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Comprehensive review on pulp extraction mechanism for various horticultural fruits

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Abstract

The growing demand for high-quality fruit pulp in the food industry has driven advancements in pulp extraction technologies to enhance efficiency, yield, and product hygiene. Traditional manual methods widely used are labor-intensive, time-consuming, high contamination and low extraction efficiency. Various mechanical and automated pulp extraction machines have been developed to optimize based on the physical and structural characteristics of different horticultural fruits such as pineapple, apple, orange, watermelon, mango and other fruits such as Baobab (*Adansonia digitata*), ginger, kendu fruits, Palmyrah fruit. This comprehensive review explores the technological advancements in pulp extraction mechanism used in the various machine, including auger-based screw presses, pneumatic separation, centrifugal separation and enzymatic-assisted methods with a focus on their working principles, performance, and efficiency. Innovative machines such as the Crushing Separation Machine (CSM) for apple juice extraction, auger-based systems for baobab and citrus fruits, and pneumatic-operated extractors for pineapple and orange have significantly improved pulp yield while reducing enzymatic browning and processing losses. Specialized mechanisms, including perforated sieves, shearing blades, and automated conveyor systems, are employed to ensure effective separation of pulp, seeds, peels, and fibrous materials. Furthermore, multipurpose extractors for small-scale farmers offer cost-effective solutions, contributing to sustainable pulp fruit processing. This review provides a comprehensive analysis of existing and emerging pulp extraction technologies, highlighting their efficiency, automation, and applicability across various fruit categories emphasize the need for continued research and development to optimize extraction mechanisms, reduce post-harvest losses, and enhance the economic viability of fruit processing industries.

Keywords: Fruits, Pulp extraction, manual and multi operation machine, evaluation

Introduction

Fruit pulp and other processed horticulture products are in high demand worldwide due to their numerous uses in the food industry, economic importance, and nutritional worth. The various researchers, scientist, food processor and manufacture have focused on the design, development, fabrication and performance evaluation of pulp extraction mechanisms tailored to specific fruits, leveraging innovative technologies and materials to enhance performance while addressing challenges such as the quality control mechanism enzymatic browning, mechanical inefficiency of extraction of the pulp, its yield and product contamination during post harvest processing, handling and storage. Traditional methods of juice extraction predominantly rely on manual techniques, which involve macerating the fruit by hand or employing sequential steps such as peeling, slicing, blending, and pressing. These include manual juicers, automatic continuous juicers, and masticating (chewing) juicers, each designed to optimize extraction yield and maintain juice quality. Various juice extraction technologies have been successfully introduced in recent years to enhance the efficiency of juice extraction processes. These labor-intensive processes are not only time-consuming and energy-demanding but also result in low extraction yields, efficiency and hygiene of the extracted juice. (Adekanye, *et al* 2017) ^[1]. A crucial stage in fruit processing is the separation of peel, skin, and seeds, which calls for specific mechanical methods depending on each fruit's physical characteristics. To effectively release arils, pomegranate deseeding machines employ a cutter and a revolving cylindrical disk with regular perforations.

The outer skin is preserved while the arils are loosened with the help of a hammer mechanism. Using sharp revolving blades, the cores of fruits with thick exterior skins-like pineapple, watermelon, and grapefruit-are extracted. For accuracy, metallic cylinders that may be adjusted are used to deseed peaches, plums, and litchi. Perforated rotating or stationary screens with slow-moving conveyors are used to separate the seeds of apples, citrus fruits, and kiwis. Circular knives are used to cut the meat from the shell of pineapples. Automated conveyor belts featuring revolving shields, blades, knives, perforated cylinders, and hammers are used in advanced industrial processes. These automated methods maximize fruit pulp extraction, increase efficiency, and improve quality control (Mushtaq, 2018) ^[14].

Various pulp extraction machines are explained here along with their mechanisms, focusing on the use of different components that influence pulp yield, machine extraction efficiency, and extraction loss. These efforts aim to optimize extraction mechanisms, minimize post-harvest losses, and enhance the economic viability of the fruit processing industry, as outlined below:

Pulp extraction machine for Fruits Baobab (*Adansonia digitata*)

A wild fruits Baobab (*Adansonia digitata*) and Chrysobalanaceae (*Parinari curatellifolia*) were processed using an efficient pulp extraction method that operated on the principles of friction and shear. This method utilized an auger screw to press the fruit against a stationary sieve, facilitating the separation of pulp. This mechanism ensures the separation of pulp from seeds and fiber of the Baobab fruit. The pulping machine was shown in fig.1. The feed system consists of an inclined chute that uses gravity for material flow, eliminating the need for external energy input. Key components include the auger screw with helically welded blades, a fixed perforated sieve, and a robust frame constructed from mild steel. The screw and sieve are made of stainless steel for durability and corrosion resistance. The design emphasized optimal screw-sieve gaps and speeds, particularly for Baobab fruit, requiring higher rotational speeds for effective shearing. Performance tests demonstrated that fruit ripeness, preservation methods, and sieve mesh size significantly influence pulping efficiency (Manditsera, 2015) ^[11].

