Design of a Pulper and Presser for African Star Apple (*Agbalumo)*

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DOI: https://doi.org/10.51584/IJRIAS.2025.100600133

Received: 10 June 2025; Accepted: 20 June 2025; Published: 22 July 2025

ABSTRACT

In Nigeria and many other African countries, fruit juice is almost becoming a luxury found only on the table of the rich. Processing of raw fruits or juice concentrate into juice is done by large-scale industries, resulting in high and unaffordable prices for the low-income earners in developing countries.

The African star apple (*Agbalumo*) has not had such attention that attracts the extraction of its juice on a large scale. This design project, therefore, highlights the numerous nutritional benefits of *Abgalumo* and focuses on the development of an equipment that would effectively extract the liquid content from the fruit as a compromise between cost, quality, and size. While having in mind to create a simple equipment to carry out the pressing operation, attention is also given to making it effective, enough to help local processors juice it on a small scale.

The equipment carried out the juicing operation in two processes – Pulping and Pressing. Pulping is done by means of centrifugal blades attached to an electric motor to make the juice extraction effective after which the pressing is carried out. The fabricated equipment resulted in a pressing efficiency of 49.32% and 40.33% for peeled and unpeeled fruits, respectively.

Keywords: Fruit Juice, Design, Fabrication, Operational Efficiency, Agbalumo fruit

INTRODUCTION

About *Agbalumo*

African star apple, also known as *Agbalumo* (Yoruba), *Udara* (Igbo) in Nigeria, is associated with the dry season and has been enjoyed over the years by Nigerians as a fruit. Botanically called *Chrysophyllum albidum*, the white star apple belongs to the Sapotaceae family. It is distributed throughout the southern part of Nigeria. *Chrysophyllum albidum* is a popular tropical fruit tree and is widely distributed in the lowland rainforest zones and frequently found in villages (Muanya, 2011).

African locals picked the "wonder fruit" centuries ago, on the way to the farm, ate it as a snack, and the seedlings became playthings for children. Now, the current generation finds it in the marketplace or the shelves of the grocery store. Researchers are currently unraveling why the unique fruit has survived several generations in the West African region, yet has preserved in huge nutritional value. (Akpabio and Akpakpan, 2006).

Also called *Chrysophyllum albidum*, African star apple belongs to the Sapotaceae family. The fruits are sub-spherical in shape, about 3cm in diameter, usually 5-celled, and contain an edible, sweet fruit pulp. The skin or peel is orange to golden yellow when ripe, and the pulp within the peel may be orange, pinkish, or light yellow, and within the pulp are at least five seeds, which are not usually eaten (Akpabio and Akpakpan, 2006).

The fleshy pulp is eaten especially as a snack, and it has been found to have high contents of ascorbic acid and is also reported as an excellent source of vitamins, iron, and flavours for diets.

In Southwestern Nigeria, the fruit is called *Agbalumo* and popularly referred to as *Udara* in the Southeast of Nigeria. *Agbalumo's* skin is rich in latex, and its seeds are light brown and hard. In Benin, where researchers recently focused on the used pattern of the fruit, the African star apple occurs on ferallitic soils. C. Albidum is a lowland rain forest tree species, which can reach 25 to 37 m in height at maturity with a girth varying from 1.5 to 2 m. It nature occurrence has been reported in diverse ecozones in Nigeria, Uganda, Niger Republic, Cameroon and Cote d'Ivoire (Muanya, 2011).

Description of *Agbalumo*

The *Chrysophyllum albidium* (Sapotaceae) tree is common throughout the tropical Central, East, and West Africa regions for its sweet edible fruits and various ethno-medical uses (Dalziel, 1937; Amusa *et al.,* 2003). *Chrysophyllum albidum* fruits (known as African star apple) are widely eaten in southern Nigeria.

The fruit is seasonal (December - March), when ripe, ovoid to sub-globose, pointed at the apex, and up to 6 cm long and 5 cm in diameter. The skin or peel is orange to golden yellow when ripe, and the pulp within the peel may be orange, pinkish, or light yellow. Within the pulp are three to five seeds, which are not usually eaten. The seeds are dark brown or blackish, obliquely ellipsoid, up to 2.8 cm long and 1.2 cm wide; their coats are hard, bony, shiny, and dark brown, and when broken, reveals white coloured cotyledons(Fig. 1.1). Its leaves are elliptic to oblong (Emmanuel & Francis, 2010).

Figure 1.1: The African star apple (*Agbalumo*). JAtto (2013).

Growing Conditions and Yield of *Agbalumo*

Chrysophyllum albidum is a popular tropical fruit tree and is widely distributed in the lowland rainforest zones and frequently found in villages in the country. The tree is not particular as to soil, growing well in deep, rich earth, clayey loam, sand, or limestone, but it needs perfect drainage.

Star apple trees are most widely grown from seeds, which retain viability for several months and germinate readily. The seedlings bear fruit in 5 to 10 years. Vegetative propagation hastens production and should be more commonly practiced. Cuttings of mature wood root well. Air-layers can be produced in 4 to 7 months and bear early. Budded or grafted trees have been known to fruit one year after being set in the ground. In India, the star apple is sometimes grafted on star apple seedlings. Grafting on the related satin leaf tree *(C. oliviforme* L.) has had the effect of slowing and stunting the growth.

During the first 6 months, the young trees should be watered weekly. Later, irrigation may be infrequent except during the flowering season when watering will increase fruit-set. Most star apple trees in tropical America and the West Indies are never fertilized, but a complete, well-balanced fertilizer will greatly improve performance in limestone and other infertile soils (Morton, 1987).

Star apples are generally in season from late winter or early spring to early summer. They do not fall when ripe but must be hand-picked by clipping the stem. Care must be taken to make sure that they are fully mature.

Otherwise, the fruits will be gummy, astringent, and inedible. When fully ripe, the skin is dull, a trifle wrinkled, and the fruit is slightly soft to the touch. In India, a mature star apple tree may bear 150 lbs (60 kg) of fruit in the short fruiting season of February and March. This is very similar to the yield condition in Nigeria. Larvae of small insects are sometimes found in the ripe fruits. The main disease problem in the Philippines is stem-end decay caused by species of *Pestalotia* and *Diplodia*. In Florida, some fruits may mummify before they are full-grown. The foliage is subject to leaf spots from attack by *Phomopsis* sp., *Phyllosticta* sp., and *Cephaleuros virescens*, the latter known as algal leaf spot or green scurf. Birds and squirrels attack the fruits if they are left to fully ripen on the tree (Morton, 1987).

Harvesting

Agbalumo fruit is common during the months of December to April. The increasing economic use of this fruit makes the cultivation conditions for high production, and thus production is of high efficiency. Star apples are generally in season from late winter or early spring to early summer. They do not fall when ripe but must be hand-picked by clipping the stem. Care must be taken to make sure that they are fully mature. Otherwise, the fruits will be gummy, astringent, and inedible. When fully ripe, the skin is dull, a trifle wrinkled, and the fruit is slightly soft to the touch (Morton, 1989).

Storage of *Agbalumo*

Ripe fruits remain in good condition for 3 weeks at 37.4º to 42.8º F (3º-6º C) and 90% relative humidity. Freshly harvested ripe African star apples were wrapped in perforated polythene, moist jute material, or without wrapping for storage. They were stored in an evaporative cooling basket (ECB), a refrigerator, and ambient shade to study some of their characteristics and compare their durability in the different storage environments. The apples were observed to be susceptible to disorders mediated by microbial infection and insects, suggesting the need for disinfection and fungicide treatment before storage. The manifestation of infestation, which affected their shelf life, was delayed the longest in the refrigerator. The level of infestation of the apples stored in the ECB was next to the refrigerator in decreasing order. Fresh weight losses were lower in apples stored in ECB than in the refrigerator and ambient shade. Shelf-life was better enhanced in the refrigerator (15 days), followed by ECB (10 days). Desiccation of apples was common only in apples stored in the refrigerator and in ambient shade. The infecting organisms detected in the deteriorating apples were yeast, *Bacillus* cells, and larvae of an insect (*Carporphillus* sp.). The potentials of the evaporative cooling basket in the post-harvest handling of African star apple were revealed in the study (Adindu *et al.*, 2003).

Anti-Nutrient Composition of *Agbalumo*

The Anti-Nutrient composition of *C. africanum* fruit is represented in Table 1.1. The Saponins are known to reduce the uptake of certain nutrients like glucose and cholesterol in the gut through intra-lumenal physicochemical interaction. Also, when Saponins are consumed, they may aid in lessening the metabolic burden that would have been placed on the liver. The Saponins are also known to inhibit structure-dependent biological activities.

The knowledge of phytate levels in food is necessary because high concentrations of phytate can cause adverse effects on digestibility. Also, phytic acid binds metal ions like calcium, zinc, iron, and other minerals, thereby reducing their availability in the body. They also inhibit the digestion of proteins by forming complexes with them. The high levels of some of the Anti-Nutrients in *C. africanum* fruit can be reduced by a number of processing methods, soaking, boiling, and fermentation etc. (Edem *et al.*, 2011).

