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Evaluation of Traditional and Recent Fruit Pulp Extraction Machines

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Abstract

Fruit pulp extraction machines have long been utilized; however, the limitations of traditional models have prompted a critical examination of their efficiency and functionality. Despite the widespread cultivation of fruits, particularly in tropical & subtropical region, a significant portion of the fruit goes to waste during peak seasons due to inadequate extraction methods. This issue necessitates the development of suitable mechanisms that can optimize the post-harvest fruit processing. Various efforts to mechanize the pulp extraction process have led to the creation of both manual and electric machines, yet many of these options remain cumbersome, inefficient, and demanding in terms of time and energy consumption. As the demand for effective pulp extraction increases, there is a clear need for a re-evaluation of existing technologies to ensure they meet economic and user-friendly standards. By exploring and improving upon these mechanisms, it becomes possible to create solutions that are not only effective but also accessible to farmers and consumers. Addressing the challenges in pulp extraction will not only enhance operational efficiency but also reduce the waste, thereby maximizing the economic potential of fruit cultivation & profitability of fruit industry.

Keywords: *Extraction efficiency, Extraction loss, fruit pulp extraction, Juice extractor, Juice yield, Pulp yield.*

1. Introduction

A Fruit Pulp Extraction Machine is a device capable of extracting pulp from edible portion of the fruits and vegetables. The types of fruit that can be pulped vary depending on the design of the Extractor [1]. A pulp can be extracted, typically by squeezing, pressing or crushing. Pulp extractors come in various types, distinguished by how they operate. The operational steps in fruit pulp extraction include sorting, grading, washing, peeling, cutting, juice formulation, clarification, storage, and packaging [2]. In India more than 20–25 percent of fruits and vegetables are spoiled before utilization. Despite being the world's second largest producer of fruits and vegetables, in India only 1.5 percent of the total fruits and vegetables produced are processed to pickles, fruit and vegetable drinks, tomato ketchup, fruit jelly, candy, juices, jam, and dried and fried fruits [3]. Due to this spoilage at different stages, the farmers have been losing approx. 30% and 40% of the value of their fruits before they reach the final consumer. These losses are observed during harvesting, handling, packaging & storage, transportation, processing stages, distribution & consumption [4].

Fruit processing and preservation play an important role in the conservation and better utilization of fruits in order to avoid the glut during season and utilize the surplus during the off season. The fair returns to the growers can be ensured if they deliver the semi-processed fruit products such as pulps & purees to the food industries for manufacture of consumer oriented finished products such as jams, jellies, syrups, fruits in syrup, etc [5]. Traditionally, pulp was extracted manually, which is a slow, labour-intensive and less hygiene, but the introduction of machines revolutionized the process as demand for semifinished product like pulp & puree increased [6]. The advantages of using machines for pulp extraction include time savings, enhanced efficiency, increased production capacity, and reduced spoilage and waste, while manually operated pulp extractors are available for home use, they typically offer limited output [7]. Electrically operated pulp extractors are generally equipped with components such as an electric motor, belt & pulley and bearings along with feature parts like a hopper that feeds fruit into the extraction chamber contains an array of strategically arranged beater blades & sieved cylinder, a pulp outlet and a waste bin for discarding residual waste [8].

As there are currently no superior methods for preserving fruits, pulp extraction has proven to be the most effective preservation technique. This extraction process allows fruit pulp to be stored for months or even years without spoiling. Therefore, there is a need for evaluation of different types of existing traditional & recent fruit pulp extraction machines.

2. Classification of Fruit Pulp Extraction Machine

Pulp Extraction Machine crushes, squeezes, and grinds the fleshy tissues of edible portion of the fruits. There are several types of pulp extractors, each designed to work best with specific varieties of fruits. Pulp Extraction Machines are classified into three main categories: centrifugal, masticating & triturating pulp extractors [9].