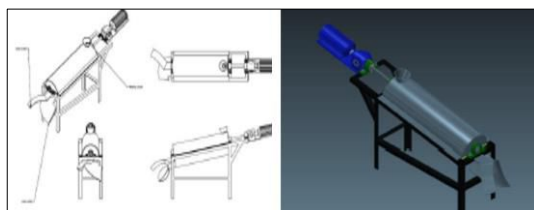


Fig 1: Wild Fruit (*Adansonia digitata*) and (*Parinari curatellifolia*) Pulping Machine

Pulp extraction machine for citrus fruit

A citrus fruit juice extractor's design, construction, and performance assessment having different components such as feeding hopper, cylindrical housing, and shaft with pressers, perforated screen, and juice outlet as shown in isometric projection of citrus fruits juice extraction machine as shown in fig 2. A feeding hopper, a cylindrical main housing, a shaft with carefully positioned pressers, a perforated screen, and an output comprise the machine. The

cylindrical main housing is composed of two chamber components, one upper and one lower. The upper chamber is made up of a shaft and two bearings, while the shaft was made from 1.5 mm thick stainless steel plate that had the presser correctly welded to it. A 5 hp electric motor required for transferring power via a V-belt and pulleys. For efficient pressing, the motor is run at 1200 rpm and the shaft at 600 rpm. Extraction efficiencies of oranges, tangerines and limes were found as 84%, 87%, and 89% respectively. Over the course of six-hour daily operations, the machine's capability was assessed by processing 3.36 tonnes of oranges, 10.85 tonnes of tangerines, and 10.47 tonnes of limes (Olabisi and Adelegan, 2015) ^[16].

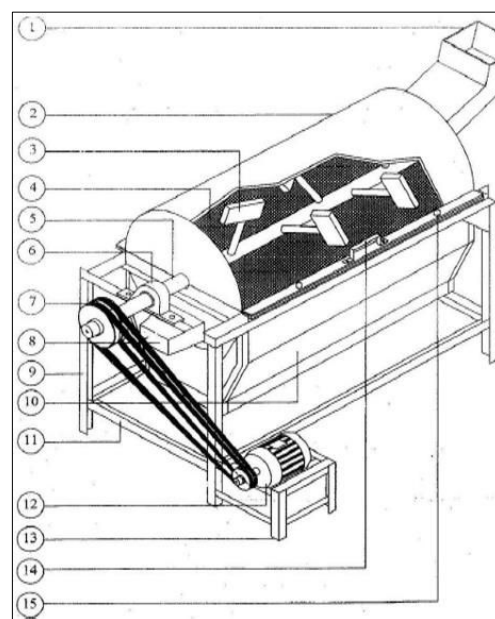


Fig 2: Isometric Projection of Citrus Fruits Juice Extraction machine

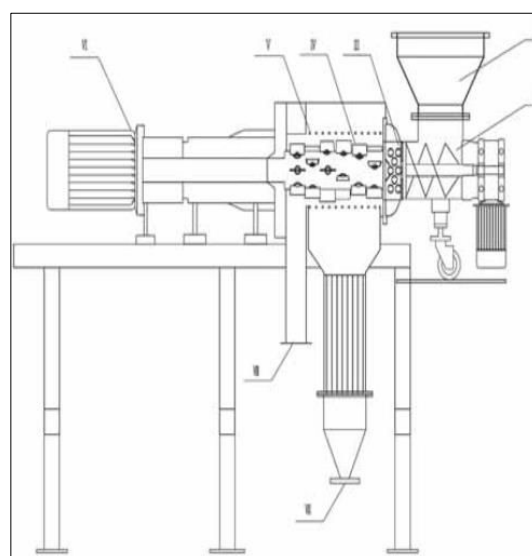


Fig 3: Schematic diagram of the crushing separation machine (CSM)