The seeds contain 1.2% of the bitter, cyanogenic glycoside, lucumin; 0.0037% pouterin; 6.6% of a fixed oil; 0.19% saponin; 2.4% dextrose, and 3.75% ash. The leaves possess an alkaloid, resin, resinic acid, and a bitter substance (Morton, 1987).

Mechanical Properties of *Agbalumo*

The viscosity, shear stress, and shear rate of African star apple juice (*Chrysophyllum albidium*) at different concentrations of 8% to 32% total solid concentration and temperature range of 20°C to 70°C were obtained to determine the effect of changes in concentration and temperature on the rheological properties of the juice.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VI June 2025

Also, upon carrying out the physico-chemical analyses of the sample, a plot of shear stress against shear rate showed that at all concentrations, African star apple juice behaved as a non-Newtonian fluid at temperatures below 60°C. At 70°C, however, lower concentrations (8% and 12%) behave as non-Newtonian while higher concentrations behave Newtonian. An increase in temperature decreases the viscosity of the juice (Awolu *et al*., 2013).

Table 1.1: Anti-Nutrient Composition of *Chrysophyllum africanum* fruits

Parameters	**Composition (mg/100g)**
Saponins	3.663 ± 0.02
Oxalates	4.995 ±0.01
Tannins	0.29 0± 0.02
Phytates	0.320 ± 0.02
Cyanogenic Glycoside	0.173 ± 0.01

Source: Edem and Miranda (2011)

Economic and Nutritional Potentials of *Agbalumo*

The fruit has immense economic potential, especially following the report that jams that could compete with raspberry jams and jellies could be made from it. The fleshy fruit pulp is suitable for jams and is eaten especially as a snack by both young and old. The fruit has been found to have the highest content of ascorbic acid per 100g of edible fruit of about 100 times that of oranges and 10 times that of guava or cashew. It is reported as an excellent source of vitamins, iron, and flavours to diets (Okafor, 1975; Amusategui. *al*, 2003). A detailed breakdown of its nutrient composition is provided in Table 1.2.

Table 1.2: Proximate Nutrient Composition of *Agbalumo.*

Nutritional Composition	
Moisture	76.3%
Protein	3.9%
Fat	5.5%
Crude Fibre	4.1%
Ash	2.2%
Carbohydrates	8.0%
Gross Energy (kcal/100g)	116.5

Source: Adepoju and Adeniji (2012)

Aside from being a rich source of food when consumed, *Agbalumo* has far-reaching nutritional benefits, some of which are highlighted below. Its fleshy and juicy fruits, which are popularly eaten, are the potential source of soft drinks and can be fermented for wine or other local production. The fruits are also suitable for the production of fruit jams and jellies. Studies also confirmed that unsaturated fatty acids are the main components of the oil (74%) and are desirable in the context of heart disease risk reduction (Ekeke and Ureigho 2010).

Okoli and Okere (2010) reported that *Chrysophyllum albidum* has antimicrobial activity. The bark is used as a remedy for yellow fever and malaria, while the leaves are used as emollients and for the treatment of skin eruptions, diarrhea, and stomach-ache, which are a result of infections and inflammatory reactions. Its rich sources of natural antioxidants have been established to promote health by acting against oxidative stress-related disease and infections such as diabetes, cancer, and coronary heart disease.

The result of the study conducted by Okoli and Okere (2010) indicated that the extracts of seeds and roots of *Chrysophyllum albidium* have good potentials as anti-inflammatory, anti-diarrheal and anti-haemorrhoidal compound and the study further provided a rationale for the use of the seed and root extracts of this plant in traditional medicine practice in Nigeria.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VI June 2025

Amusa *et al.* (2003) reported that within the hard seed coat of *Chrysophyllum albidum* is the whitish cotyledons which are useful in the preparation of medicines for the treatment of secondary amenorrhea in women (loss or absence of menstrual cycle); infertility due to the presence of abnormalities within the uterus and female tubes; abdominal pains in dysmenorrhea and infertility due to oligospermia in males.

Adewoye *et al*. (2010) reported that *Chrysophyllum albidum* has an anti-plasmodia effect. In essence, the methanolic bark extract was a remedy for malaria and yellow fever. Ugbogu and Akukwe (2009) confirmed further the antimicrobial effects of seed oils from Chrysophyllum albidum.

Duyilemi and Lawal (2009) validated the antibacterial activity of *Chrysophyllum albidum* water and methanolic leaf extracts. The methanolic extracts had stronger inhibitory effects on the tested microorganisms. Egunyomi *et al*. (2005) reported that *Chrysophyllum albidum* is good for the treatment of fibroids.

Prof. Saburi Adejimi Adesanya of Obafemi Awolowo University, Ile-Ife, Nigeria, in his inaugural lecture delivered in July (2005) confirmed that *Chrysophyllum albidum* cotyledons are useful for the treatment of vaginal and dermatological infections.

Conclusions of research work done by Ekeke and Uriegho (2010) also pointed out that the "*Agbalumo*" fruit, whether sweet, very sweet, or sour, will contribute a lot towards providing nutritive supplements for children and women in rural communities. The research further recognized that better utilization of the species should be supported in domestic industries.

Uses in Nigeria

The locals, for several centuries, have traditionally used the bark of the tree to treat yellow fever and malaria, while the leaf treated wounds, stomachache, and diarrhea. These fruits are good remedies for sore throat, toothache, constipation, and much more. The seeds were also used to treat vaginal and skin infections in some parts of Nigeria. Earlier findings on the fruit had suggested that it contains more vitamin C than a guava or an orange. They are also an excellent source of calcium, potassium, phosphorus, magnesium, tannins, flavonoids, terpenoids, and phytochemicals (Akpabio and Akpakpan, 2006).

While they are regularly consumed as a snack, recent studies indicate that it has properties that can be used to lower blood sugar and cholesterol, prevent and treat heart diseases. It has anti-oxidant properties, and the bark is considered a tonic and stimulant. A number of closely related species, also called star apples, are grown in Africa, including C. albidum and C. africanum (Akpabio and Akpakpan, 2006).

Herbal therapy is a system of medical treatment in which parts, leaves, barks, roots, seeds, fruit, latex, and resin of different plants are used in the treatment of ailments to enhance good health. Different ethnic groups in Africa have their myths about the origin of herbal medicine.

The seeds contain 1.2% of the bitter, cyanogenic glycoside, lucumin; 0.0037% pouterin; 6.6% of a fixed oil; 0.19% saponin; 2.4% dextrose, and 3.75% ash. The leaves possess an alkaloid, resin, resinic acid, and a bitter substance (Morton, 1989).

The latex obtained by making incisions in the bark coagulates readily and has been utilized as an adulterant of guttapercha. It was formerly proposed as a substitute for wax on the shelves of wardrobes and closets (Morton, 1989).

Objective of the Project

The objective of this project is to develop equipment that would effectively pulp and press *Agbalumo* fruits. This would involve:

i. Designing and fabrication of juicing equipment with proper attention to making it cost-effective.

ii. Testing the performance of the machine.

Justification

It has already been discussed that *Agbalumo* is a common fruit in Nigeria and that it has several purposes, such as medicinal, food, and as a means of income. Thus, its importance cannot be overemphasized. Short shelf life makes "*Agbalumo*" decay in a short time. To curb this loss, it is necessary to convert large quantities of the fruit to juice.

This design project – Development of a Pulper and Presser for *Agbalumo*, which would involve the design, fabrication, and testing of the juicing equipment, is to help bridge the gap between the harvesting of the African Star Apple and consumption. Being an obvious fact that extracted fruit juice readily releases its nutrients to its consumer, makes the fruit easily consumed by all ages, both young and old, as well as provides room for commercialization on both small and industrial scales. Juicing equipment has been made for various fruits like apple, pineapple, orange, etc., but none is recorded to have been done for the African Star Apple.

LITERATURE REVIEW

The need to employ various juice extraction methods for diverse fruits and vegetables, depending on their peculiar properties, has evolved. It involved incorporating several factors such as: hardness of pulp, size of seed, texture of the fruit, density of the fluid, stickiness, acidity, etc.

Juice Extraction

Juice Extractor

Whether electrical or manual, a juice extractor is a device that removes the juice from a fruit or vegetable. It can be hand-held and manually operated or free-standing and operated by hand or powered by electricity. A juice extractor is a device that differs greatly in its effectiveness depending on the power source behind it. A juice extractor offers the opportunity to not only juice the fruit or vegetable, but to pulverize the skin, which in some cases contains vital nutrients that are often lost in the manual juicing process (Adams, 2013).

Most electric juice extractors will have a device that will eliminate or separate the pulp from the juice. Pulp is used by some who favor healthier lifestyles as an ingredient in recipes that do not necessarily even contain the juice from the fruit or vegetable. The pulp can be taken as a natural fiber source.