2.1. Centrifugal Pulp Extraction Machine

Centrifugal Pulp Extraction machines are known for their quick processing and most cost-effective motorized fruit pulp extractors. They feature a mesh chamber where sharp blades spin at high speeds to grind them in the form of pulp. These machines are equipped with advanced features that enable them to process pulp in just seconds. With a large feeding chute, they can accommodate whole pieces of fruit without the need for extensive pre-processing, significantly reducing preparation time. However, the high-speed operation of centrifugal pulp extractor can generate noise, heat, and oxidation in the pulp. The heat produced can break down certain enzymes and nutrients, while the introduction of air leads to oxidation, resulting in a loss of nutrients and a decrease in pulp quality and shelf life [10]. Key components of a centrifugal pulp extractor include the plunger, top cover, top latch assembly, top blade, bottom blade, basket, pulp bowl, and mesh screen. Brands like Breville, Omega, Hamilton Beach, and Black and Decker manufacture these pulp extractors. The advantages of centrifugal pulp extractors include their quick processing and cleaning times, ease of assembly and disassembly, compact design for processing and affordability.

2.2. Masticating Pulp Extraction Machine

A masticating pulp extraction machine utilizes a screw worm shaft, the fruits while passing through the screw worm shaft are get pressed and crushed to form pulp in the designated compartment. These pulp extractors are also known as single auger pulp extractor or slow pulp extractor, as they take longer to produce fruit pulp compared to centrifugal pulp extractor [11]. Based on the design, masticating pulp extractors are categorised in two main types: vertical and horizontal models. Vertical masticating pulp extractor have larger augers and feeding chutes, allowing for more efficient processing. In contrast, horizontal models feature smaller feeding chutes, which can be prone to blockages due to the positioning of the pulp ejector. To mitigate this issue, it's essential to pre-cut the produce before feeding it into the machine. Unlike centrifugal juicers that operate at high speeds, masticating machines work at a slower pace, effectively crushing and squeezing produce to extract pulp. This method reduces oxidation, ensuring that the pulp retains more of its vitamins and enzymes, which is essential for health-conscious consumers [12].

Masticating machine consists of hopper, auger screw, perforated screen, spinning brush, serve multiple functions, acting as both a grocery processor and grinder. Despite their slower operation, they excel at juicing & pulping of both hard and soft produce, such as kale and oranges and deliver exceptional juice quality by minimizing heat exposure, which can destroy enzymes and antioxidants. These machines provide high yield with improved quality but tend to be more expensive due to their robust construction and versatility [13].

2.3. Triturating Pulp Extraction Machine

Triturating Pulp Extraction Machine also known as twin-gear pulp extractor, which utilizes two interlocking gears designed to crush, grind, and extract pulp from various agricultural produce at low speeds. This method results in smooth, nutrient-rich juices with a pulsating texture [14]. These machines are equipped with an adjustable knob that allows users to modify the back pressure, providing greater control over the extraction process for different types of produce with varying firmness, which enhances juice yield. Triturating juicers are generally heavier and bulkier, making them more suitable for commercial use rather than home kitchens [15].

3. Manually operated fruit Pulp Extraction Machine Operational Assessment

3.1. Multipurpose Fruit Pulp Extraction Machine

The machine comprised of two major parts, extraction chamber & structural frame. The extraction chamber made of food grade stainless steel featured with several essential parts, including a turning handle, a screw rod, a compression plate, a perforated inner cylinder, a non-perforated outer cylinder, and a discharge pipe. The structural frame is constructed from mild steel in a U-channel section, providing stability and support to the entire machine. The machine uses compressive force to extract pulp from fruits. The performance evaluation of the machine revealed that the impressive results obtained for pineapple fruit with 68.74% pulp yield, extraction capacity of 92.85 g/min, and extraction efficiency at 82.99%. In contrast, sweet orange and lime demonstrated the lowest extraction loss of 1.67% accompanied with lower extraction capacity of 29.81 g/min recorded [16]. These findings highlight the effectiveness of the machine in extracting pulp, particularly from pineapple, while also noting the less efficient extraction characteristics of lime. The efficiency observed in manual extraction can likely be attributed to factors such as the skill level of the operator, the design of the extractor, and the inherent characteristics of the fruits.