Pulp extraction machine for Apple fruits

In order to produce apple juice with less enzymatic browning, the study presents a revolutionary Crushing Separation Machine (CSM) for apple fruit as shown in fig.3 by combining crushing and separating operations, the machine overcomes the drawbacks of conventional techniques, such as high enzymatic activity and browning brought on by peroxidase (POD) and polyphenol oxidase (PPO). A high pulp yield of 91.33% was attained by optimizing key operating parameters, including screen perforation size, separation gap, rotor speed, and feeding screw speed. When compared to conventional methods, the ideal parameters (1.5 mm perforation size, 1.5 mm separation gap, 300 rpm feeding screw speed, and 1400 rpm rotor speed) dramatically decreased PPO and POD activity by 29.17% and 82.3%, respectively. By separating the peel, seeds, and stems, the machine's creative design minimizes enzyme substrates and lessens browning. With a 75% decrease in browning rate during 9 hours of storage, juice treated with the CSM showed slower browning rates and higher quality. Furthermore, a non-toxic and environmentally responsible substitute for conventional enzyme inhibition techniques is provided by the small, energy-efficient CSM. This study demonstrates how the CSM is a useful development in juice extraction technology as it may enhance apple juice quality while lowering processing energy and expenses (Meng, 2015) ^[13].

Multipurpose juice extractor for Pineapple and Sweet orange fruits

A portable multipurpose juice extractor was developed for extracting juice from tropical fruits such as pineapple, orange, and watermelon. The pulp extraction machine for multiple fruits as shown in fig 4 was fabricated using locally available materials, primarily stainless steel. The main functional components include a cylindrical drum with dimensions of 30 cm in length and 20 cm in diameter, a screw rod measuring 28 cm in length, a sieve, and a hopper with dimensions of 10.2 cm × 6.4 cm × 7.5 cm. The machine was evaluated using standard methods to determine its performance under varying conditions. Three test trials

were conducted with different sieve opening diameters (0.5 mm, 1 mm, 1.5 mm, and 2 mm) for both peeled and unpeeled fruits. The time taken for juice extraction, the mass of juice extracted, the mass of fruits, and the residual waste were recorded to calculate the juice yield, extraction efficiency, and extraction losses. The highest juice yield and extraction efficiency for peeled fruits were observed with oranges (45%), pineapples (46.5%), and watermelons (50.8%), while unpeeled fruits showed yields of 60.1%, 55.3%, and 47.6%, respectively. The highest values were achieved using a 2 mm sieve diameter (Amru and Ogunlade 2016) ^[3].

Manual juice extractor for watermelon, orange, and pineapple

A manual juice extractor for watermelon, orange, and pineapple as shown in Fig. 5 was developed and built using locally found materials. A feeding unit, an extraction unit, a waste outlet, a juice collection, a frame, and bearings make up the extractor. The handle is used to manually operate the pulp extraction machine, which transfers rotation to the Polytetrafluoroethylene (PTFE) screw via roller bearings that support the auger. The PTFE screw rotates as the handle is turned, moving the fruit through the extraction chamber. The compressive and shearing forces applied on the fruits by the PTFE screw results in the extraction of the juice content from the fruits. Residues are crushed, squeezed, and sent to the waste exit by the screw shaft while the juice passes through the screen to the juice collector. Experiments were conducted to examine the machine's performance in terms of water melon, orange, and pineapple fruit juice output, extraction efficiency, and extraction loss. The corresponding juice yields for water melon, tangerine, and pineapple were 57%, 53.6%, and 52.9%. Water melon, orange, and pineapple had extraction efficiencies of 71.3%, 65.8%, and 63.8%, respectively. Orange, pineapple, and watermelon had extraction losses of 2.5%, 4.3%, and 3.5%, respectively. For watermelon, oranges, and pineapples, the machine's respective capabilities were 19.51 kg/hr, 15.97 kg/hr, and 18.10 kg/hr. Eyeowa *et al.* (2017) ^[9].