Juice Extraction in a Historical Perspective

The concept of extracting nutritious juices from various fruits and vegetables, as well as grasses and herbs, has been around for ages. Sources state that state juicing was mentioned in the Dead Sea Scrolls, which date back before 150 BC**.** Throughout history, there have been many people who realized the benefits of consuming juices from raw fruits and vegetables.

As a result, many commercial juicers were developed. The initial cumbersome machines removed the juices by using a hydraulic press, and this concept is still used today, although there have been many upgrades and alterations to streamline the juicing process and make the machines more user-friendly.

Most improvements to the juicing process were credited to a man named Dr. Norman Walker, who did a lot of research on the benefits of consuming the juice of fresh, raw fruits and vegetables. Around 1930, he developed a line of juicers called the Norwalk juicers, which are still available on the market today. The health-conscious people of the world took note of Dr. Walker's work, and the popularity of juicing grew, especially in the 70's. Various types of juicers, including the centrifugal and twin gear juicers, were developed for easy use in the comfort of people's homes everywhere.

As technology developed alongside the manufacturing of the juicers, innovative new machines were created. The price of owning a juicer decreased due to the fact that manufacturing them became easier and more efficient. With lower pricing, it was not long before consumers around the world were producing their own raw fruit and vegetable juices right in the comfort of their kitchens (Fox, 2011).

Types of Juice Extractors

Basically, there are three types of juice extractors, though various forms are available in the market. The three basic types are: Centrifugal Masticating Juicers (single gear juicers), Triturating Juicers (twin gear juicers)

Centrifugal Juicers

Centrifugal Juice extractors are made with powerful, high-speed motors that make juicing quick and easy. The motors can run anywhere between 3,000 RPM and 14,000 RPM. This makes the centrifugal juicers the fastest juicers. Centrifugal juice extractors are generally the cheapest of the various electric juicers available, so they are also a great choice for a limited budget.

Centrifugal juice extractors work by placing produce into a feed chute where it comes into contact with a round spinning grater blade that looks similar to a cheese grater. The high speed of this disc then grinds and grates down the produce rapidly. Then the centrifugal force created by the high RPMs separates the pulp from the extracted juice, allowing the juice to run out into the collecting container.

There are several main drawbacks of a centrifugal juice machine. These include: Noisiness due to the sheer power at which they operate. High heat generation due to high rpm. This heat will kill off some of the enzymes and antioxidants in the fruits and vegetables it juices and produces a slightly less nutritious juice than a masticating juicer. Being not very good at juicing leafy greens and the inability to juice wheatgrass (Haynes, 2013).

Masticating Juice Extractors

Masticating juice extractors run at a slower speed than centrifugal juicers and extract juice by a different mechanism. Masticating juicers use a single gear through which produce is broken down slowly and extensively to wring out a considerable amount of juice. So the juice yield, and therefore the nutritional value, is higher than that of a centrifugal juicer. The slow speed of operation also drastically reduces the amount of heat that fruits and vegetables are subject to in comparison to a centrifugal juicer. This preserves a lot more of the living enzymes and antioxidants, producing a more health-promoting juice. The low speed also makes masticating juicers very quiet machines, a reason why masticating juicers are the popular choice for those focused on making healthier juice (Haynes, 2013).

Triturating Juice Extractors

Triturating juice extractors are the elite of juice extractors and work in the same way as a masticating juicer, but with two gears and not one. The gears run side by side and extremely close together. As vegetables pass through the gears, they get just about every last drop of juice squeezed out of them at a very slow speed. So, triturating juice extractors are a little more effective than single-gear masticating juicers and produce a higher yield and less oxidation. For this reason, triturating juicers provide the best benefits of juicing. These juicers are exceptionally good for wheat grass juicing and other ‘thin’ vegetables like leafy greens. Naturally, triturating juice extractors are more expensive (Haynes, 2013).

Some Fabricated Juice Extracting Machines

Many juice extracting machines have been designed and fabricated both locally and internationally. They have been made for various fruits, ranging from apples, pineapples, mangoes, sugarcane, etc. However, just a few would be considered in this sub-section.

A Small-Scale Whole Pine Apple Fruit Juice Extractor

Adeyemi and Badmus (2004) designed and fabricated a small-scale whole pineapple fruit juice extractor. The machine consisted of beater blades and a shaft in conjunction with a powered screw pressing mechanism. The machine processed 12kg of ripe pineapple fruit into 8 litres of pineapple juice.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VI June 2025

A Banana Juice Extractor

Kasozi and Kasisira (2005) developed a banana juice extractor that operated on the principle of impact and friction due to the action of a mixer on a banana-grass mixture and the rough wall of the extraction chamber, and obtained a juice extraction efficiency of 47%.

A Small-Scale Motorized Multi-Juice Extractor

Oyeleke and Olaniyan (2007) tested a small-scale motorized multi-juice extractor developed in India to determine the juice yield of orange, grape, tangerine, watermelon, melon, and pineapple and obtained an extraction efficiency of at least 81.3%.

A System for Fresh Fruit Extraction and Dispensary

Olukunle *et al.* (2007) developed a system for fresh fruit extraction and dispensing. The system worked on the principle of shearing, impacting, and squeezing from the knife, nail brush, and wire brush for washing, peeling, extracting, and filtering. The unit cost of this system is 1,500 US dollars, which could not be affordable to small-scale processors.

Challenges Posed to Local Juice Processing

The yield from any fruit juice depends on good solids handling. Extracting equipment should therefore be designed to handle high levels of solids content during separation. Removing the solid matter and pulp and then clarifying the juice can control the color, taste, and overall quality of the end product.

Kazembe (2005) reported that the National production of fruits in Malawi is estimated at over 200,000 metric tons per year. Unfortunately, most of this undergoes post-harvest losses, accounting for over 70% due to fruit perishability, poor marketing, and lack of improved post-harvest processing techniques and strategies for product development for value addition to fruits. Nanjundaswamy (1986) confirmed that the lack of local and simple mechanical means for fruit processing into juice and other intermediate products results in limitations on fruit utilization and thus more post-harvest losses due to rotting. These inefficiencies, in turn, present limitations to the rural income of small-scale farmers.

In Africa, especially in Nigeria, there is a dearth of small to medium-scale processing equipment for fruit juice production. FAO (1995) reported that there is far less attention paid to minor juices, small or local manufacture of such products, and the specific problems faced by producers who have not shared in the growth recorded by large-scale manufacturers of fruit juice. Other fruits, such as mango, guava, etc., require pulping – that is, after peeling and stone removal, the flesh of the fruit is pushed through a perforated metal plate. For this process, there is a range of equipment available, including several versions of hand-powered pulpers/sieves, all of which force the fruit pulp down through interchangeable metal strainers.

Effect of Moisture, Acidity, and Stickiness on Machine Materials

Considering the unique characteristics of the African star apple, it is necessary to review the effects of moisture, acidity, and stickiness. Moisture content ranged from 53.5 per cent in peel to 86.3 per cent in juice, while the peel had the highest total solids and the least was in the juice. The pH of the peel was lower than that of other components. The peel had lower titratable acidity (1.2 per cent) and sugar (0.9 Brix), while the juice had a higher value (5.4 Brix) in sugar and 15.0mg/100g carotenoid. The juice was rich in ascorbic acid (28.5mg/100g), followed by the pulp (25.0mg/100g). The pulp had the highest total soluble solids (24.8 per cent), and the least was in the pericarp (9.8 per cent) (Abiodun and Oladapo, 2011).

Consequently, the equipment must be made of a material resistant to corrosion and have minimal stickiness or adhesion to the fruit juice. As such, stainless steel could be used for those parts in direct contact with the fruit juice.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VI June 2025

MATERIALS AND METHODS

Materials

The fruits to be processed (about 100) were obtained from local farmers. Only ripe *Agbalumo* fruits harvested fresh (about 6 hours prior to processing) were employed to reduce possible desiccation and infestation. Prior to usage, the fruits were cleaned manually to remove dirt, dust, sand, stone, and other foreign particles.

State of Ripeness

The quantity and quality of the liquid extract from a fruit are highly dependent on the state of ripeness of the fruit. To ensure maximum extraction from the fruit and to ensure its good taste, only ripe fruits will be employed in this project. Unripe *Agbalumo* fruits will not be pulped to avoid contamination with the taste. Ripeness of *Agbalumo* fruit is usually determined by its physical appearance (i.e., its colour variation) and softness. Ripe *Agbalumo* should be uniformly brown in appearance and soft.

