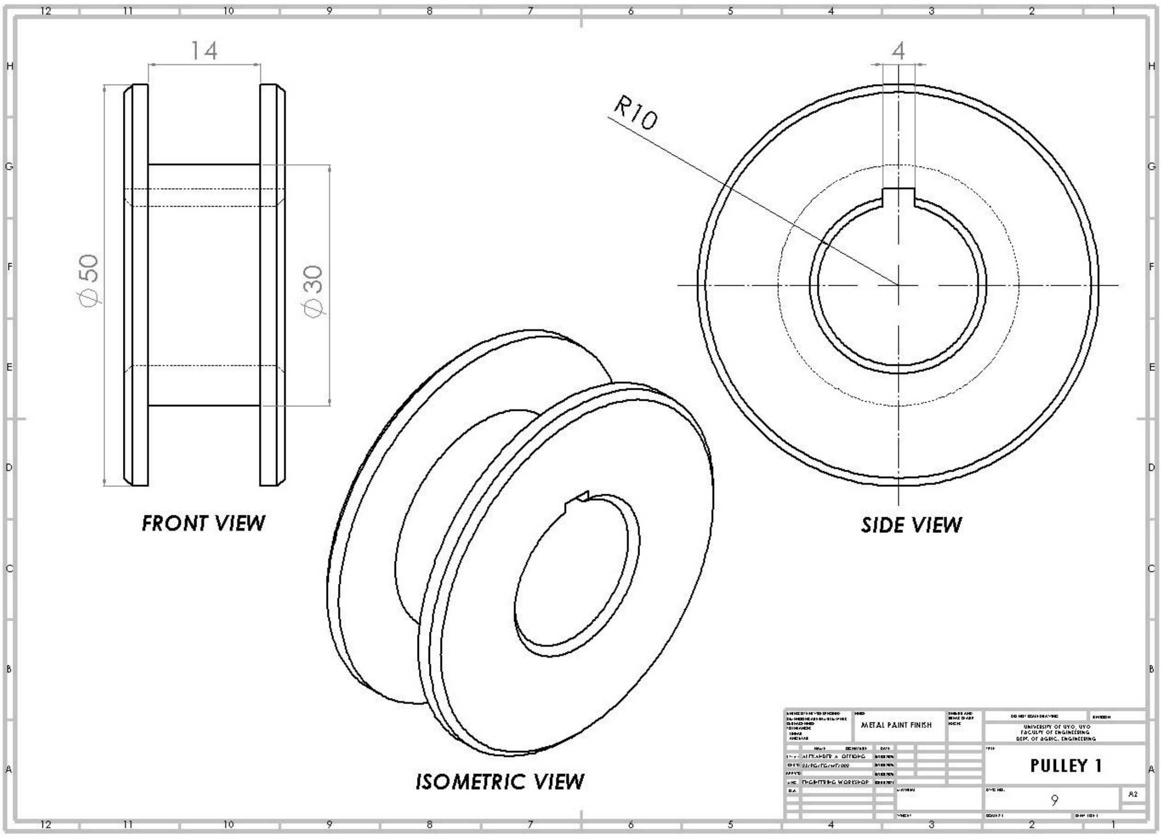

Figure 2.10: Component drawing of the vertical palm fruit digestion machine (Pulley I) by Reseracher (2025)

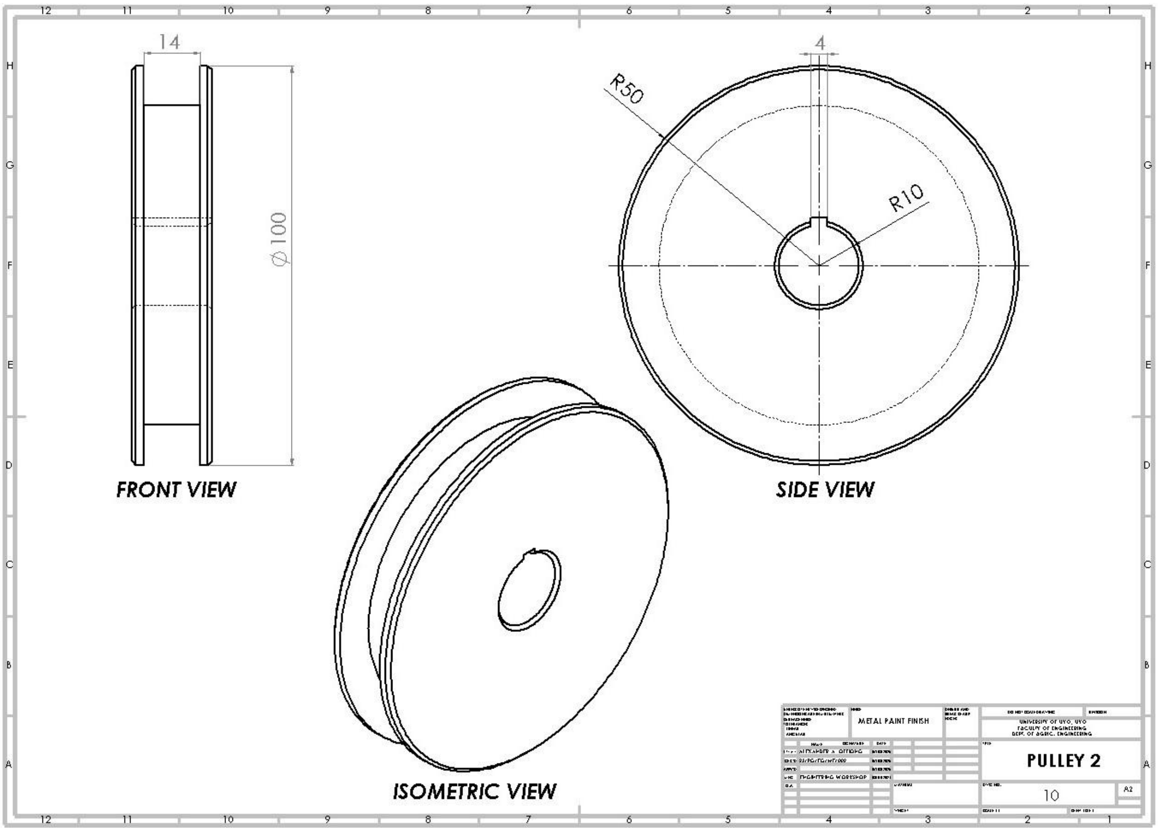

Figure 2.11: Component drawing of the vertical palm fruit digestion machine (Pulley 2) by Reseracher (2025)

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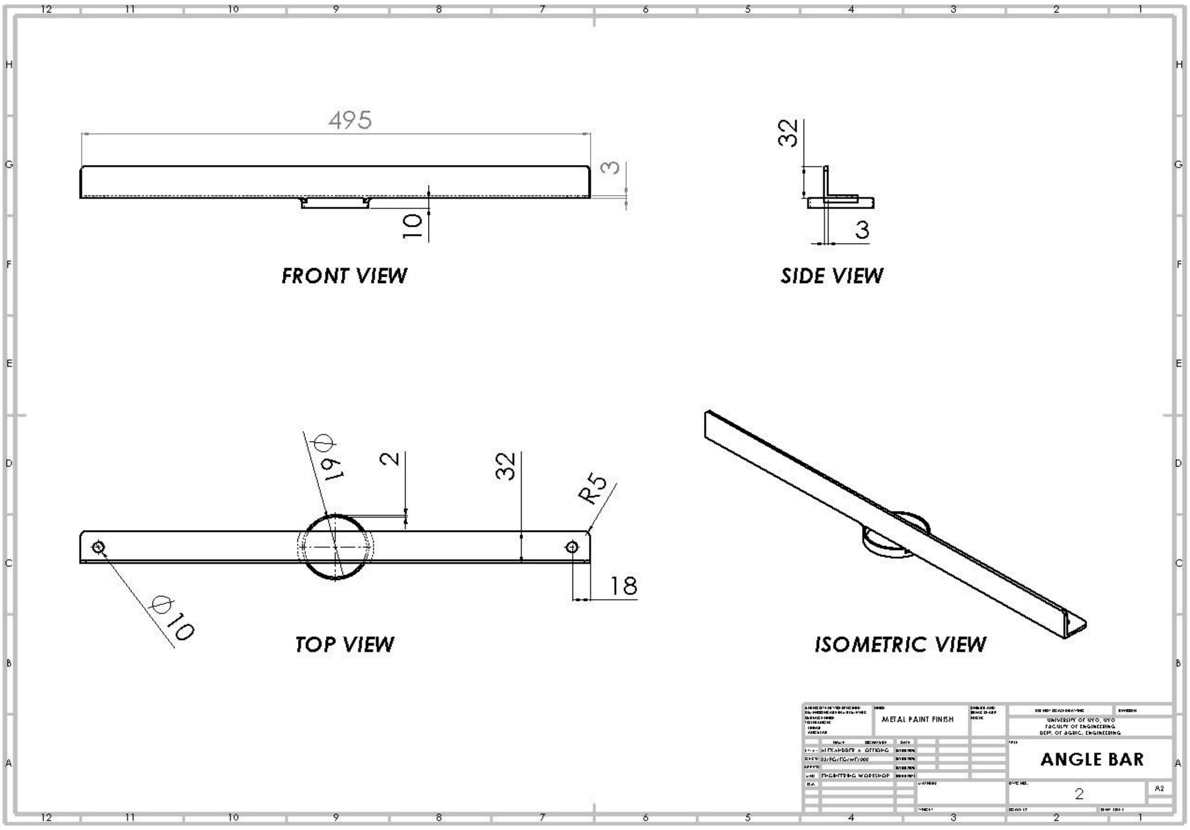