3.2. Multi Fruit Juice Extractor

The manual juice extractor functions by masticating sliced fruits while simultaneously extracting juice. It incorporates a PTFE screw conveyor that compacts and crushes the fruit against a static sieved cylinder. This

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design allows juice to flow through the screen, while the pulp is expelled through a separate outlet, ensuring effective separation of liquids and solids. The machine achieved average juice yield of 57% for watermelon, 53.6% for orange, and 52.9% for pineapple, the extraction efficiencies recorded were 71.3% for watermelon, 65.8% for orange, and 63.8% for pineapple & the extraction losses were relatively low, with values of 2.5% for watermelon, 4.3% for orange, and 3.5% for pineapple [17]. Notably, watermelon exhibited the highest extraction efficiency among the three fruits analysed, aligning with the findings of Aviara et al., 2013 [18], who also reported superior extraction efficiency for watermelon among peeled fruits.


Fig.1(a). Photograph of the manual fruit juice extractor [17]

Fig.1(b). Photograph of the multi fruit juice extractor [18]

3.3. Orange Juice Extractor

This orange juice extractor is a specially designed and constructed machine with a diameter of 160 mm and a height of 350 mm. It features small sharpened blades coupled to a rotating shaft, powered by a bevel gear drive mechanism that facilitates efficient juice extraction. The machine is manually operated by turning a handle, which rotates the components to perform both extraction and maceration of the fruit, enhancing both efficiency and ease of use. The orange juice extractor consists of two main components, a goblet and a physically operated mechanism. The mechanism includes a pair of bevel gears, two bearings, and two shafts encased in a housing. These components are assembled to form the drive system, which includes the handle, small sharpened blades, impeller shaft, bearings, dynamic seals, and a leak-proof goblet. Performance testing of the machine revealed that it could process approximately 180-220 oranges per hour, demonstrating its efficiency in high-volume juicing tasks [19].

3.4. Household Citrus Pulp Extractor

The household manual pulp extractor operates using the rack and pinion mechanism, a linear actuator system that converts rotational motion into linear movement. In this setup, the pinion which is a circular gear engages with the rack, a bar featuring teeth. As the pinion rotates, it causes the rack to move linearly, resulting in a translational motion. In this arrangement, the rotation of the lever arm turns the pinion, which in turn drives the downward movement of the rack arm that rests on the strainer or perforated sieve. This motion effectively squeezes the fruit against the sieve, the extracted pulp is then deposited into a collection cup, making the process efficient and straightforward for users. The results of the performance evaluation indicate that the highest pulp yield for peeled fruits was 54.50% for oranges, 55.90% for lemons, and 53.40% for limes. In contrast, the yield for unpeeled fruits was higher with 59.50% for oranges, 61.50% for lemons, and 66.30% for limes. The maximum extraction efficiency noted with peeled oranges achieving 59.20% and unpeeled oranges reaching 69.50%. For lemons, the extraction efficiency was 57.50% for peeled and 66.10% for unpeeled. Similarly, for limes, the highest efficiencies were 55.30% for peeled and 61.70% for unpeeled. The extraction losses for peeled oranges had 10.90%, while unpeeled oranges had a significantly lower loss of 1.73%. For lemons, the losses were 9.70% for peeled and 3.8% for unpeeled. Limes showed losses of 8.80% for peeled and 4.20% for unpeeled [20]. These findings highlight the advantages of leaving the peel on for optimal pulp extraction.