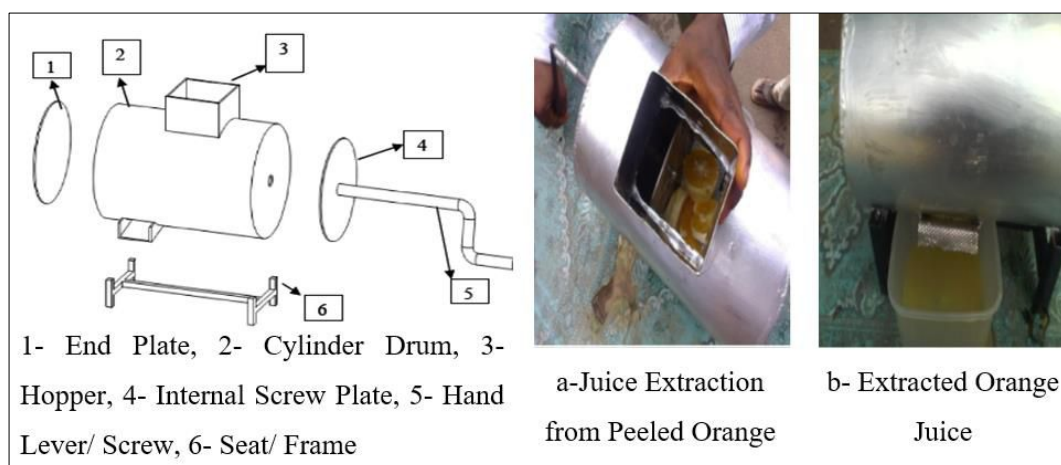


Fig 4: Multipurpose Juice Extractor



Fig 5: Isometric and photographic view of the manual fruit juice extraction machine

Manually-operated multipurpose fruit juice extraction machine

A simple and manually-operated multipurpose fruit juice extractor as shown in fig.6 was designed, fabricated, and evaluated for its performance in terms of juice yield, extraction efficiency, juice content, extraction loss, and extraction capacity. The machine primarily consists of the extraction chamber is constructed from stainless steel and includes key parts such as a turning handle (24.5 mm x 400 mm), a screw rod (32 mm x 620 mm), a compression plate (100 mm), a perforated inner cylinder (115 mm x 180 mm), a non-perforated outer cylinder (120 mm x 180 mm), and a discharge pipe. The structural frame, measuring 350 mm x 415 mm x 60 mm, is fabricated from mild steel in a U-channel section, providing the necessary support and durability for the system. The machine operates on principle of the transmission of compressive force. Fruits loaded into the perforated internal cylinder within the compression chamber are subjected to compressive force applied by the operator through the turning handle and the screw rod. As the force is transmitted, the juice cells embedded within the fruits are compressed to the point where they can no longer withstand the applied pressure. This results in the liberation of juice from the fruit, which is subsequently collected through the discharge point, ensuring efficient juice extraction. Sweet orange, watermelon, red apple, green apple, pineapple, lime, lemon and grape were used for the performance evaluation process. Results obtained showed that pineapple had the highest values of juice yield (68.74%), juice content (66.40%), extraction capacity (92.85 g/min) and extraction efficiency (82.99%) while sweet orange and lime had the lowest extraction loss and extraction capacity of 1.67% and 29.81 (g/min) respectively (Marteen, et. al 2018) [12].

Motorized citrus juice extractor for citrus

A motorized citrus juice extractor is design and constructed as shown in fig 7 comprises of stainless steel aluminum alloy which is used for the construction of the feed hopper, compression chamber and collector or receiver of the pulp. The presser and perforated cylindrical sieve of the machine were fabricated from stainless steel sheets, ensuring durability and resistance to corrosion. The power shaft was machined from a solid stainless steel shaft to provide strength and longevity. The main frame was constructed using a mild steel angle bar, while the transmission pulleys were machined from mild steel material. The performance evaluation of the machine shows that the machine extraction capacity and extraction efficiency are significantly affected by the prime mover speed in rpm. The machine efficiency is

found to be 84.54%, average juice extraction capacity is 10.92 cm³/sec or 39.312 lit/h at 600 rpm and the machine capacity is 38.89 kg/h.