Figure 2.12 Component drawing of the vertical palm fruit digestion machine (Angle Bar) by Reseracher (2025)

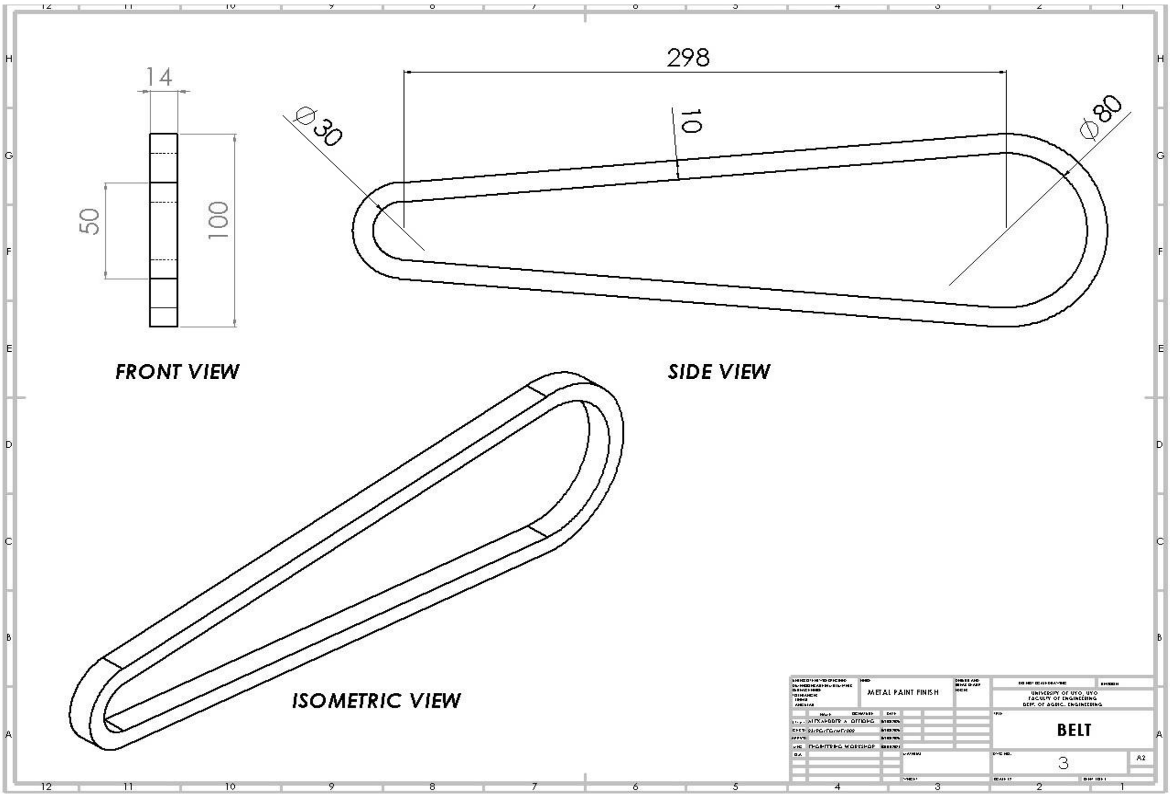

Figure 2.13: Component drawing of the vertical palm fruit digestion machine (Belt) by Reseracher (2025)

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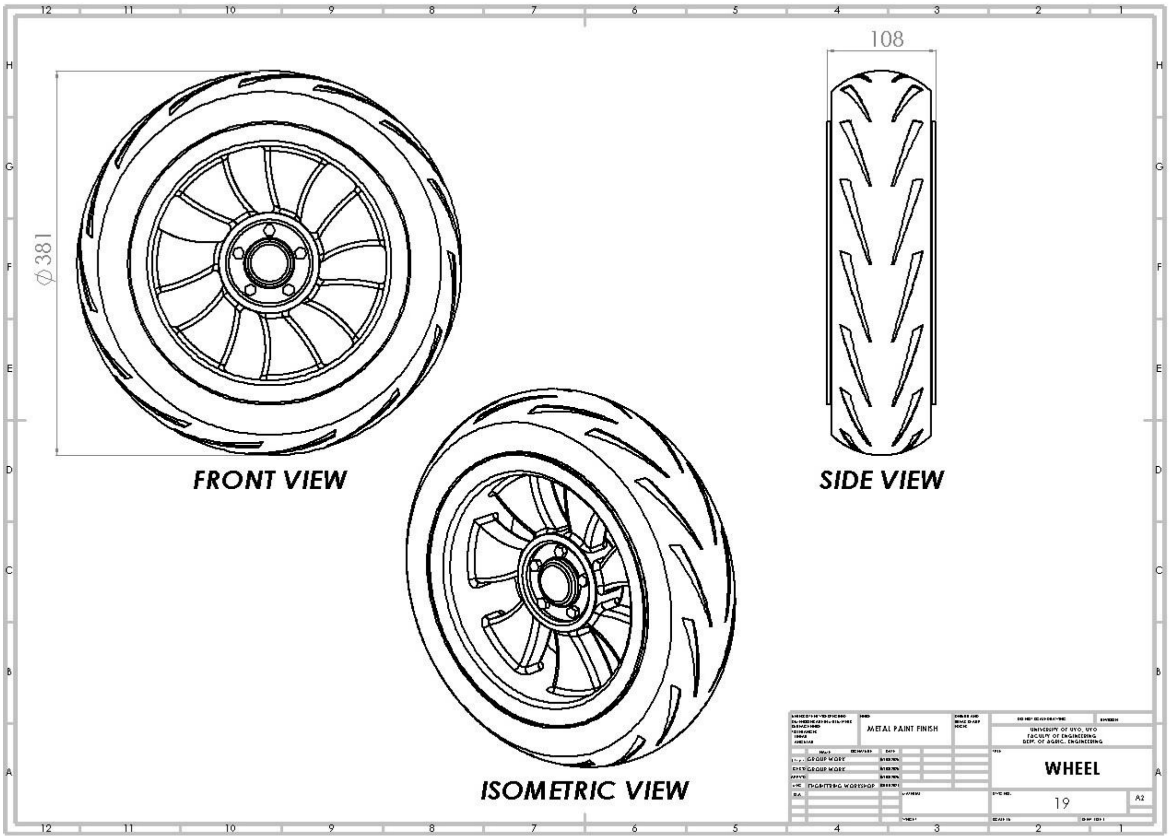

Figure 2.14: Component drawing of the vertical palm fruit digestion machine (Wheel) by Reseracher (2025)

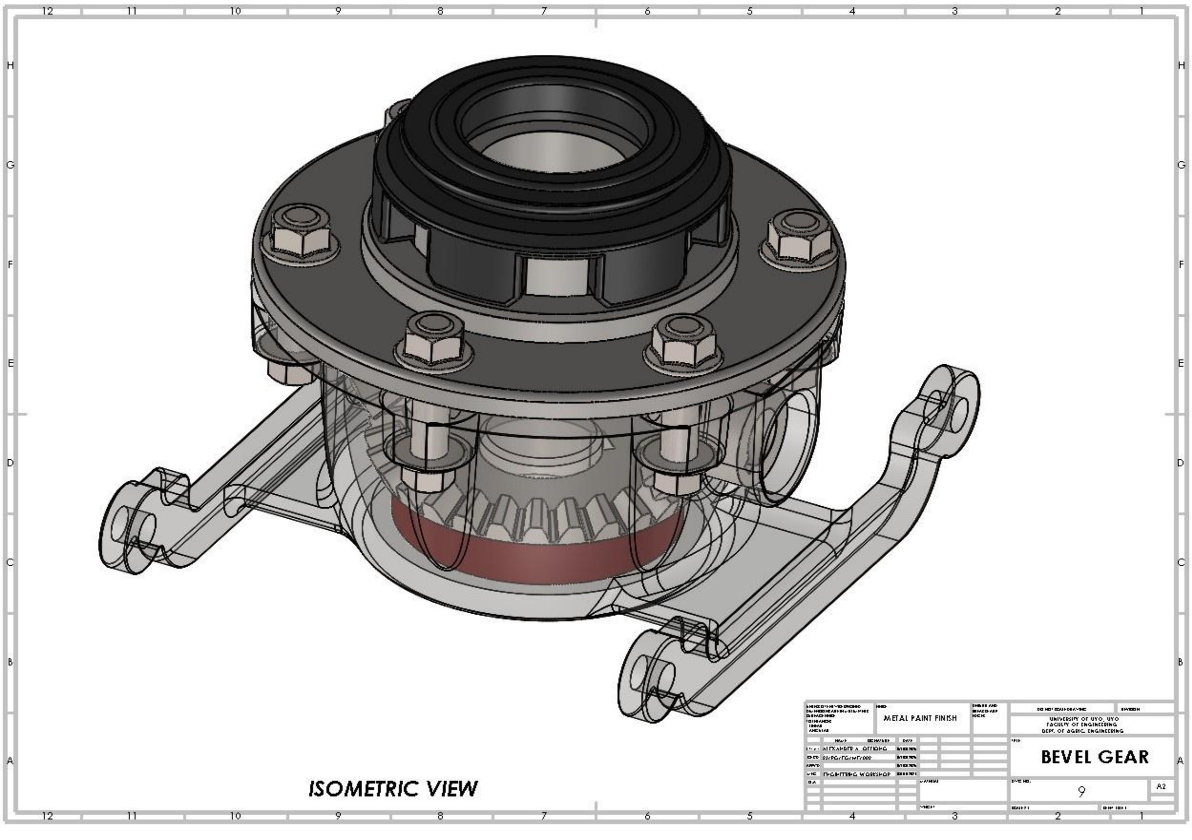

Figure 2.15: Component drawing of the vertical palm fruit digestion machine (Bevel Gear) by Reseracher (2025)