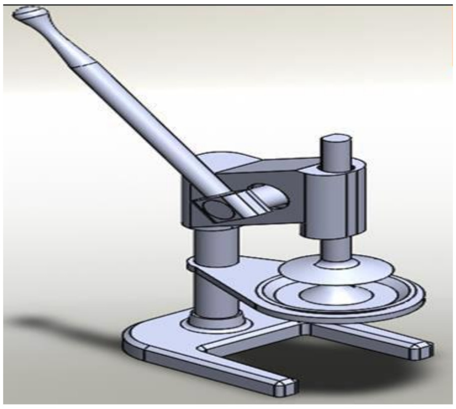

Fig 2. 3D Model of household citrus pulp extractor [20].

4. Electric Power Operated Fruit Pulp Extraction Machines

4.1. Masticating Machines

In testing the masticating machines, the mass of pulp left in the waste product was determined following the technique outlined by the American Society of Agricultural Engineers (1982). This method involved oven-drying the chaff at 130˚C until a constant weight was achieved. A stopwatch was used to record the extraction time, while a weighing balance measured the mass of both the extracted juice and the remaining chaff. The experiment was replicated five times for a multipurpose extraction machine, it was repeated three times for each type of fruit. The tests were conducted at various extraction speeds, which were adjusted through a gear arrangement to optimize performance. The key performance indicators, including pulp yield, extraction efficiency, and extraction loss, were calculated using the equations given by Olaniyan A.M., et al. 2011 [21].

- **Pulp Yield (J_Y) :** $\mathrm{J_y} = \frac{W_{JE}}{W_{JE} + W_{RW}}\ X\ 100$ (1)
- **Extraction Efficiency (EF)**: $EF = \frac{W_{JE}}{XW_{FS}}\ X\ 100$ (2)
- **Extraction Loss (EL) :** $\mathrm{EL} = \frac{[W_{FS} - (W_{JE} + W_{FS})]}{W_{FS}}\ X\ 100$ (3)

Where:

W_{JE} = Weight of Juice Extracted

W_{RW} = Weight of Residual Waste

XW_{FS} = Weight of Fresh Sample (the total mass of the fruit before extraction)

4.1.1 Motorized Ginger Juice Expression Machine

The motorized ginger juice expression machine is designed with several key components that work together to efficiently process ginger. These include, feeding unit, pulverizing unit, juice expression unit, juice outlet, waste outlet, Frame & Power Transmission System. The machine efficiently performs two key operations simultaneously, size reduction and separation. Ginger rhizomes are introduced into the pulveriser via the hopper, where they passed through the shearing and rubbing mechanisms, the screw shaft in the expression unit crushes, presses, and transports the pulverized ginger. This action effectively squeezes the juice from the ginger rhizomes. The extraction occurs as the screw shaft compresses the pulverized material against itself and the surface of the perforated cylindrical barrel throughout its movement. The extracted juice flows through a dedicated channel into the outlet, where it is collected for further use. Meanwhile, the residual waste is funnelled into a separate waste outlet, ensuring a clean and efficient operation. This design not only maximizes juice yield but also simplifies the overall process of ginger juice extraction. The results indicated that the mean expression of the machine decreased as the screw shaft speed increased and as the moisture content of the ginger decreased within the studied ranges. The peak expression efficiency recorded was 91.62%, with a juice yield of 61.28%, achieved at a screw shaft speed of 420 rpm and a moisture content of 72% [22].

Fig 2. Motorized Ginger Juice Expression Machine [22].