A quantitative method that can be used to determine the stage of ripeness is the use of penetrometers. Hardness is indicated by penetrometers in their measurements (g) as well as the pressure exerted (Kg/cm^2) corresponding to the penetration point used. To take a penetration measurement, there are different types of penetration points available for use and a suitable range for each type of fruit. For fruits such as grapes and cherries, the 6mm diameter point is required, to work in a range of 0 - $1kg/cm^2$, for fruits such as plums, lemons and other medium hard fruit, the 6mm diameter point or the 8mm diameter point can be used to work in a range of 0 - $5kg/cm^2$. For apples, pears peaches or kiwis, the 8mm diameter point or the 11.3mm diameter point is needed to work in a range of 0 - $13kg/cm^2$, and for very hard fruit the 11.3mm diameter point, will be required to work in a range of 0 - $20kg/cm^2$. From 10 - 15 days before the usual start time of harvest season each year, a sample of 10 - 15 fruits should be taken every 3 - 4 days to represent the entire crop, taken at random across the entire plot. It's important that the fruit taken should be uniform in size, representing the average size, as the fruit's hardness will vary with the size of the fruit. At 150 penetration and below, the fruit is not ripe, whereas at penetration higher than 150, the fruit is ripe.

The Juice Extraction Process

The juice extraction process was divided into 2 sub-processes:

A. Slicing and Seed Removal

B. Juicing.

Slicing and Seed Removal

The African star apple has large seeds that could easily be crushed upon application of pressure forces. To prevent this, the seeds were removed before processing by slicing the fruit and plucking out its seeds.

To do this, a knife was employed to:

a. Slice the fruit into two, and

b. Pluck out the seeds.

This was quite a simple operation. A kitchen knife of average sharpness was employed to carry out both processes of slicing and seed removal.

The shaft of the apple was also gotten rid of manually while slicing.

Process input: Whole African star apple (*Agbalumo*)

Output: *Agbalumo* with seeds and shaft removed.

However, one may choose not to pluck out the seeds or shaft and process the entire fruit. This is possible because the blades of the pulper operate centrifugally and were designed not to be able to generate enough crushing force to damage the seeds.

i. A three-layer sieve, comprising a plastic plate, an improvised net, and a stainless plate, was employed in the presser to cushion the pressing action of the presser, hence, minimising damage to the fruit.

Juicing

Upon slicing and seed removal, the fruit is now rid of its solid constituents, and attention is then given to removing its usually brown flesh and extraction of the liquid content.

The schematic of the equipment to carry out the operation is shown in Fig. 3.1. Basically, three vessels were employed in the process - the cutting vessel (2), the connecting vessel (4), and the pressing vessel (13).

Considering the sticky nature of the fruit and the sometimes bitter taste of the flesh, which may be undesirable, employing a mechanism such as direct pressing could crush the fruit with its flesh. Thus, to reduce the crushing effect of the press, cutting is first carried out.

The equipment employs two processes:

a. Cutting and

b. Pressing.

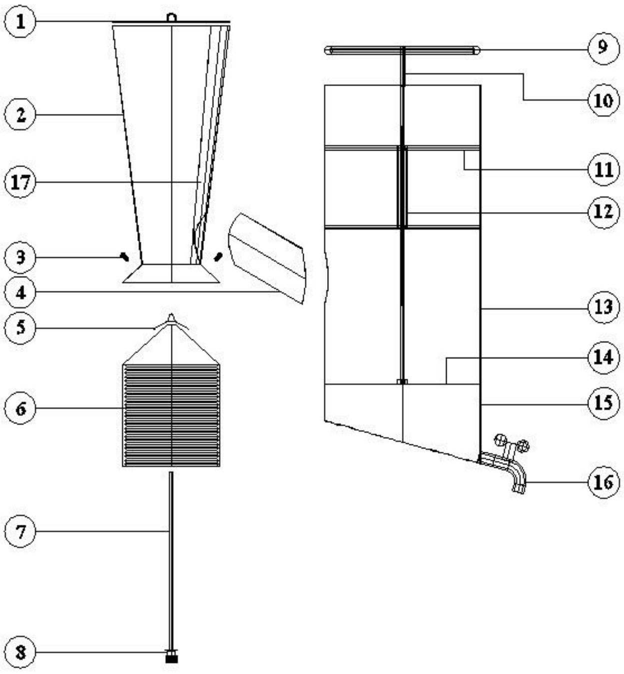

Figure 3.1: Exploded view of the Fabricated Pulper and Presser for *Agbalumo*

Table 3.1: Parts of the fabricated equipment and their names

Part No.	Name	Part No.	Name
1.	Cover	13.	Pressing vessel
2.	Cutting Vessel	14.	Three-layer sieve
3.	Screw and washer	15.	Collector vessel
4.	Connecting Vessel	16.	Tap
5.	Blade	17.	Gate
6.	Cutting the vessel seat		Bolt

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VI June 2025

7.	Blade holder		Nuts
8.	Flange coupling		Blades
9.	Press wheel		
10.	Pressing rod		
11.	Support for the press nut		
12.	Press nut		

a. The Cutting Operation

This is done in the cutting vessel (2) as illustrated in Fig. 3.1. The cutting helps to reduce the size of the unit material and, as such, increases the quantity of juice likely to be extracted. To improve the effectiveness of the cut, little water may be added to the feed to improve flow circulation in the containing vessel, reduce friction and noise, as well as prevent sticking of the fruit material to the blade of the motor.

Cutting is carried out centrifugally, by means of a vertically mounted, electrical-powered motor operated by a switch. The motor employed is a low-speed type providing power at a speed enough to cut the fruits into small pieces without necessarily blending them. *Agbalumo* fruits that have been sliced (into two) and their seeds removed are poured into a container screwed to the top of an extension mounted on the table. A pair of blades designed for effective cutting is mounted on the blade holder held by a shaft and connected by means of a bolt coupling to the electric motor. The actual cutting is carried out via rotation of the blade around the vertical axis. An electric switch would be employed to start and stop the cutting operation.

Process input: *Agbalumo* with seeds and shaft removed

Output: Marshy *Agbalumo* mix cut into pieces

Considering the nature of the fruit under study, the extract obtained may need to be worked upon to get a clear juice. The marshy output is conveyed via a cylindrical connecting vessel (4) as depicted in Fig. 3.1. The gate (17) is opened to allow flow into the pressing vessel (8), after which it may be closed.

b. The Pressing Operation

This may be powered electrically or manually, depending on the size of the equipment. For this design project, having considered simplicity, cost, and size of the machine, pressing is powered by the operator.

The operator turns the projecting handle of the setup about its vertical axis. This rotary motion is converted into linear motion by means of the screw-press setup. As such, power from the operator is transmitted into pressure forces which act on the *Agbalumo* mix and presses out the juice upon pushing against the three (3) layer sieve (14). Streams of the juice are received via a collector vessel (15) attached to the setup. The collector is an extension of the pressing vessel, separated only by the three-layer sieve. For cleaning purposes, water is run continuously in the set-up with the tap open at the end of each processing. The set-up of the equipment is illustrated in Fig. 3.2, Fig. 3.3, and Fig. 3.4.

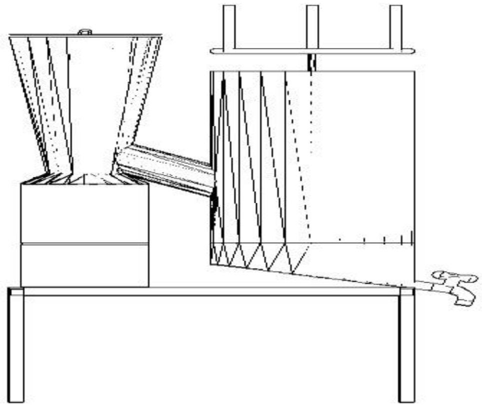

Figure 3.2: Front view of Fabricated Juicing Equipment

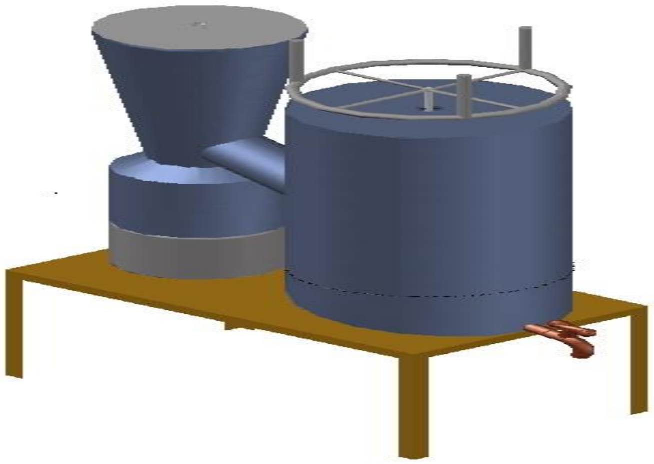

Figure 3.3: Designed Juicing Equipment (Assembled)