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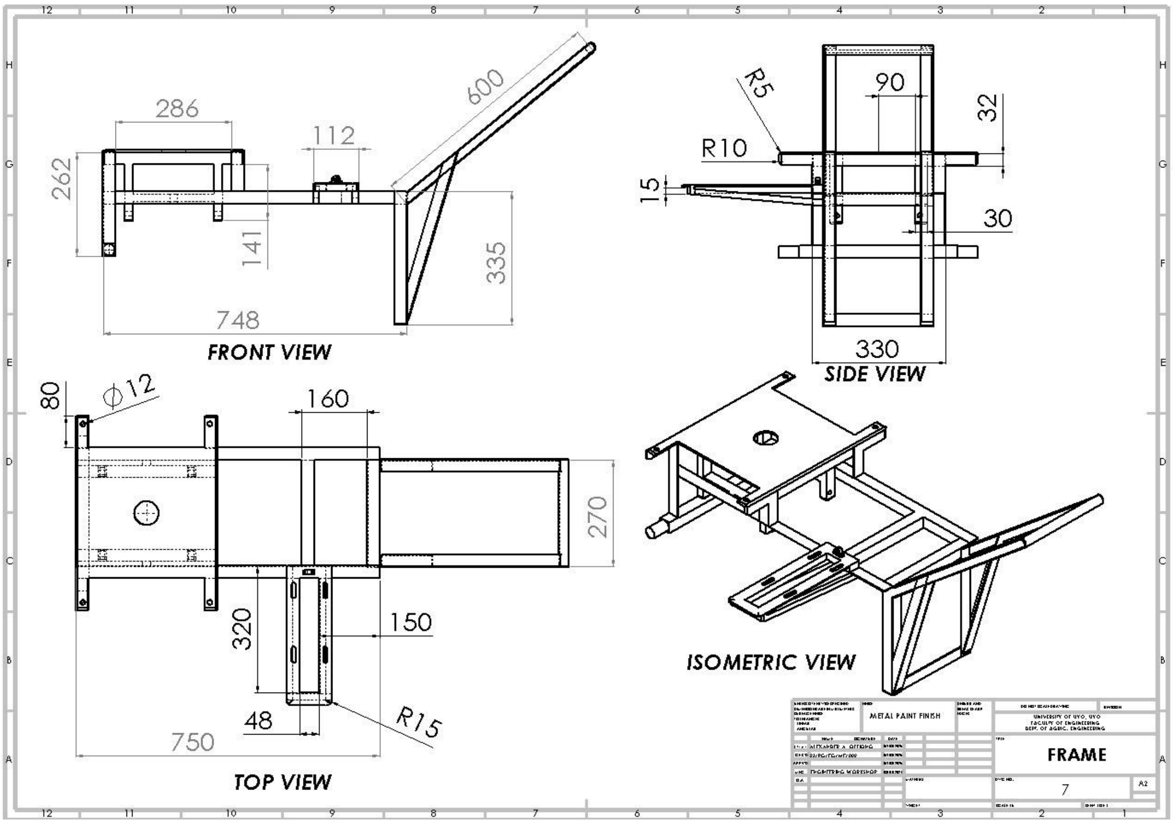

Figure 2.16: Component drawing of the vertical palm fruit digestion machine (Frame) by Reseracher (2025)

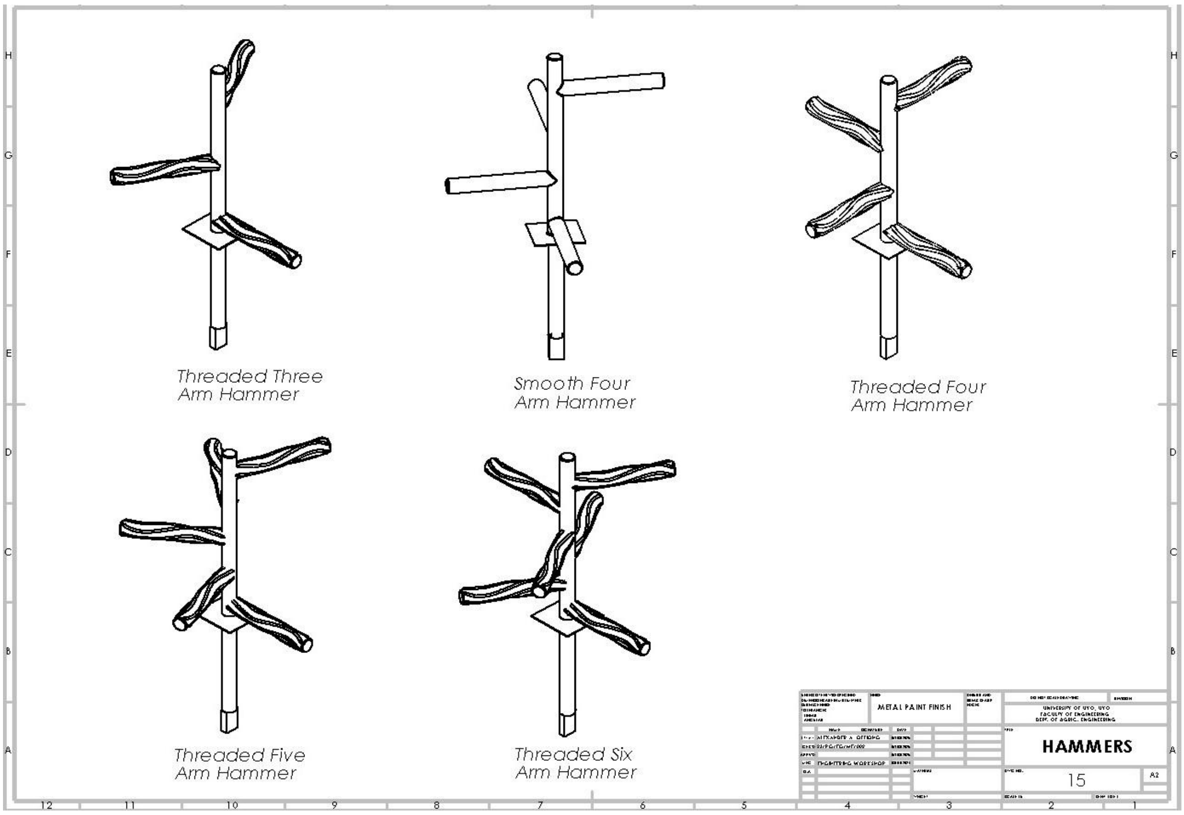

Figure 2.17: Component drawing of the vertical palm fruit digestion machine (Hammers) by Reseracher (2025)

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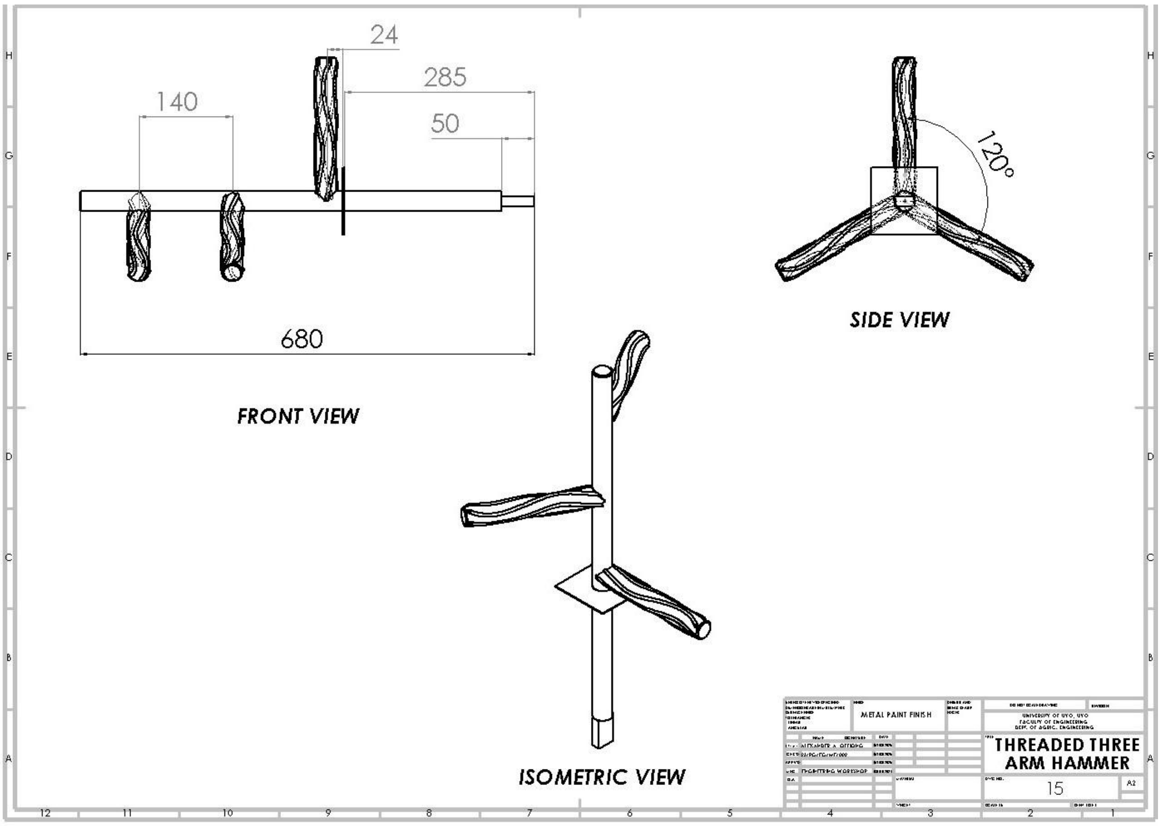