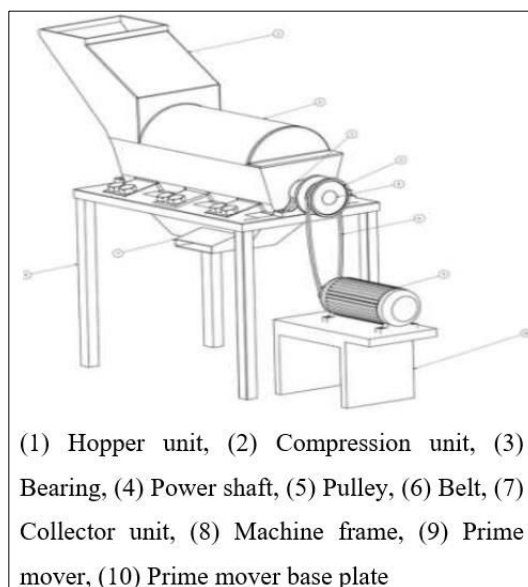


Fig 6: Isometric view of Orange Juice Extraction Machine

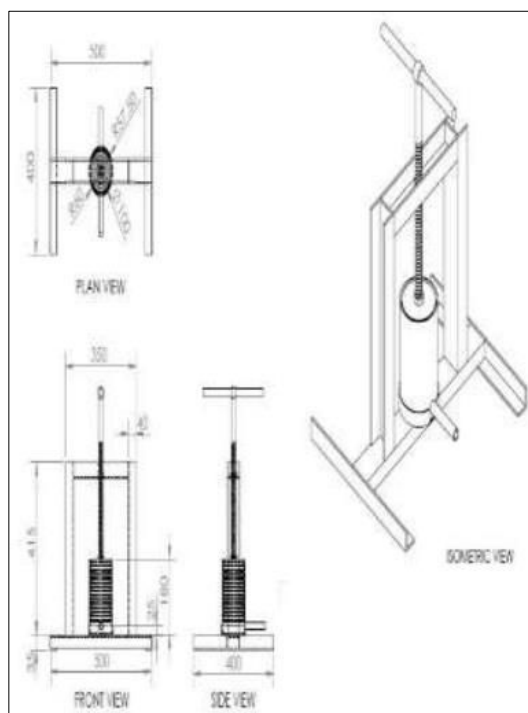


Fig 7: Orthographic and Isometric views of the machine

Fruit juice extractor pineapple and sweet orange

The fruit juice extractor as shown in fig 8 was designed with three primary components such as a feeding unit, a crushing unit, and pulp extraction unit with inlet and outlet. The extraction unit incorporated a stainless steel screen for sieving the juice before discharge. The feeding unit featured a prismatic hopper made of stainless steel, with its sides inclined at a 60° angle to the horizontal, mounted on a removable concave top cover that provided protection for the serrated auger. The serrated auger, constructed from stainless steel with a diameter of 0.18 m, operated at an average rotational speed of 1400 rpm, effectively cutting and squeezing the fruits fed into the hopper to separate the juice from the pulp. Juice extracted during operation was collected via the juice delivery chute located beneath the crushing unit, while the residual pulp was discharged through the pulp delivery chute positioned at one end of the machine. A multipurpose juicing machine with a serrated auger was developed and tested with peeled pineapples and sweet oranges. The performance evaluation revealed that the machine achieved an extraction capacity of 88.4 kg/h for pineapples, with juice extraction efficiency of 91.13% and for sweet oranges; the machine demonstrated an extraction capacity of 84.5 kg/h, with a juice extraction efficiency of 85.96% as compared with a manual juice extractor has an average extraction capacity of about 53% for both pineapple and sweet orange.

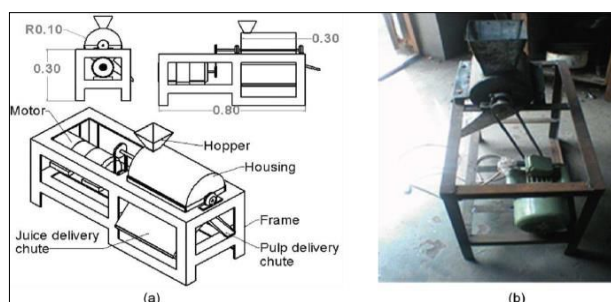


Fig 8: (a) Schematic and (b) pictorial view of the fruit juice machine

Pneumatic operated juice extractor orange and pineapple

The pneumatic operated juice extractor machine as shown in fig. 9 was constructed has two feeding hoppers, chopping unit with spikes on shaft, screw (auger) conveyor housed in a cylindrical barrel, waste outlet, juice outlet and main frame. In the operation of the pulp extraction machine, fruits are initially introduced through the primary feeding hopper. Within the chopping unit, the fruits are sliced and chopped using blades (knives) mounted on a rotating shaft. The chopped fruits are then directed into the cylindrical barrel via the secondary hopper, where they undergo crushing during their transfer into the barrel. Inside the cylindrical barrel, the machine performs multiple functions, including conveying, crushing, grinding, and pressing the fruits. These processes are facilitated by a screw conveyor, which continuously compresses the fruits to extract juice. The extracted juice is subsequently drained through perforations located at the bottom of the cylindrical barrel, ensuring efficient separation of juice from the fruit pulp. Force generated by the machine is 100.158 N and force required for fruits 32.298 N and 36.98 N for orange and pineapple respectively. (Bhalekar, *et al* 2019) [5].