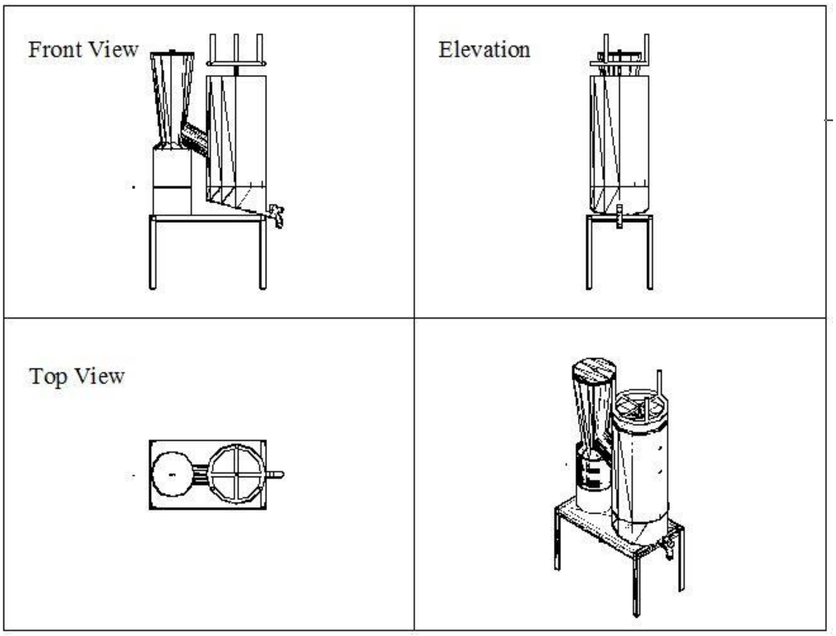

Figure 3.4: Orthographic views of Juicing Equipment

Design Considerations

To obtain high efficiency and reliability, the following are key notes: The equipment should be relatively cheap and be within the buying capacity of small-scale juice processors.

i. The equipment should be able to handle different varieties of fresh fruits.

ii. The equipment should be made with readily available materials. The machine should necessarily reduce the labour input in the traditional methods of handling and processing the fruit.

Design Calculations

The equipment is simple and quite affordable. It is able to process a reasonable quantity of fruits per operation.

Size Calculation:

- Volume of *Agbalumo*:

The average diameter of *Agbalumo* is 5cm (Emmanuel and Francis, 2010). For this design project, *Agbalumo* was modelled as spherical in shape.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VI June 2025

Volume of a sphere (John, 2003) = $\frac{4}{3} * \pi * r^3$------------------------------------ (3.1)

Volume of one *Agbalumo* = $\frac{4}{3} * \pi * 25^3$

= $65.5 * 10^3 mm^3$

Since the equipment is to carry out the juicing operation in batches, it was designed to be able to juice a reasonable quantity of the fruit at a time. For 45 fruits in a batch process:

Total Volume of *Agbalumo* = $45 * 65.5 * 10^3 mm^3$

= $2.95 * 10^6 mm^3$

Hence, the volume of *Agbalumo* that can be crushed in a single process was approximated as:

= $3.0 * 10^6 mm^3$

- Cutting Vessel (2)

Considering an appropriate size for the equipment, a volume of 3.0 litres was chosen for vessel A to provide for tolerance. This size was obtained from the quantity of *Agbalumo* that can be pulped per feed. The size of the container was therefore taken as 3.0 litres, equivalent to $3.0 * 10^6$ mm^3.

A conical frustum was chosen to direct content in the vessel towards the blade. For the frustum shown in Fig. 3.5, the following values were chosen from which the volume of the vessel was calculated.

Height (h) = 300mm

Top diameter (D) = 150mm and

Base diameter (d) = 75mm.

Volume of a conical frustum (John, 2003):

$$\frac{1}{3} * (\pi * R^2) * (H) - \frac{1}{3} * (\pi * r^2) * (H - h) \text{ ---------------------------- (3.2)}$$

Radius = $\frac{diameter}{2}$ -- (3.3)

Top radius(R) = 75mm

Base radius(r) = 37.5mm

Applying *similar triangles* to the shape as shown in Fig. 3.5 (John, 2003):

$$\frac{H-300}{75} = \frac{H}{150}$$

⇨ H = 600mm

⇨ Volume of Cutting Vessel (2)

= $\frac{1}{3} * (\pi * 75^2) * (600) - \frac{1}{3} * (\pi * 37.5^2) * (600 - 300)$

= $3.10 * 10^6$mm^3.

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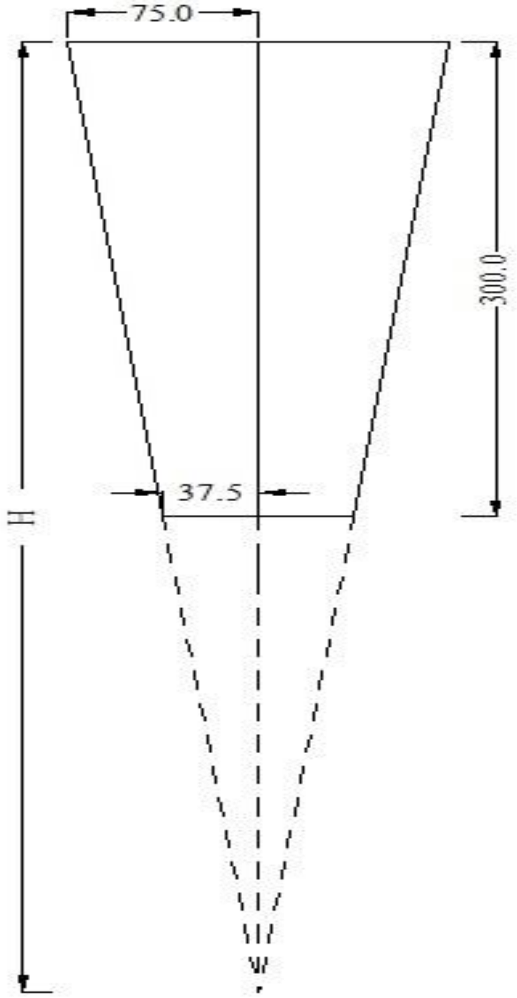

Figure 3.5: Analysis of the Cutting vessel (2)

- Connecting Vessel (4)

The connecting vessel must be such that it allows for the easy flow of the mix. As such, it would be inclined.

Since it only acts as a conveyor, its volume is not a deciding factor; instead, its inclination is. The connecting vessel connects parts 1 and 3 at their bases to maximise flow through them, and a 30 ° inclination was chosen. Hence, a small cross-section was considered appropriate. The following dimensions were therefore chosen as appropriate for the connecting vessel (4) depicted in Fig. 3.1.

Diameter: 60mm

Length: 125mm

Inclination: 30^o.

- Pressing Vessel (13):

Considering the estimated size of the equipment, a diameter of 200mm was chosen.

Volume of a cylinder (John, 2003) = $(\pi r^2) * h$---------------------------------- (3.4)

Employing a diameter of 300mm:

⇨ Height of vessel = 350mm

Piston height is taken as 100mm (which is the maximum expected height of pulp from the cutting vessel.

The detailed dimension is provided in Fig. 3.6.

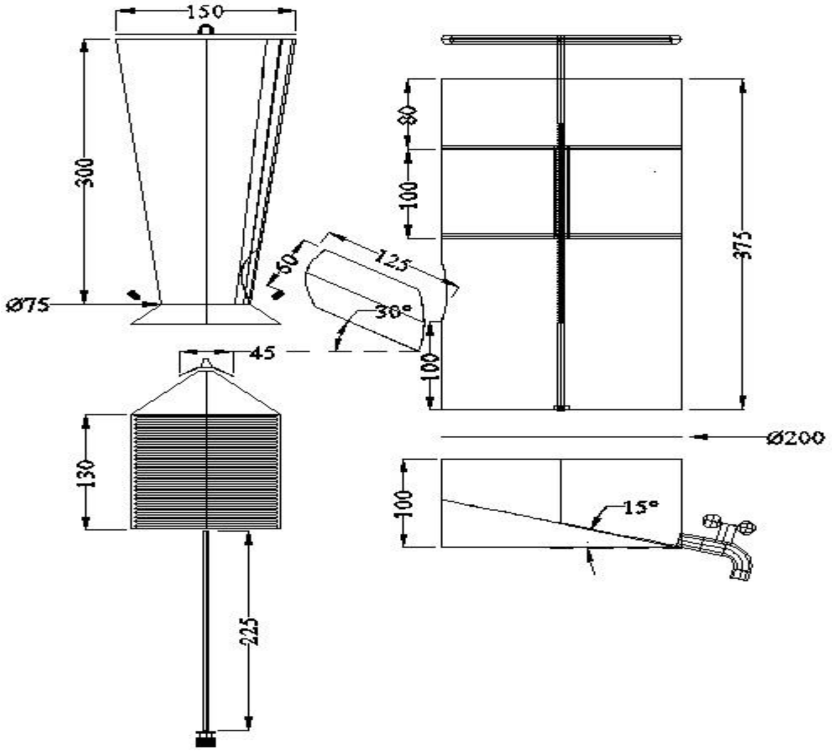

Figure 3.6: Detailed dimensioning of the fabricated Pulper and Presser showing vital components

- Piston Set-up:

To provide for a downward movement of the piston over a depth of 100mm in a 200mm diameter pressing vessel, the following dimensions were considered as appropriate:

Length of pressing rod	=	420mm
Piston diameter	=	200mm.
Length of threaded portion	=	225mm

The new volume of the pressing vessel:

Diameter (d)	=	200mm		
Calculated Depth of press	=	$4 * \frac{Volume}{\pi * d^2}$	----------------------------- (3.5)	
	=	$4 * \frac{3.14*10^6}{\pi * d^2}$	=	100mm

This implies that the depth of 100mm would suffice to hold the entire volume of the mix when the piston is at its maximum height.