Figure 2.18: Component drawing of the vertical palm fruit digestion machine (Threaded Three Arm Hammer) by Reseracher (2025)

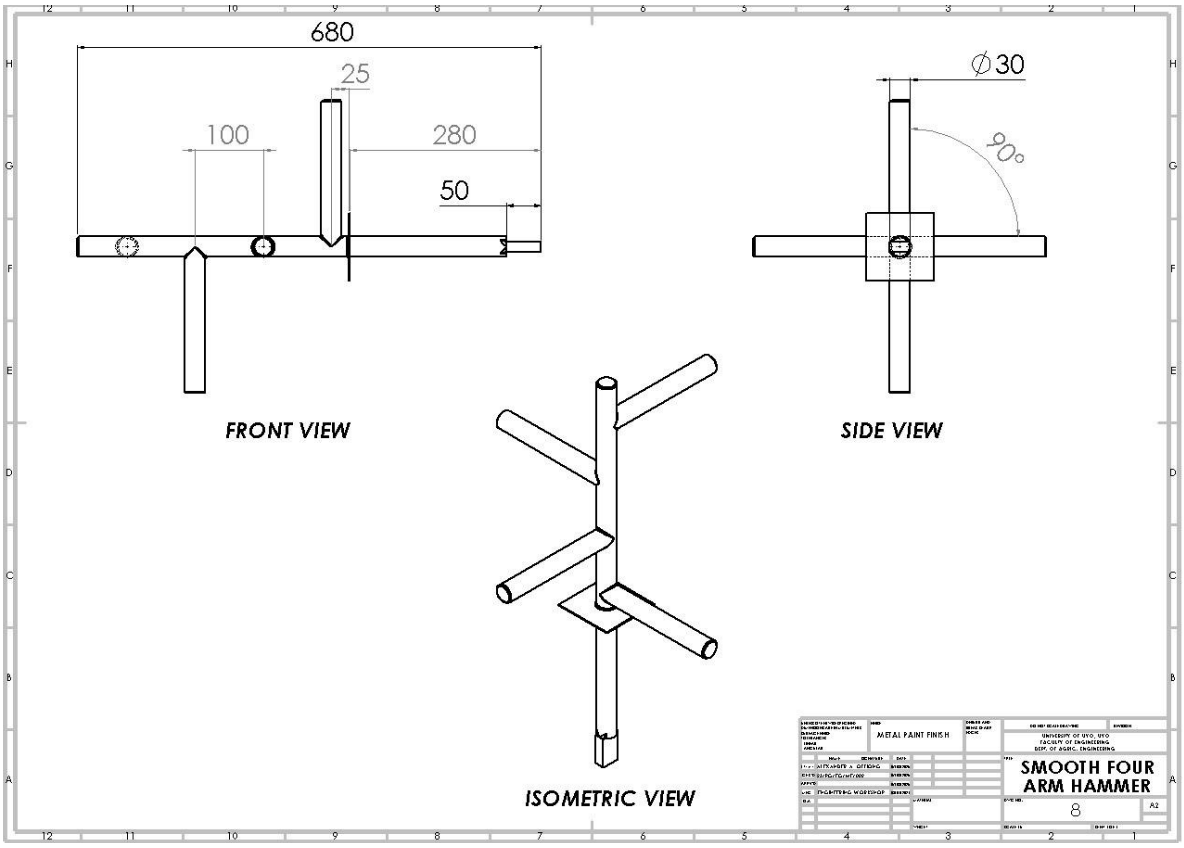

Figure 2.19: Component drawing of the vertical palm fruit digestion machine (Smooth Four Arm Hammer) by Reseracher (2025)

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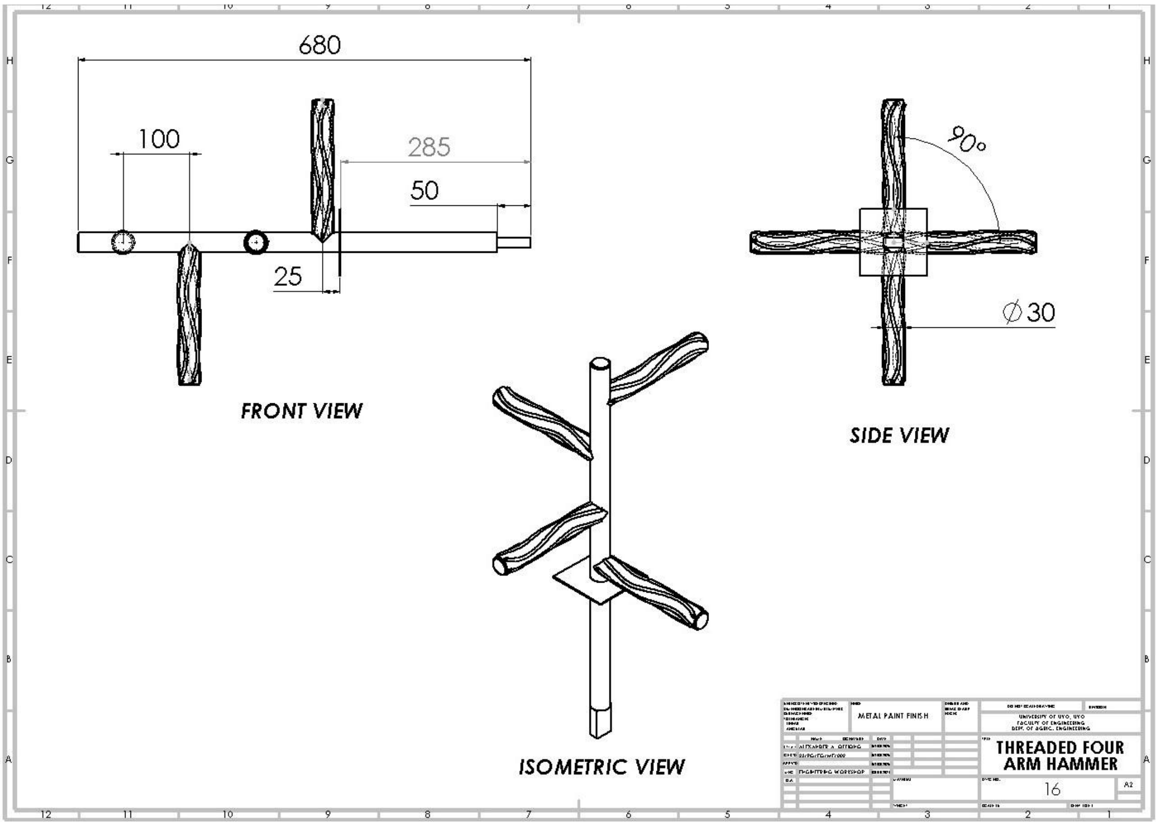

Figure 2.20: Component drawing of the vertical palm fruit digestion machine (Threaded Four Arm Hammer) by Reseracher (2025)

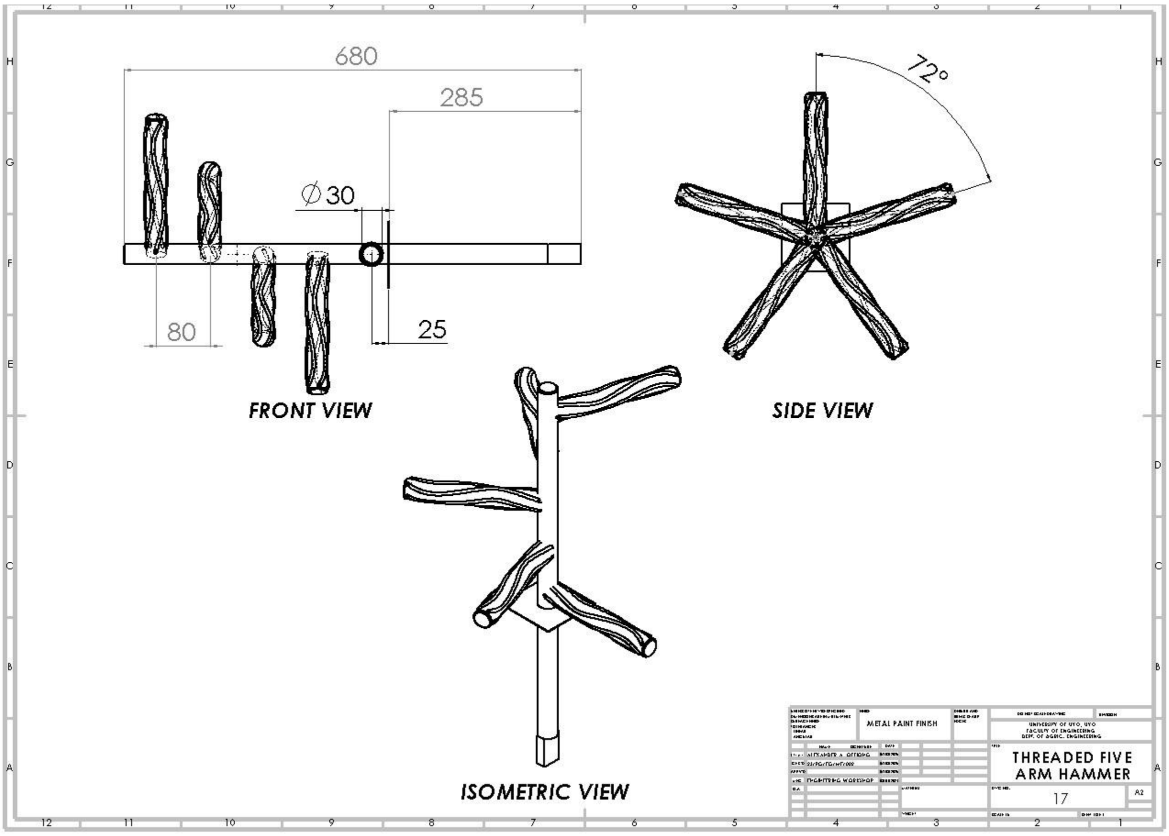

Figure 2.21: Component drawing of the vertical palm fruit digestion machine (Threaded Five Arm Hammer) by Reseracher (2025)