4.1.2 Motorized Multi Fruit Pulp Extraction Machine

The machine operates with a power requirement of 1.17 kW and is driven by a 1420 rpm electric motor. The extraction capacity and efficiency of the machine were evaluated, revealing an average pulp extraction capacity of 5.10 kg/hr for oranges with an extraction efficiency of 78.78%. For grapes, the machine achieved a pulp extraction capacity of 2.79 kg/hr and an efficiency of 75.66%. In comparison to manual extraction methods, the pulp extractor demonstrated a capacity increase of 280% for orange and 220% for grape. Using a domestic extraction cup further improved the orange pulp extraction capacity by 304%, while it increased for grape pulp extraction by 180%. The introduction of a straight auger to replace the tapered one significantly enhanced the pulp extraction efficiency to 89.20%, with a pulp extraction capacity of 15.8 kg/hr for sweet oranges. The shaft speed of the machine was analysed in conjunction with different grades of fruits categorized by size and thickness to assess their impact on extraction efficiency and capacity. The tests employed fruit thicknesses of 20 mm, 40 mm, and 60 mm, and extractor shaft speeds of 300, 400, 500 and 600rpm. Results indicated that extraction efficiency and capacity exhibited a strong quadratic relationship with speed across the various fruit thicknesses tested. Notably, a clear linear relationship was observed between extractor shaft speed and capacity specifically for 60 mm thick apples [23].

4.2 Orange Juice Extractor

The components of the extractor include a hopper, slicing chamber, extracting chamber, frame support, and channels for both juice and waste discharge. The machine is powered by 2 hp electric motor, which enhances its operational efficiency and effectiveness in extracting juice from various fruits. A motorized juice extractor machine was yielding fruit extraction rates of 38.00% for oranges, 51.43% for pineapples, and 39.67% for golden melons. The extraction efficiencies were recorded at 65.47% for oranges, 83.94% for pineapples, and 53.17% for golden melons, with corresponding juice extraction losses of 6%, 9%, and 28% for these fruits, respectively. [24].

4.3. Mechanized Fruit Pulp Extraction Machine

The mechanized fruit pulp extraction machine serves the dual purpose of slicing and extracting pulp from fruits and vegetables. It utilizes various components to achieve this, including slicing blade screw conveyor shaft, hopper, electric motor, gear train, conical resistor, juice collector, waste collector, barrel & ball bearings. The machine exerts shear and compressive forces to efficiently extract pulp. The fruits are fed into the hopper, the shaft which is driven by a gear train, rotates counterclockwise, activating the slicing blade that cuts the fruit and transfers it to the conveyor for squeezing. The pulp flows through the holes in the cylindrical chamber of the conveyor and enters the collection tank. Meanwhile, the residual waste, is directed to the barrel, where it is collected in a designated waste collector. This machine operates continuously, allowing for the simultaneous feeding of fruit, squeezing, extracting pulp and drawing away the chaff. This efficient design streamlines the juicing process, making it suitable for high-volume production. This masticating machine features a robust construction and a convenient tabletop design with dimensions of 500 mm x 300 mm, making it suitable for both domestic and commercial activities. The machine is capable to deliver 14.5lit/min pulp with the extraction efficiency of 67% [25].

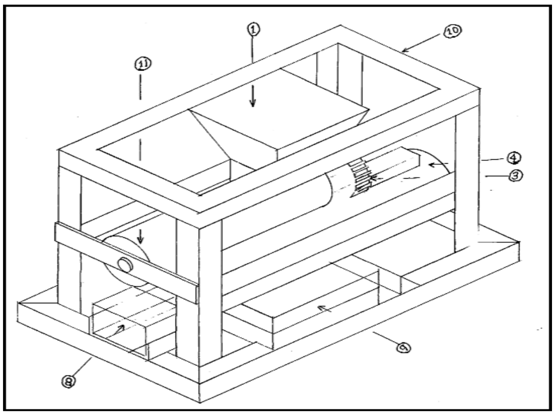

Fig. 3: Isometric view of the Fruits Juice Extracting Machine: 1 - Feed hopper, 2 - Slicing blade, 3 – Conveyor shaft, 4 - Juice collector, 5 - Waste collector, 6 - Electric motor, 7 Gear train, 8 -Barrel, 9 - Ball bearing & 10 - Main frame [25].