Juice extraction machine for ginger

A small-scale motorized ginger juice extractor as shown in fig10 having the dimensions of 0.61 m in length, 0.46 m in width, and 0.97 m in height was designed and fabricated. The machine consists of essential components, including a worm shaft fabricated from a stainless steel rod with a diameter increasing from 0.036 m to 0.044 m. A stainless steel square bar with a cross-section of 0.0095 m is wound around the shaft to serve as the screw, featuring 12 pitches across the root diameter of the shaft. The screw conveyor alone measures 0.286 m in length. The strainer, made of pure stainless steel to ensure food safety, has a cylindrical shape with a length of 0.26 m, an inside diameter of 0.061 m, and an outside diameter of 0.072 m. The pulleys used for the motor, conveyor, and shredder have diameters of 0.051 m, 0.102 m, and 0.051 m, respectively, and are driven by a V-belt with a specification of A-45 and a pitch length of 1.176 m. The machine is powered by a 0.5 hp (373 W) electric motor with a speed of 1740 rpm. The base and stand were constructed with dimensions of 0.497 m in height, 0.452 m in width, and 0.603 m in length. During performance evaluation, ginger was fed into the grinder to reduce its size. The worm shaft, or screw conveyor, then conveyed, crushed, pressed, and squeezed the ground ginger to extract the juice. The extracted juice was filtered through a sieve into the juice collector, while residual waste was discharged through a waste outlet. The results showed an average juice yield of 80 ml per 1 kg of ginger. With a capacity of 0.5 kg/min, the machine is efficient, compact, and suitable for small-scale ginger juice extraction (Dela Cruz, *et. al* 2016) [7].

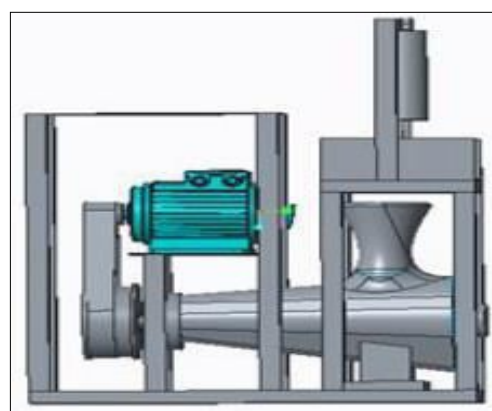


Fig 9: Pneumatic operated juice extract machine



Fig 10: Ginger juice extractor

Juice extraction machine for watermelon fruit

A small-scale machine for extracting watermelon juice as shown in fig. 11 was developed with locally available materials and evaluated to determine its best extracting operating factors. The machine slices a whole watermelon and extracts its juice. This machine operates on the principle of compressive and shearing force which exerts through an auger. Component parts includes feeding hopper, conveyor shaft, auger conveyor housed in a cylindrical chamber, juice sieve, juice collector, seed and pulp outlet, gear and main frame. The machine was powered by a 1 hp electric motor, coupled to a gear reduction speed to operate at 46.67 rpm. The operation of the watermelon juice extraction machine begins with the introduction of watermelon fruits through the feeding hopper. The screw conveyor presses the watermelon fruits against the internal surface to extract the juice. The fruits are squeezed and transferred to the auger conveyor, which applies compressive and shearing forces to extract the juice. The juice extracted was drained through the stainless screen into the base collector, discharged through the juice channel and weighed while the residual wastes were collected and weighed separately. Performance evaluation of the machine was conducted using watermelon fruits of varying weights (2.3 kg, 2.6 kg, 2.8 kg, 3.1 kg, and 3.3 kg) to obtained, juice yield, extraction efficiency, and extraction loss and extraction capacity. The results demonstrated a maximum juice yield of 86%, an extraction efficiency of 92.6%, and an extraction loss of 18%. The machine has a processing capacity of 49.04 kg/hr (Adekanye, et.al, 2017) ^[1].