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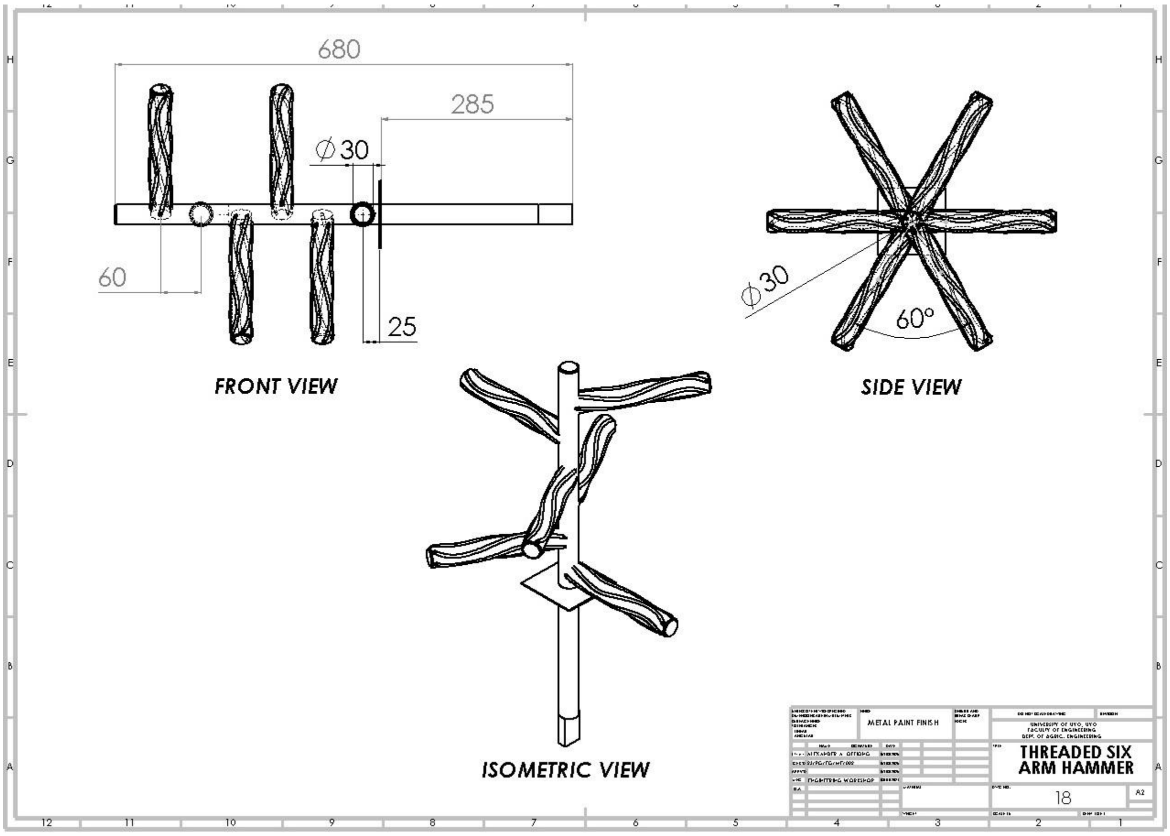

Figure 2.22: Component drawing of the vertical palm fruit digestion machine (Threaded Six Arm Hammer) by Reseracher (2025)

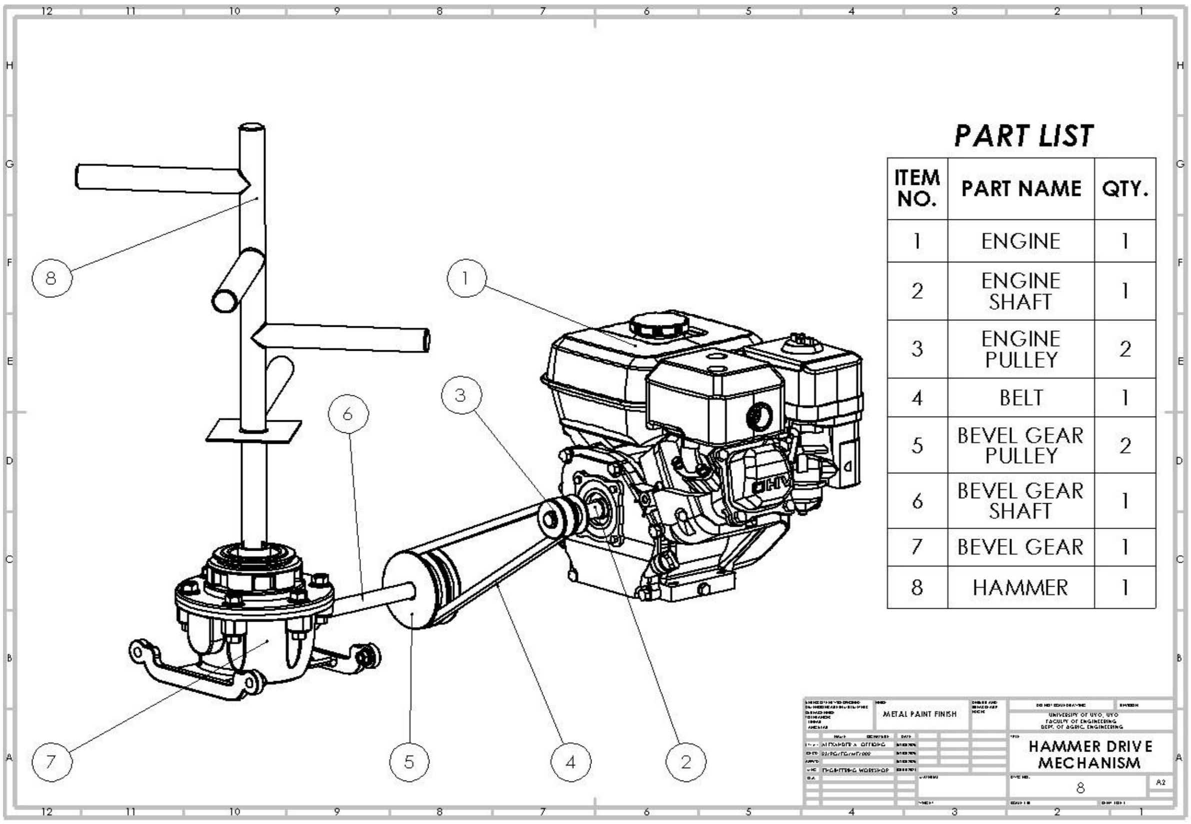

Figure 2.23: Component drawing of the vertical palm fruit digestion machine (Hammer Drive Mechanism) by Reseracher (2025)