4.4. Mango Pulp Extraction Machine

The mango pulp extraction machine consists of feed hopper, pulp extraction compartment, pulp outlet, power unit & frame. The pulp extraction compartment of the machine comprised of a cylindrical sieve inside this a shaft conveyor equipped with teflon brushes and supported by pulleys with bearings at both ends. The screw shaft drives the auger conveyor and the sieve, both of which are constructed from food grade stainless steel (SS-304) material. The pulley is is mounted on the screw shaft, transmits power from the electric motor (3 hp, 3-phase) to the pulp extraction compartment via a V-belt drive. The V-belts allow for adjustable speed settings, enhancing the machine's versatility. The optimum operating speed of electric motor used for pulp extraction is 900 rpm & the ideal feed rate is 2.5 kg/min, The results indicated that the mango pulp extraction machine achieved a maximum pulp yield of 77.90% and an impressive extraction efficiency of 96.03%, with an extraction loss of 9.30%. This machine is not only affordable but also user-friendly and easy to maintain. At its peak capacity, the machine reaches a breakeven point after approximately 40 hours of operation [26]. These findings recommend the machine is an affordable option for small-scale farmers and cottage industries in rural communities. Its efficiency and accessibility make it a valuable investment for those looking to enhance their fruit processing capabilities.

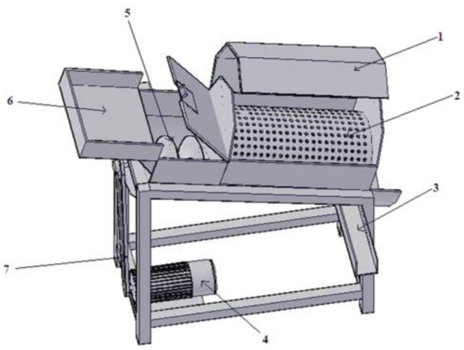

Fig. 4 - Mango pulp extractor: 1- Pulp extraction compartment Cover, 2 - Sieve, 3 - Pulp outlet, 4 - Electric motor, 5 - Auger conveyor, 6 - Feeding hopper & 7 - V-Belt [26].

4.5. Portable Motorized Pineapple Pulp Extractor

The motorized pulp extractor consists of several key components, including the hopper, barrel, shaft with an auger, juice outlet, fruit pulp outlet, pulley, and frame. Except pulley and frame, all other parts are fabricated from stainless steel to ascertain the pulp remain free from contamination. Inside the extractor, an auger screw is mounted on a rotating shaft that moves within a fixed tube known as the barrel. When fruit material is introduced into the extracting compartment through the hopper, the auger pushes it against the barrel's walls. This forward motion generates sufficient pressure to extract the pulp. One of the key advantages of this pulp extractor is its continuous feed system, which can handle multiple types of fruit, such as pineapple, pawpaw and orange due to their good flow characteristics. The evaluation of the pulp extractor was conducted using two key operating factors - operating speed and feed rate. The operating speed was assessed at three different levels - S_1 = 565 rpm, S_2 = 479 rpm, and S_3 = 380 rpm. The feed rate of the fruit material was also tested at three levels - F_1 = 0.5 kg/min, F_2 = 1.0 kg/min, and F_3 = 1.5 kg/min. The average extraction efficiency of the machine was found to be approximately 72% at the optimum operating speed of S_3 (380 rpm) with a feed rate of F_1 (0.5 kg/min), which demonstrated the highest extraction efficiency. Therefore, these parameters S_3 and F_1 are recommended as the optimal operating conditions for this prototype. Furthermore, it is important to note that the juice extraction capacity at these settings was relatively low, at C_{ex} = 5.4 liters per hour. Despite this, the pulp extraction efficiency was notably high, reaching ε_f = 78.13%. Additionally, extraction losses were recorded at ε_L = 21% during the S_3F_1 run [27]. These findings suggest that while the extraction efficiency is commendable, further improvements to the prototype could enhance overall performance and capacity.