Force and Power Calculation

- Electric Motor

The equipment would require a low-speed electric motor to carry out the cutting operation. Since the cutting operation should not blend the fruit into pieces, a cutting speed of 400 rpm would be sufficient.

[d = diameter of blade, m = mass of blade];

Cutting speed (rpm): N = 400 rpm

Cutting speed (m/s): v = $\frac{\pi * N * d}{60}$ -------------------------------------- (3.6)

= 3.142m/s

Using a blade diameter of 150mm (d)

Cutting (or centrifugal) force: (John, 2003) (F_c) = $\frac{m * v^2}{\frac{d}{2}}$ -------------------- (3.7)

= 197N

⇨ Cutting Power (Colton , 2009) = F_c * v --------------------------------------(3.8)

= 620W

Hence, an electric motor of 1 kW was considered appropriate to provide for tolerance.

- Pressing Force

This is a function of the weight of the material to be crushed.

Density of *Agbalumo* fruit = 1.42g/cm3; Volume = 3.10 litres

Mass of *Agbalumo* per press = Density × Volume per batch ----------------------------------- (3.9)

[Density of Agbalumo = 1.42g/cm^3 (Odugbenro, 2005)];

Hence, mass of *Agbalumo* = 1.42 × (3.1 × 1000)

= 4.402 ×1000g

= 4.5kg

⇨ The force required for each press is equivalent to the weight of the *Agbalumo* mix

= Mass of *Agbalumo* × Acceleration due to gravity (g = 9.81m/s^2) ---------------------- (3.10)

= 4.5 × 9.81

⇨ Pressing Force = 44.2N

Work to be provided by the piston = Force * depth of press -------------------------- (3.11)

= 44.2 N * 0.1 m

= 4.42 J

For an average operator; Power = Force/time of press ------------------------------ (3.12)

= $\frac{68.25J}{60s}$

= 1.1375W

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VI June 2025

Since the pressing required turning;

$$\text{Torque require} = \frac{Power}{Speed\ of\ turn\ (=\frac{2\pi N}{60})} \quad \text{---------------------------- (3.13)}$$

$$= \frac{1.1375}{(\frac{2\pi * 20}{60})}$$

$$= 0.543\text{Nm}$$

A torque of 1Nm can be provided by an average operator. Hence, the equipment can be powered manually.

Material Selection

The type of material to be used for the design project is a result of a careful consideration of the chemical constituents and possible reactions that could occur between the materials and the fruit.

Maduofor *et al.* (2013) wrote that *Chrysophyllum albidium* Fruit Extract (CAFÉ) acts as an inhibitor for aluminium corrosion in 0.1M H_2SO_4 solution. This tells of the inhibiting effect of corrosion of *Agbalumo*. Drawing from this, and the additional fact that stainless steel does not corrode, one could assert that metals such as Aluminium and stainless steel are viable options in implementing the design project. Though aluminium has a cost advantage, welding of stainless steel can be easily carried out, unlike aluminium, which may require special joining techniques.

Electric Motor

This device would be purchased. The required power rating would be about 1 kW, run at a speed of about 400 rpm, and utilise electricity of 230V.

Power Source

An alternating current (AC) source will serve as a source of power. It would be connected to the electric motor to carry out the cutting operation.

Switch

Switches are employed for shutting off and allowing the flow of current. An appropriate switch would be purchased for the system. This would be done upon consideration of the frequency of operation of the switch, power requirement, and current flow into the system.

Connecting Rod

The connecting rod used is made of mild steel. It connects the crank to the piston and, as such, would be suspended close to the center of the cylinder, joined to the projecting rod and connected to the cylinder body by a link mechanism.

Blade

The cutting blade would be mounted vertically on the rotating projection–blade holder (6). The type of blade that is employed would provide for effective cutting, be rigid, able to withstand vibration, and be replaceable.

The diameter of the blade is about 125mm so as to cut effectively without causing much vibration against the wall of the cutting vessel (2).

Joining Devices and Methods

For the permanent joints, welding would be employed, while bolts and nuts, hinges, and keys would be employed for the non-permanent joints.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VI June 2025

Testing and Evaluation

The fabricated equipment, comprising two main parts, would have to be evaluated by assessing the effectiveness of both parts, thus, evaluation of its pulping rate and pressing efficiency. Samples of African Star Apple were divided into two equal numbers and tagged as A and B. The samples were sliced and their seeds removed before processing. (This is in cognizance of the fact that samples whose seeds were not removed before processing resulted in a relatively very small quantity of extract). Sample A was left unpeeled while sample B was peeled. The two samples, A and B, were then further subdivided into A_1, A_2, and B_1, B_2, respectively, where samples with subscript (1) connote samples for which water was not employed during their processing, and those with subscript (2) connote those for which water was employed.

Pulping Rate of the equipment

The weight of *Agbalumo* pulped per minute is considered the pulping rate for the equipment.

Some samples of African Star Apple were divided equally and tagged as samples A and B. The samples were sliced and their seeds removed before pulping.

The weight of the samples and time taken to pulp to a fine, marshy mix were measured and recorded in Table 4.2.

From the data obtained, the pulping rate of the equipment was then evaluated using the formula:

$$\text{Pulping Rate } (r_p) = \frac{Weight\ of\ pulped\ samples\ (g)}{Total\ pulping\ time (mins)} \quad \ldots\ldots\ldots\ldots\ldots\ (4.1)$$

$$r_p\ (\text{Unpeeled}) = \frac{589\ g}{7\ mins} = 84.1\ \text{g/mins}$$

Similarly, $$r_p\ (\text{Peeled}) = \frac{510\ g}{4\ mins} = 127.5\ \text{g/mins.}$$

It is thus apparent that the pulping rate for peeled samples (127.5g/min) is greater than for unpeeled samples (84.1g/min). As such, peeled fruits have a higher pulping rate than unpeeled fruits.

Table 4.1: General data on *Agbalumo* fruit/seed

Samples	**Unpeeled *Agbalumo***	**Peeled *Agbalumo***
Number of fruits	26	26
Weight of samples (minus seeds) (g)	851	750
Weight of Pulp (g)	851	549
Weight of Peel (g)	N/A	201
Weight of Seed (g)	484	498
Total weight of sample (g)	1335	1248

Table 4.2: Data on evaluation of Pulping Rate

Samples	**Unpeeled *Agbalumo* (A)**			**Peeled *Agbalumo* (B)**		
	A_1	A_2	A_{avg}	B_1	B_2	B_{avg}
Number of fruits	13	9	11	13	9	11
Weight of samples (minus seeds) [g]	430	748	589	299	721	510
Pulping Time (mins)	4	10	7	2	6	4
Pulping Rate (r_p) [grams/min]	107.5	74.8	84.1	149.5	120.2	127.5

Pressing Efficiency of the equipment

To evaluate the pressing efficiency of the fabricated equipment, the following factors were considered:

- Percentage (weight) of Liquid Extract

- Percentage reduction in weight
- Comparison with literature values.

The Percentage (weight) of Liquid Extract was obtained by comparing the weight of the samples, with peel and without peel, before and after processing.

The weight reduction should be equivalent to the weight of the net liquid extract, and may be evaluated by:

Percentage reduction in weight =

$$\frac{weight\ before\ processing - weight\ after\ pressing}{weight\ before\ processing} * \ldots\ldots\ldots\ldots (4.2)$$

Similarly,

Percentage (weight) of Liquid Extract =

$$\frac{weight\ of\ net\ liquid\ exract}{weight\ of\ samples\ before\ pressing} * \ldots\ldots\ldots\ldots (4.3)$$

Where

Weight of net liquid extract = net volume of liquid extract * density

Density of *Agbalumo* = 1.42g/cm^3

Having already ascertained that the (maximum) moisture content of *Agbalumo* is **47.95 %** (Odugbenro, 2005), the Pressing efficiency of the fabricated equipment can then be calculated using values from Table 4.3.

$$\text{Pressing Efficiency } (\eta) = \frac{\%\ \text{weight average of liquid extract}}{\%\ weight\ of\ moisture\ content\ in\ Agbalumo} * 100\% \ldots\ldots\ldots\ldots (4.4)$$

The pressing efficiency of the equipment, also recorded in Table 4.3, was calculated from the weight of the liquid extract and not from the reduction in weight of the samples. This is due to losses during processing, which might have resulted from the inability to retrieve all the leftover pulp after pulping and pressing.