DOI: 10.5281/zenodo.18647850

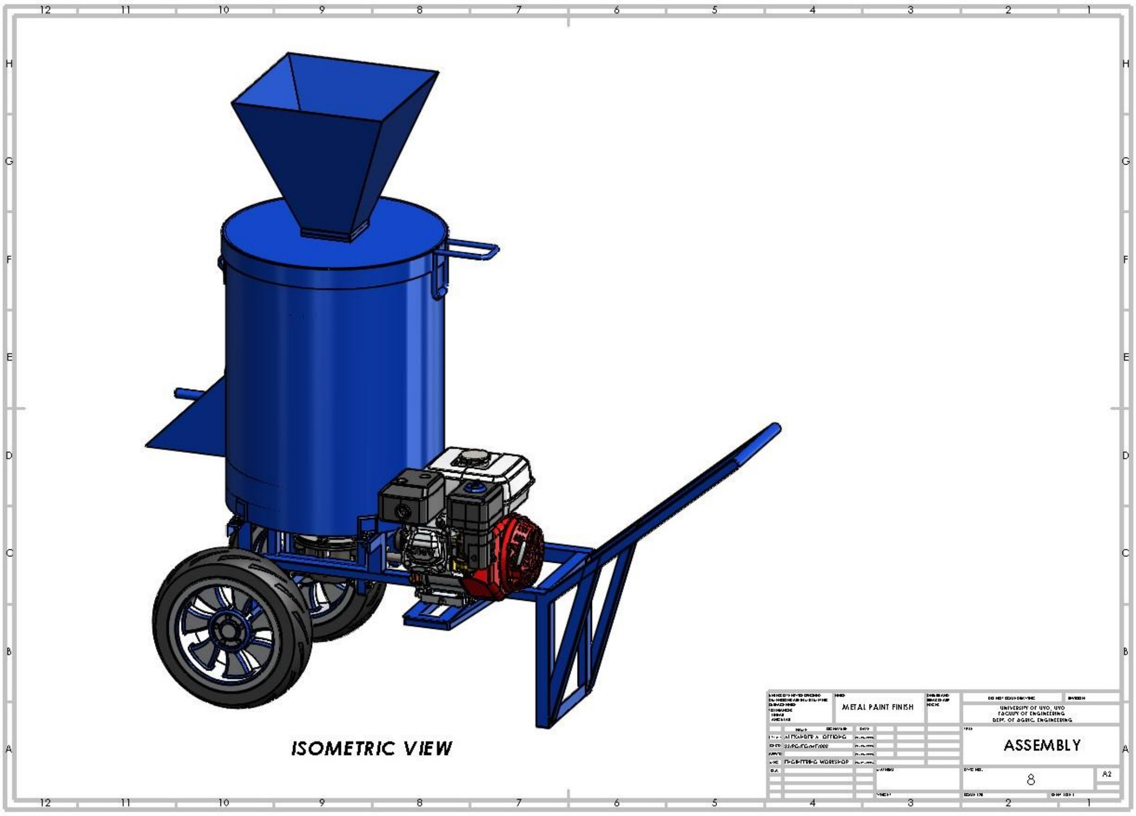

Figure 2.24: Three dimensional coloured model drawing of the vertical palm fruit digestion machine by Reseracher (2025)

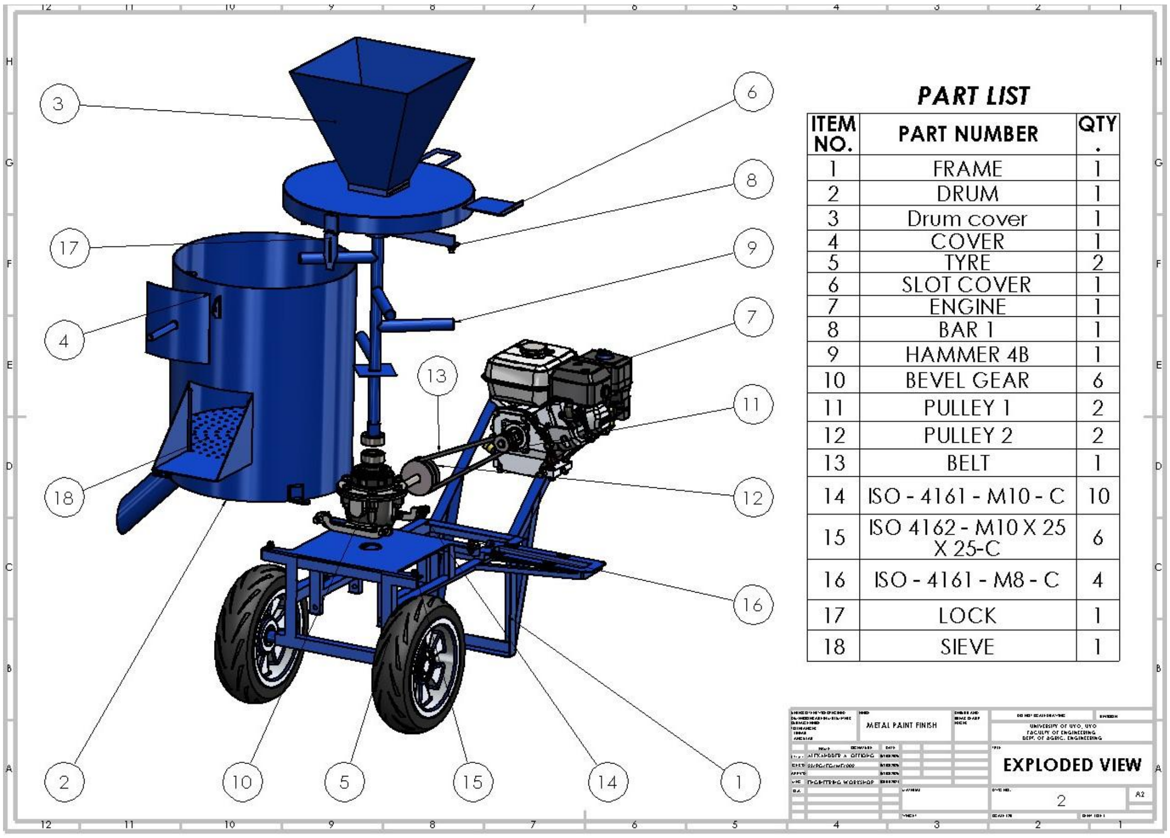

Figure 2.25: Exploded coloured view of model drawing of the vertical palm fruit digestion machine by Reseracher (2025)

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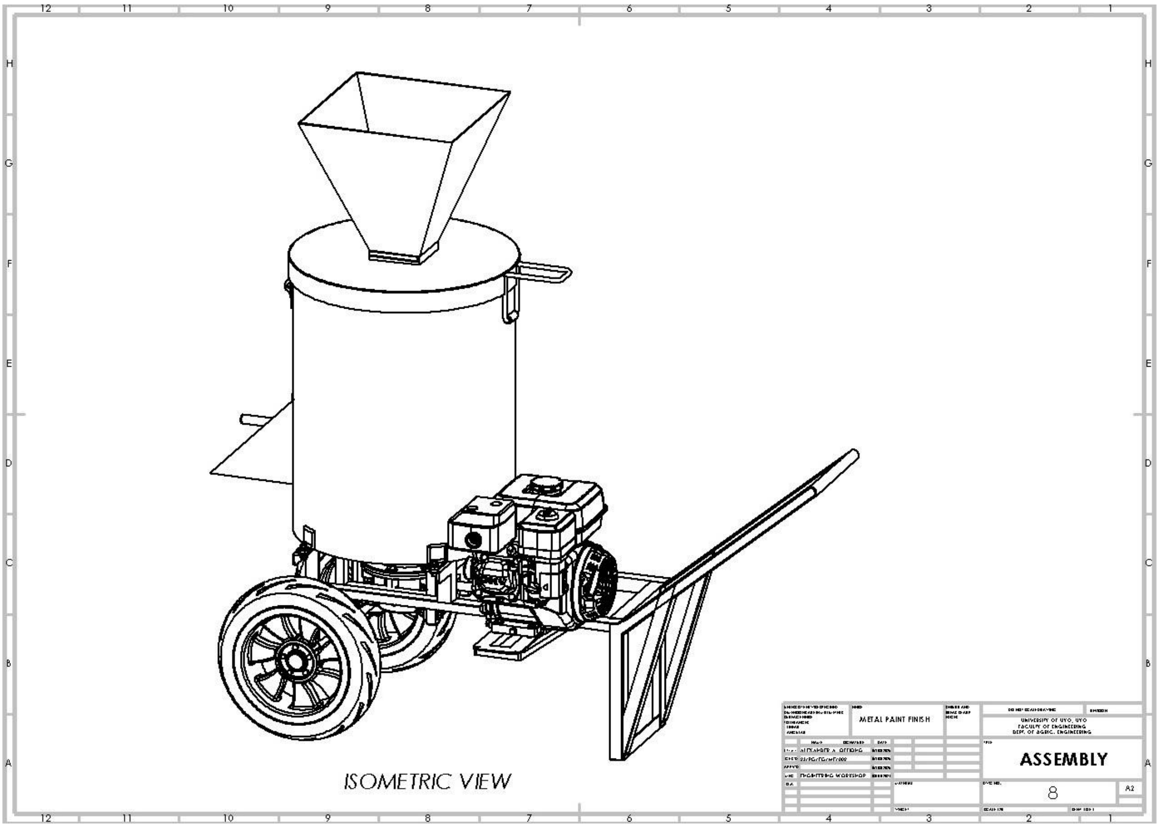
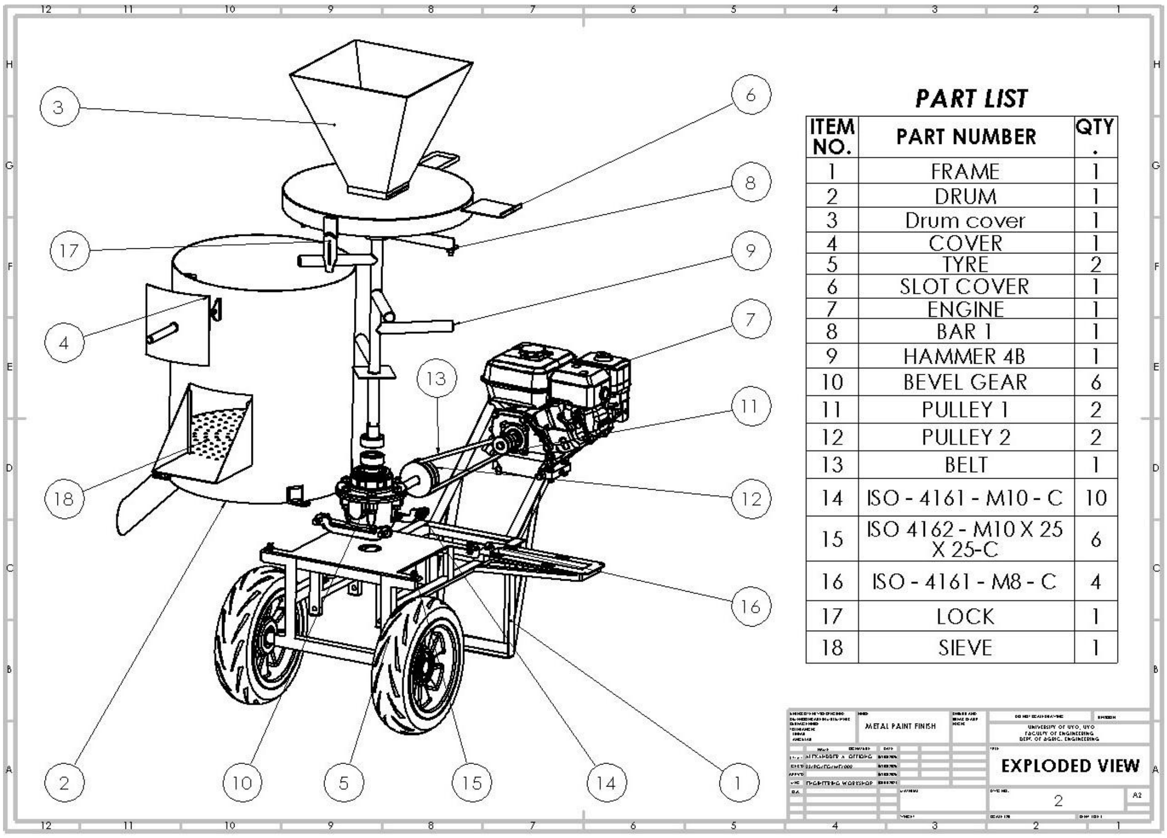