4.6. Centrifuge Juice Extractor Machine

4.6.1. Centrifugal Beach Juicer Machine

This centrifugal juice extractor features a 76 mm big mouth feed chute and has a power capacity of 800W. The unit includes several essential components – a reamer for efficient juicing, a strainer for filtering pulp, and a knob for easy operation. Additional elements include a bumper for stability, a collection cup supported by a sturdy frame, a gear rack for smooth functionality, and an under-counter pulp chute for convenient waste disposal. It is also equipped with a micro mesh metal strainer and a blade set to ensure maximum juice extraction while minimizing pulp in the final product. This design optimizes both efficiency and ease of use, making it suitable for various juicing tasks [28].

Fig. 5: Image of a centrifugal pulp extractor [28]

4.7. Triturating Pulp Extraction Machine

4.7.1. Semi-Automated Citrus Pulp Extraction Machine

The pulp extractor is equipped with several essential components, including an electric motor, hopper, orange waste collectors, shafts, knaggy rotary balls, gears, waste outlet, pulp outlet, and a sturdy main frame. The design of the extractor operates on three key principles - convey, slice, and squeeze. The components are secured within a rectangular main frame, which provides a compact and robust structure. The circular feed hopper is positioned at top of the extraction chamber and is connected to a shaft that facilitates the feeding of fruit material into the chamber. Below the two knaggy rotary balls, there are perforations designed to allow for effective pulp extraction. The pulp extractor consists of fruit collector and rotary balls arranged alternately along a shaft. At the centre of the two collectors, a knife is positioned to cut the fruit into equal halves. Additional components of the extractor include shafts, spur gears, chain drives, and an electric motor that rotates the shaft connected to the knaggy balls. Bearings support the rotating elements, while a waste separator effectively removes chaff from the extracted pulp. The shaft serves as the main rotating element of the machine and constructed from stainless steel. The press components, including the fruit collectors and rotary balls, are typically made from Teflon and are mounted on the shaft at equal intervals. The machine has seven shafts, six of which carry spur gears with the same number of teeth, while the seventh shaft carries a bevel gear with fewer teeth, which engages with another bevel gear on a horizontal shaft. The six spur gears are arranged in parallel, with three on each side, facilitating the movement of the fruit collectors and rotary balls through two additional gears that transmit torque to the main shaft. The optimal operating speed for the pulp extraction machine was determined to be 15 rpm, with the ideal feed rate identified as 2.5 kg/min. At this optimal speed and feed rate, the machine achieved an average pulp extraction efficiency of 64%. The corresponding pulp yield was 60%, while extraction losses amounted to 35% [29]. These findings highlight the efficiency of the machine under optimal operating conditions, providing valuable insights for maximizing pulp extraction.

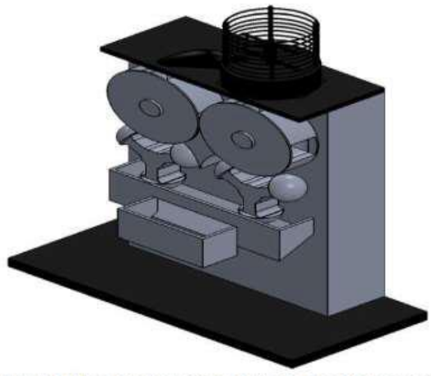

Fig. 6: Solid work Design of Pulp Extractor Machine [29].

5. Conclusion

Fruit pulp extraction machines have been in use for a considerable time, yet the limitations of traditional models have highlighted the need for the development of more efficient systems to maximize fruit utilization during harvest seasons. The challenge of pulp extraction remains significant, as a substantial portion of the fruit goes to waste annually. Various efforts have been made to mechanize the pulp extraction processes, resulting in both manual and electric machines. However, many of these machines tend to be large, inefficient, and demanding in terms of time and energy. Therefore, there is a pressing need to investigate and improve upon existing technologies to ensure that they are economical and meet the needs of end users. Ultimately, selecting the appropriate extraction mechanism should be guided by the specific requirements of farmers and consumers. By doing so, the efficiency of pulp extraction can be enhanced and waste can be minimized, thereby maximizing the benefits derived from the fruit processing.

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