Conclusively, the pressing efficiency of the equipment, obtained as 49.32% and 40.33% for Peeled and Unpeeled samples, respectively, showed that the equipment is fairly effective.

Table 4.3: Performance Evaluation values of the Presser for African Star Apple *(Agbalumo)*

	Peeled *Agbalumo*(A)			Unpeeled *Agbalumo* (B)		
Sample ID	A_1	A_2	A_{avg}	B_1	B_2	B_{avg}
Number of fruits	13	13	13	13	13	13
Weight of fruits before processing (g)	299	251	275	430	421	426
Weight of pressed fruits (g)	157	151	154	324	212	268
Pressing Time (mins)	10	10	10	15	15	15
Total Volume of Liquid Extract (ml)	40	100	70	63	103	83
Volume of water added (ml)	0	50	25	0	50	25
Net Volume of Liquid Extract (ml)	40	50	45	63	53	58
Calculated Weight of liquid extract (g)	56.88	71.00	63.94	89.46	75.26	82.36
Percentage weight of Liquid Extract	19.00	28.29	23.65	20.80	17.88	19.34
Efficiency of equipment (%)	49.32			40.33		

Fig. 4.1: Set-up of the equipment

Fig. 4.2: *Agbalumo* Juice collection

CONCLUSION AND RECOMMENDATION

Conclusion

The design aimed at fabricating a Pulper and Presser for *Agbalumo*. The equipment was fabricated, and a Pulping rate of 127.5g/min and 84.1g/min was achieved for peeled and unpeeled fruits, respectively. Also, the equipment yielded a Pressing efficiency of 49.32% and 40.33% for peeled and unpeeled fruits, respectively. This efficiency is low, though the equipment is compact and not too expensive.

Recommendation

The fabricated Pulper and Presser for *Agbalumo* needs some improvement if it is to carry out the juice extraction process effectively and meet or possibly surpass the target efficiency. Highlighted below are suggestions for improving some engineering defects in the machine

a. Difficulty in turning of screw press;
b. Inefficient Flow of Pulp to the Pressing cylinder;
c. Noise during Pressing;
d. Incorporation of a scrubbing mechanism after each press.

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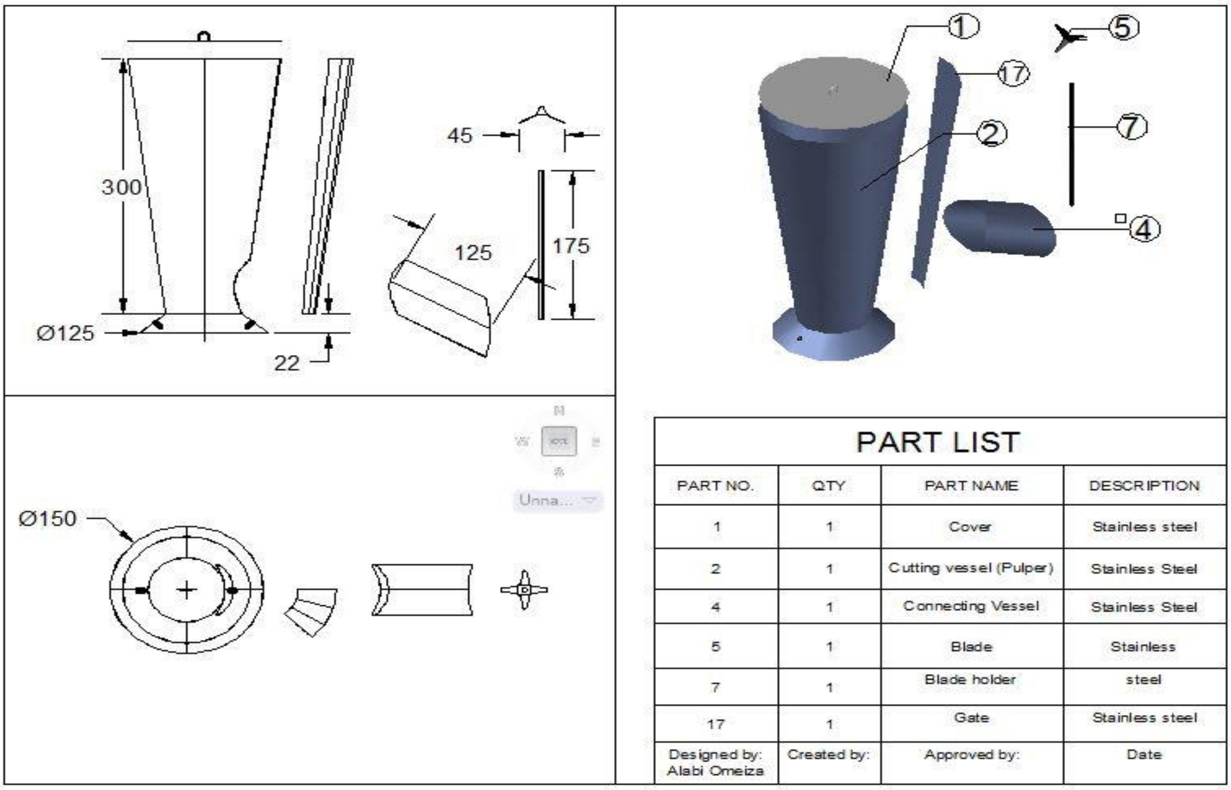
ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VI June 2025

APPENDIX

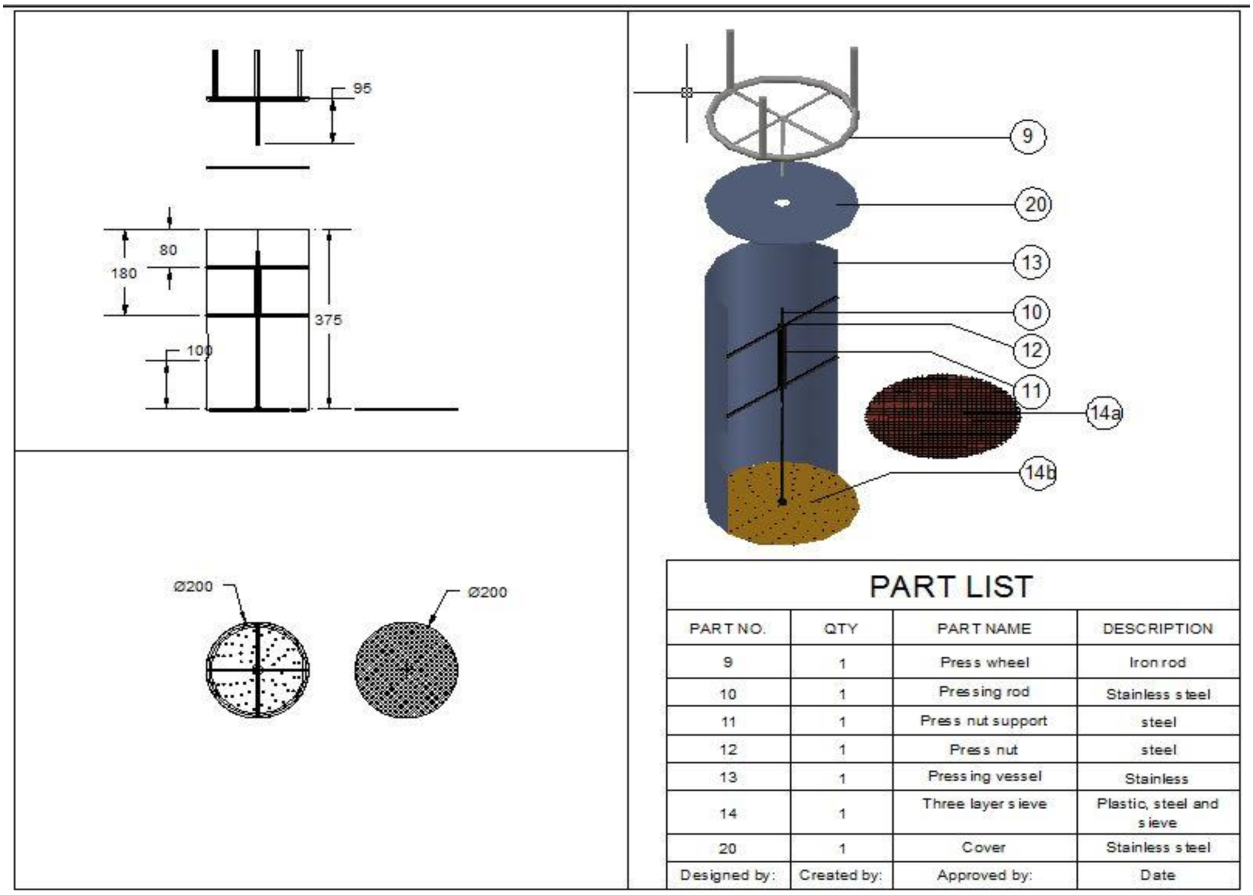
Detailed Drafting of Pulper and Presser for African Star Apple