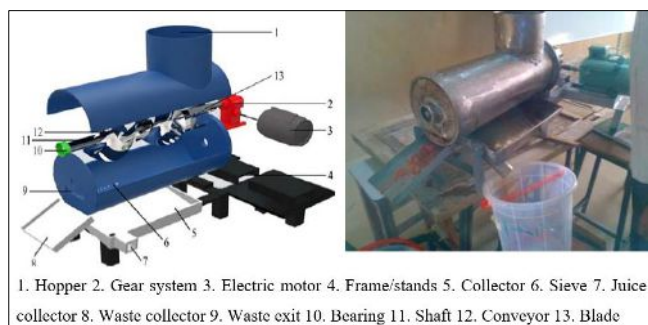


Fig 11: Exploded view and photographic view of watermelon juice extractor

Brush type pulping machine Kendu fruit

Kendu a brush type pulping machine as shown in fig 12 was developed for Kendu (*Diospyros melanoxylon Roxb.*). The pulp extraction machine consists of the feed hopper, feed rollers, barrel housing, stainless steel cylinder, and a shaft with two nylon brushes. The feed rollers are provided with conical spikes to compress and shear the hardcover of the fruit. The pulper has an overall dimension of 1.2 m×0.75m×0.40m and a throughput of 50 kg/hr. The housing field area of the machine is 1.130 m². The operating conditions such as speed and feed rate of the pulper for maximum extraction and minimum loss were optimized as fruit input through feed hopper 50 kg having machine operating time 60 min, operating speed 220 rpm, 260 rpm, 300 rpm and feed rate 2 kg/min, 2.5 kg/min, 3 kg/min. The performance of the machine was tested on the basis of pulp yield, extraction efficiency, and extraction loss of the pulper was found 36.04, 78.36, and 19.17%, respectively. The desirability function analysis suggested optimum values of

speed and feed rate as 264.58 rpm and 2.41 kg/min, respectively with a desirability value of 0.929. The suggested operating conditions such as speed and feed rate are 260 rpm and 2.5 kg/min, respectively. (Hmar *et al*, 2017) ^[10].



Fig 12: Orthographic and photographic image of the fabricated Kendu pulper

Pulp extraction machine for Mango fruit

The design, construction, and testing of a mango pulp extractor as shown in fig. 13 incorporated key components such as Teflon brushes mounted on a shaft, an electric motor, a main frame, a feed hopper, an extraction chamber, a pulp outlet, a fruit residue outlet, a perforated sieve, and bearings. The performance of the developed pulp extraction machine for mango fruit was evaluated at three extraction speeds (500, 900, and 1400 rpm) and three feed rates (2.0, 2.5, and 3.0 kg/min). The study aimed to determine the optimum operating parameters to achieve maximum pulp yield, extraction efficiency, and minimal extraction losses. Results revealed that at the optimum motor speed (S2: 900 rpm), the machine achieved a maximum pulp yield of 77.9%, an extraction efficiency of 96.03%, and an extraction loss of 9.3% for mango fruits. The ideal feed rate was F2 (2.5 kg/min), though the machine also performed effectively at F3 (3.0 kg/min). The breakeven point of the machine was determined to be 40 hours when operating at its maximum capacity (Akram, *et al*, (2021) ^[2].

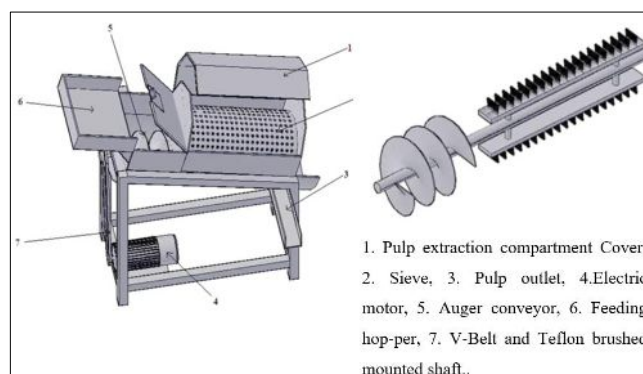


Fig 13: Mango pulp extractor

Pulp extraction machine for Bocaiuva (*Acrocomia aculeata*) fruit

Bocaiuva (*Acrocomia aculeata*) fruit pulp extraction machine was design, fabricate, and evaluate an experimental bench device. The bench device was fabricated in three units such as processing, secondary, and peripheral. The processing unit of the experimental bench device consisted of shaft, vanes, and cylinder. The secondary unit consisted of input compartment, belt, pulleys, bearing housings, and output compartment. The peripheral unit consisted of carcass, chassis, and motor. The external dimensions of the

experimental bench device were 850 mm in length, 280 mm in width, and 500 mm in height, with a total weight of 25 kg. The device comprised 12 components as shown in fig 4 was designed and integrated to ensure compactness, operational efficiency, and ease of use for bocaiuva fruits. The pulp extraction by the combined effect of centrifugal force and shear of the fruits by the pulping cylinder wall was the concept of the bench device offering an efficient alternative to manual methods. Performance evaluation was conducted using fruits dehydrated at 70°C for varying drying periods (6, 12, and 24 hours). The weight of the Pulp was measured every 15 seconds during the 150-second pulping process. The highest efficiency (96%) was achieved with fruits dehydrated for 24 hours, using a pulping time of 120 seconds, resulting in a production rate of 5.5 kg/h (Chuba, 2018) [6].