Figure 2.26: Three dimensional model drawing of the vertical palm fruit digestion machine by Reseracher (2025)



ITEM NO.	PART NUMBER	QTY.
1	FRAME	1
2	DRUM	1
3	Drum cover	1
4	COVER	1
5	TYRE	2
6	SLOT COVER	1
7	ENGINE	1
8	BAR 1	1
9	HAMMER 4B	1
10	BEVEL GEAR	6
11	PULLEY 1	2
12	PULLEY 2	2
13	BELT	1
14	ISO - 4161 - M10 - C	10
15	ISO 4162 - M10 X 25 X 25-C	6
16	ISO - 4161 - M8 - C	4
17	LOCK	1
18	SIEVE	1

Figure 2.27: Exploded view of model drawing of the vertical palm fruit digestion machine by Reseracher (2025)

2.2.5 Evaluation parameters of the Digestion Machine were determined.

The parameters involved in evaluating the developed palm fruit digestion machine include throughput (kg/hr) and efficiency (percentages). Equation (2.9) and equation (2.10) can be used to compute these parameters.

$Dc = 60\ [Wi/T]$ Equation 2.9

$ŋ = 100$ Equation 2.10

$Wd = Wi – Wu$ Equation2.11

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Dc is the rate of throughput or digestion (kg/hr) (Rate of digestion). Wi is the weight of feed of the palm fruit into the digestion machine (Initial weight of palm fruit). T is the average digestion time (minutes) is the efficiency (percentage)

Wu and Wd are the weight of undigested/partially digested palm fruit and the weight of the digested boiled palm fruits respectively. It has to be understood that in all the experiments initially the weight of the boil palm fruits will be noted as well as the weight of the undigested/partially digested boiled palm fruits and the time of digestion (Wd) will be made known and the weight of the digested boiled palm fruits (Wd) will be determined using the equation 3. To the information on the parameter used to assess palm fruit digestion machines (Asoiro and Udo 2013, Agbonkhese *et al*, 2018; Alam *et al.*, 2020; and Erhimona *et al* 2023).

2.2.6 Experiment to assess the performance of the developed machine

This was done by shopping a bulk sample of matured palm fruits of tenera specie of circa 2000kg that was obtained at one plantation in Nsit Atai. The palm fruit was checked to determine its quality. The fruits were cleansed to extract contaminated dirt and boiled in approximately an hour at 100^{o}C. The experimental process assumes the same approach as Agbonkhese *et al.,* (2018) with the difference that the test was performed to the 3,4,5 and 6 arm configuration with the same speed of 580, 600, 620, 640 and 660 rpm. Once the digester was assembled and installed with a specific arm configuration, there were experiments that would have been carried out with the boiled palm nuts. The fresh oil palm fruit of different weights was boiled and the boiled fruit digested through the hopper in the experimental plan after the duration, the machine was turned on. The stopwatch was to be used to record the digestion time taken when the digestion machine is used in the 3, 4, 5 and 6 arm hammer configuration and when running at the various speeds of 540, 580, 620 and 660 rpm. A tachometer was used to measure speed. The time in which proper maceration of the various weights of boiled fresh oil palm fruit is noted in every experiment.

The experiment was conducted by replacing the designed digester in an existing digestion machine within a farm in Vika Farm Limited, Idu road, Mbak Etoi, Uyo Local Government Area, Akwa Ibom State Nigeria. When this version of machine was eventually perfected, the farm was assured of being the first beneficiary of the machine. The weight of palm fruits that have not been digested appropriately will be divided and weighted in each run. Equation 1-3 will be used to calculate the digesting or throughput capacity of the machine (kg/h) and the efficiency (percentage).

Having identified the best setting of the digestion machine, another batch was conducted to identify this best setting Quantity and Quality of oil got during the developed machine under the use of sterilization time of 60, 90, 120, 150 and 180 minutes and under fruit storage period of 1,3,5,7 and 9 day.

At optimum setting of the digestion machine analysis was also done to give the performance of the machine when using threaded iron rod stirring mechanism in comparison to the smooth iron rod stirring mechanism. The variables of interest above include the amount of oil and the quality of the oil since the market/industrial survey has already indicated that threaded stirrer mechanism has more throughput and efficient that smooth stirrer mechanism.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Performance Testing of the Built Machine

Once the different parts of the palm fruit digesting machine were constructed, all the parts were combined and the machine was experimented to determine how it would perform when put together with (a) three blades; (b) four blades; (c) five blades; (d) six blades. The pictorial representation of the developed palm fruit digestion machine is depicted in Figure 3.1. The picturesque perspective of the component parts of the developed palm fruit digestion machine is depicted in Figure 3.2. Figure 3.3 a-d depicts results of test runs of the developed palm fruit digestion machine. (a) fresh palm fruit before being processed by the digestion machine; (b) un-separated palm fruit before being processed by the digestion machine; (c) digested palm fruit before being processed by the digestion machine and (d) undigested palm fruit before being processed by the digestion machine.

The results of the experiment conducted to identify the performance of the developed palm fruit digestion machine at the pace of 540, 580, 620 and 680 rpm when digesting 2kg, 4kg, 6kg and 8kg in different experiment configurations are presented in Table 3.1. The pictorial view of the developed palm fruit digestion machine is shown in Figure 3.1.

The pictorial view of the component part of the developed palm fruit digestion machine is illustrated in Figure 3.2.

Figure 3.1 shows the pictorial view of the developed palm fruit digestion machine

Figure 3.2 shows the pictorial view of the component part of the developed palm fruit digestion machine

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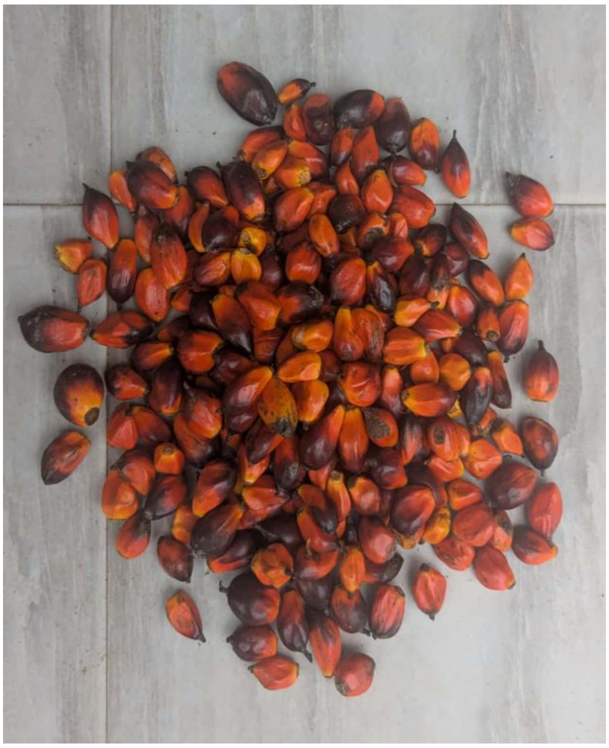

(a) Sample of fresh palm fruits before Being process in the digestion machine

(b) Sample of unseparated palm fruits after being process in the digestion machine

(c) Sample of digested palm fruits after being process in the digestion machine

(d) Sample of undigested palm fruits after being process in the digestion machine

Table 3.1: Experimental Results

	Factor 1	Factor 2	Factor 3	Response 1	Response 2	Response 3	Response 4	Response 5	Response 6
Run	A: Speed	B: Initial weight of palm	C: Number of Blades	Weight of digested fruit (Wd)	Weight of undigested fruit (Wu)	Digestion time (Tn)	Digesting capacity (Dc)	Efficiency (ŋ)	Viscosity of the Produced Oil