PART LIST

PART NO.	QTY	PART NAME	DESCRIPTION
1	1	Cover	Stainless steel
2	1	Cutting vessel (Pulper)	Stainless Steel
4	1	Connecting Vessel	Stainless Steel
5	1	Blade	Stainless
7	1	Blade holder	steel
17	1	Gate	Stainless steel
Designed by: Alabi Omeiza	Created by:	Approved by:	Date

Fig. A.: Detailed Drafting for Pulper



PART LIST

PART NO.	QTY	PART NAME	DESCRIPTION
9	1	Press wheel	Iron rod
10	1	Pressing rod	Stainless steel
11	1	Press nut support	steel
12	1	Press nut	steel
13	1	Pressing vessel	Stainless
14	1	Three layer sieve	Plastic, steel and sieve
20	1	Cover	Stainless steel
Designed by:	Created by:	Approved by:	Date

Fig. B.: Detailed Drafting for Presser

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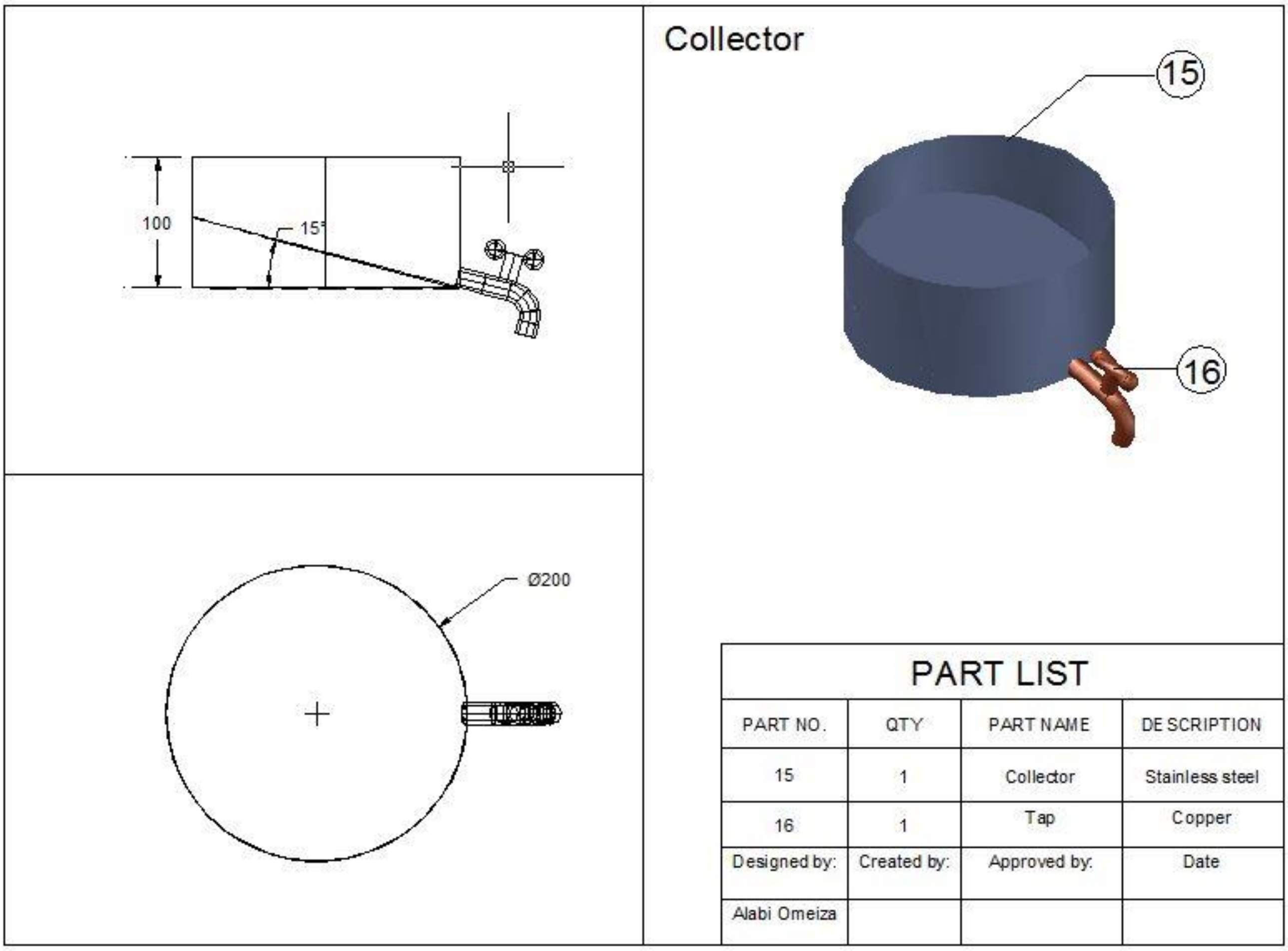

Fig. C.: Detailed Drafting for Collector

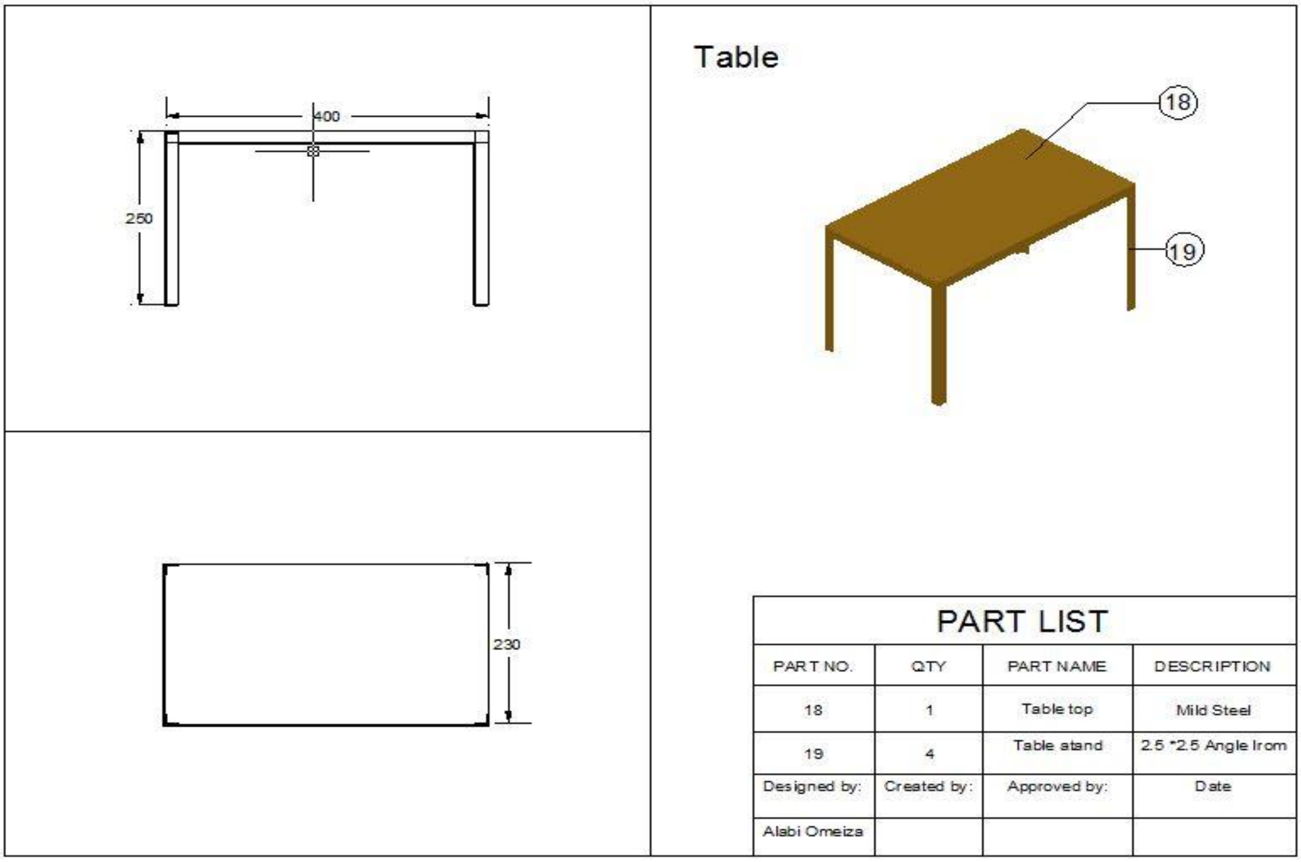

Fig. D.: Detailed Drafting fo Equipment stand (Table)