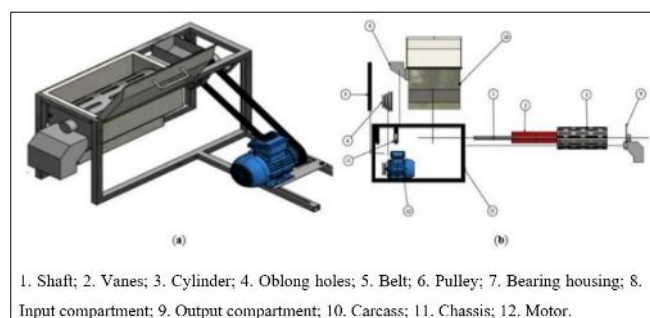


Fig 14: Projection of the experimental bench device built for pulping bocaiuva fruits

Pulp extraction machine for Palmyrah fruit

The pulp of palmyrah (*Borassus flabellifer* L.) fruit is usually used by Indian rural communities where the small scale food processors use manual operation pulp extraction process. This process is not only more time-consuming but also less pulp yields in India as the fruit found as a seasonal fruit during the period from July to August every year. Therefore, the objective was frame the development and performance evaluation the pulp yield efficiency of fruit pulp extraction machine. This machine developed to be compact and easy for operation. The developed extraction machine which consists of main housing prepared from stainless steel material having teeth on rotating shaft and pulping performed by beating and shearing action. The performance evaluation of the developed machine was carried out at different rpm, input capacity and fixed time of operation is 6 minutes in each combination. The speed of the rotating shaft was carried out at 320 rpm, 360 rpm, 410 rpm and input capacity with 8 Kg, 10 Kg and 12 Kg. The testing indices such as pulp yield, extraction efficiency, and extraction loss of the pulp extraction machine were 33.90, 84.78 and 8.25%, respectively. The desirability function analysis suggested optimum values of speed and feed rate as 412.33 rpm and 10.33 kg of fruits for batch for 6 minutes of operation respectively with a desirability value of 0.892. The suggested operating conditions such as speed and input are 410 rpm and 10 kg for batch. In palmyrah fruit processing, the high efficiency makes the developed mechanized system highly effective for pulp extraction of palmyrah fruits, providing a viable alternative to manual pulping operation in rural communities of India. (Vengaiah *et al* 2022) [18].

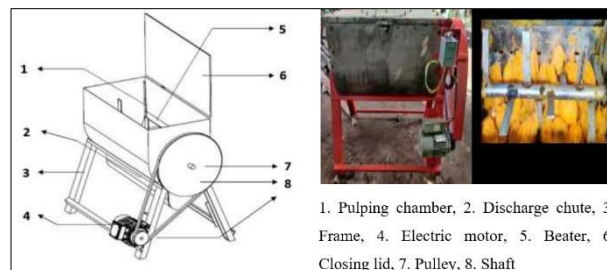


Fig 15: View of the Palmyrah fruit pulper with its inside view

Conclusion

Advancements in pulp extraction mechanisms have significantly improved efficiency, yield and quality of fruit pulp extraction. Various extraction technologies, including auger-based screw presses, pneumatic and centrifugal separation, enzymatic-assisted techniques, and multipurpose extractors, have been developed to enhance extraction efficiency and minimize losses. Fruit-specific designs, such as Crushing Separation Machines (CSM) for apples, auger-based systems for baobab and citrus fruits, and pneumatic-operated extractors for pineapple and orange, have improved extraction rates while reducing enzymatic browning and mechanical inefficiencies. Integration of perforated sieves, shearing blades, and conveyor-based automation ensures effective separation of pulp from seeds, peels, and fibrous components, leading to higher yields and reduced wastage. Development of mechanized pulp extraction systems will contribute to reduce post-harvest losses, improving product hygiene and enhancing the economic viability of the fruit pulp processing sector.

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