DOI: 10.5281/zenodo.18647850

		fruit (Wi)							
	RPM	Kg		Kg	Kg	min	kg/h	%	Pa.s
1	620	2	4	1.76	0.24	0.87	121	88.9	0.046
2	660	4	5	3.7	0.3	0.7	319	92.3	0.046
3	540	4	4	3.16	0.84	1.28	148	86	0.054
4	660	2	3	1.71	0.29	0.78	132	88	0.047
5	540	8	3	6.84	1.16	2.2	186	85	0.058
6	580	8	5	6.7	1.3	1.86	217	89.5	0.053
7	580	2	4	1.81	0.19	1.08	100	88.5	0.049
8	540	6	6	5.06	0.94	1.28	236	87.4	0.052
9	580	8	4	6.93	1.07	1.92	217	88.1	0.055
10	660	4	4	3.52	0.48	0.82	257	90.9	0.047
11	620	4	6	3.99	0.01	0.72	335	91.8	0.048
12	620	6	3	5.27	0.73	1.5	211	87.9	0.049
13	620	6	3	5	1	1.54	195	88.6	0.052
14	540	6	6	5.35	0.65	1.55	206	85	0.052
15	620	4	6	3.38	0.62	0.7	290	90.6	0.046
16	540	2	5	1.72	0.28	1.05	98	85	0.05
17	660	8	6	6.78	1.22	1.18	344	94.5	0.045
18	580	2	3	1.58	0.42	1.28	74	85.7	0.051
19	660	6	4	5.49	0.51	1.05	315	90.5	0.049
20	540	2	6	1.77	0.23	0.93	114	85	0.05
21	540	4	3	3.46	0.54	1.45	143	85.7	0.054

Table 3.2: Determination of Quantity and Quality of oil produced using a given quantity of palm fruit by using machine at optimal setting at different sterilization time.

S/N	Sterilization time minutes	Weight of sterilized palm fruit kg	Weight of kernel nut from digester kg	Weight of mesocrp from digester kg	Weight of mesocrp from press kg	Weight of crude oil from press kg	% of water content	% of Free-Fatty Acid content	∝ - Tocopherol Content in PPM	B-Carotene content in PPM
1.	60	4	2.0	2.0	1.2	0.80	1.0	1.1	920	700
2.	90	4	2.0	2.0	1.18	0.82	1.2	2.3	890	670
3.	120	4	2.0	2.0	1.16	0.84	1.3	3.5	840	630
4.	150	4	2.0	2.0	1.2	0.80	1.4	4.5	780	570
5.	180	4	2.0	2.0	1.3	0.70	1.5	5.9	680	500

Table 3.3 Breakdown of the Cost of the Developed Palm Fruit Digestion Machine by component/activity

S/N	COMPONENT/ACTIVITY	ESTIMATE COST (₦)
1.	Frame Assembly	20,000.00
2.	Hopper Unit	10,000.00
3.	Bearings	7,000.00

DOI: 10.5281/zenodo.18647850

4.	Bearing Cover	6,000.00
5.	Chamber Digesting	12,000.00
6.	Blades	5,000.00
7.	Shaft	7,000.00
8.	Pulley	8,000.00
9.	Rolling Tyres	10,000.00
10.	Finishing/Painting	10,000.00
11.	Gasoline Motor	100,000.00
12.	Labour	18,000.00
	Total	**600,000.00 ($400)**

3.2 Discussion

3.2.1 Analysis of the Quantity and Quality of Oil Obtained by the Developed Digestion Machine.

Table 3.1 shows the experimental results and Table 3.2 shows the determination of quantity and quality of oil produced using a given quantity of palm fruit by using machine at optimal setting at different sterilization time. The designed digestion machine was evaluated in regards to two major parameters, namely, the amount of oil produced (throughput and yield) and the quality of the oil produced (with the measures of moisture content, free fatty acid levels, viscosity, and retention of micronutrients), see Tables 3.1 and 3.2. The findings confirm that operating conditions, including sterilisation time, storage time, shaft speed, and blade design, have a strong effect on machine performance (Adebayo, 2004; Alade et al., 2020; Alade et al., 2021).

Regarding the machine, the digesting capacity remained high under different machine-set-ups with the highest conditions producing an above 340 kg/h and at a 94% of efficiency. These values draw our attention to the fact that the machine will maximize the release of oil in order to provide maximum maceration of the mesocarp and minimise residues that are not digested (Stephen and Emmanuel, 2009; Ekine and Onu, 2009;Aniekan 2025). Smaller batch sizes and decreased shear forces were linked to lower capacities (less than 120 kg/h) and proved that optimal combinations of speed, batch weight, and blade number are required. Processing conditions also influenced the quality of oil. Optimal sterilisation (120 minutes) and storage (3 days) resulted in oil that contained low amounts of water and low free fatty acids with 3 days maintaining its 0 tocopherol and 0 -carotene. Long sterilisation or long storage however resulted in an increase in FFA, decrease in antioxidants, and colour decay, which are indicators of oxidative degradation (Ibrahim and Onwalu 2005; Adeniyi, et al., 2014; Adetola, et al., 2014; Agbonkhese, et al., 2018; Aniekan 2025).

3.2.2 The Cost of Production and Running the Palm Fruit Digestion Machine

The success of implementing newly designed agricultural machines is not only determined by the efficiency of such machines in terms of their technical efficiency but it is also influenced by the cost of production and use of such machines. To this effect, cost analysis of the developed mobile vertical palm fruit digestion machine was done in details. The cost to construct the machine is estimated as shown in Table 3.3 as follows, by major construction components and fabrication activity:

In the table, the total cost of producing the machine is ₦600,000 ($400) and the most expensive part of the machine is the gasoline motor which was ₦100, 000 ($66.67) whose value is approximately 16.7 percent of the total cost. The frame, hopper, digesting chamber, and shaft are moderate costs that are easy to handle in the local market, since mild and stainless steel are available. The cost of fabrication for labor was ₦18,000 ($12) and finishing was ₦10,000 ($6.67) which is still relatively low, which implies that small-scale workshops have the capacity to re-produce the machine without more restrictive overhead expenses. The locally-developed machine is also much cheaper than imported palm fruit digestion machines, which can range between ₦2,000,000 ($1333.33) and ₦3,500,000 ($2333.33) depending on capacity and specifications. This affordability will make it available to rural cooperatives, small-scale processors, and community-based businesses, which is why it supports the local content policy in Nigeria and lessens reliance on imported equipment. The running cost, besides capital cost, is also vital to long-term sustainability. A gasoline motor powers the machine at a fuel consumption rate of about 1.2 litres per hour. The fuel cost will be ₦840 ($0.56) per hour at a petrol price of approximately ₦700 ($0.47) per liter. With the optimised machine throughput of 289.3 kg/h and efficiency of 90.2, the fuel price represents a cost of less than 3% per kilogram of palm fruit carried through the machine. This production efficiency gives smallholder farmers a competitive advantage because manual processing as it was initially used involves multiple labourers, a lengthy process and in most cases the yield is still low. Maintenance is also optimised as there is the utilisation of standard bearings, pulleys and mild steel components which are easily acquired in the local markets. Routine maintenance, e.g. lubrication, tightening of bolts and a few times changing of belts or bearings costs less than ₦30000 ($20) per annum which is small compared to the revenue earned due to constant running. The mobility of the design with rolling tyres further lowers the costs of transportation as the digester can be driven to the processing sites in the rural settings (Aniekan, 2025).

4. CONCLUSION

This work ‘Design and Production of a Vertical Palm Fruit Digester’ has been carefully carried out. The digester was initially conceived to meet design requirements like functionality, strength and robustness, corrosion resistance, capacity delivery, aesthetics, efficiency and others. To achieve the design requirements design software and laptop was used for the engineering drawing of detailed parts and assembly drawing, while design calculations and analysis of loads and forces acting on the vertical palm fruit digester was carried out to assist in the materials selection for the production of the digester. The detailed parts were produced

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according to the design and standard parts selected in line with design calculations. The digester was assembled using welding machine, bolts and nuts and the right fastening strength and technique was used to ensure rigidity and prevent leakages. The digester was then evaluated for performance and the following conclusions were drawn from the study:

1. A vertical palm fruit digester was designed, produced and tested.
2. The designed digestion machine was evaluated in regards to two major parameters, namely, the amount of oil produced (throughput and yield) and the quality of the oil produced (with the measures of moisture content, free fatty acid levels, viscosity, and retention of micronutrients). The findings confirm that operating conditions, including sterilisation time, storage time, shaft speed, and blade design, have a strong effect on machine performance.
3. The machine digesting capacity remained high under different machine-set-ups with the highest conditions producing above 340 kg/h, and at 94% efficiency.
4. Optimal sterilisation (120 minutes) and storage (3 days) resulted in oil that contained low amounts of water and low free fatty acids with 3 days maintaining its 0 -tocopherol and 0 -carotene. Long sterilisation or long storage however resulted in an increase in FFA, decrease in antioxidants, and colour decay, which are indicators of oxidative degradation
5. The total cost of producing the machine is ₦600,000 ($400) and the most expensive part of the machine is the gasoline motor which was ₦100, 000 ($66.67) whose value is approximately 16.7 percent of the total cost.
6. The locally-developed machine is also much cheaper than imported palm fruit digestion machines, which can range between ₦2,000,000 ($1333.33) and ₦3,500,000 ($2333.33) depending on capacity and specifications.
7. This affordability will make it available to rural cooperatives, small-scale processors, and community-based businesses, which is why it will support the local content policy in Nigeria and lessen reliance on imported equipment.

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