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DESIGN AND FABRICATION OF A LOCALLY MADE FRUIT JUICE EXTRACTOR

YEREL OLARAK ÜRETİLMİŞ BİR MEYVE SUYU ÇEKİCİ TASARIMI VE İMALATI

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ABSTRACT

This project focuses on the design and fabrication of a locally made fruit juice extractor to address the need for affordable, efficient juice extraction solutions for small-scale and rural fruit processors. The machine was developed with the aim of optimizing juice yield while maintaining mechanical simplicity and energy efficiency. Key mechanical parameters such as crushing force, torque, and power requirements were carefully calculated to ensure optimal performance. For soft fruits like oranges and pineapples, a crushing force of 1500 N was determined, based on an average compressive strength of 1.5×10^5 N/m² over a 0.01 m² contact area. The required operating torque was 225 Nm, which justified the selection of a 1.5 kW electric motor operating at 60 rpm. Shaft design required a diameter of 32 mm, and a belt-driven transmission system was designed with a velocity of 9.05 m/s and a belt tension of 165.75 N. The juice chamber, with a 17.7-liter capacity, and a filtering surface of 0.075 m², facilitated efficient separation. Alternative manual operation was evaluated, requiring 30 Nm of torque. Performance evaluation showed a mechanical efficiency of 80.3% and juice extraction efficiencies of 80.3% (mass basis) and 88.3% (volume basis), respectively. These results affirm the extractor's reliability, cost-effectiveness, and suitability for local environments. With its ease of operation and minimal maintenance needs, the machine represents a sustainable solution for improving juice production in underserved regions.

Keywords: Design, Efficiency, Fabrication, Juice Extraction, Local Production.

ÖZET

Bu proje, küçük ölçekli ve kırsal meyve işleyicileri için uygun fiyatlı ve verimli meyve suyu çıkarma çözümlerine olan ihtiyacı karşılamak amacıyla yerel olarak üretilmiş bir meyve suyu çıkarıcının tasarımı ve imalatına odaklanmaktadır. Makine, meyve suyu verimini optimize ederken mekanik sadeliği ve enerji verimliliğini korumayı hedefleyerek geliştirilmiştir. Ezme kuvveti, tork ve güç gereksinimleri gibi temel mekanik parametreler, en iyi performansı sağlamak amacıyla dikkatle hesaplanmıştır. Portakal ve ananas gibi yumuşak meyveler için, 0.01 m²'lik temas alanı üzerinde ortalama 1.5×10^5 N/m²'lik basma dayanımına dayanarak 1500 N'luk bir ezme kuvveti belirlenmiştir. Gerekli çalışma torku 225 Nm olarak hesaplanmış ve bu da 60 dev/dak hızında çalışan 1.5 kW'lık bir elektrik motorunun seçimini haklı çıkarmıştır. Mil tasarımı için 32 mm çap gerekmiş, kayışla çalışan bir aktarma sistemi ise 9.05 m/s hız ve 165.75 N kayış gerilimi ile tasarlanmıştır. 17.7 litrelik kapasiteye ve 0.075 m² filtreleme yüzeyine sahip meyve suyu haznesi, verimli ayrıştırmayı sağlamıştır. Alternatif manuel kullanım seçeneği değerlendirilmiş ve bunun için 30 Nm tork gerektiği belirlenmiştir. Performans değerlendirmesi, %80.3 mekanik verimlilik ve sırasıyla %80.3 (kütle bazında) ve %88.3 (hacim bazında) meyve suyu çıkarma verimlilikleri göstermiştir. Bu sonuçlar, çıkarıcının güvenilirliğini, maliyet etkinliğini ve yerel koşullara uygunluğunu doğrulamaktadır. Kullanım kolaylığı ve düşük bakım gereksinimi ile bu makine, yetersiz hizmet alan bölgelerde meyve suyu üretimini artırmak için sürdürülebilir bir çözüm sunmaktadır.

Anahtar Kelimeler: İmalat, Meyve Suyu Çıkarma, Tasarım, Verimlilik, Yerel Üretim.

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1. INTRODUCTION

The increasing demand for fresh, natural fruit juices has intensified the need for efficient and cost-effective juice extraction technologies, especially in developing countries where the availability of imported machinery is limited due to high costs and technical complexity. In response, there has been a growing interest in designing and fabricating locally made fruit juice extractors that utilize accessible materials and simple engineering principles [1]. The development of locally fabricated juice extractors is vital for enhancing agricultural value addition and minimizing post-harvest losses, particularly in rural communities. These machines support small-scale agro-processors by providing them with affordable and user-friendly tools for extracting juice from a wide variety of fruits such as citrus, mangoes, pineapples, and bananas [2, 3]. Unlike large industrial extractors, locally fabricated machines are tailored to specific regional needs, available materials, and local fruit types [4]. For example, in cottage industries, mango pulp extractors have been successfully fabricated and tested for performance using cost-effective methods and materials [4]. The core principles behind the design and fabrication of juice extractors involve mechanical pressing, pulping, and filtration. Machines are designed to operate manually or be powered electrically, depending on the intended scale of operation and energy availability [5, 6]. The simplicity of design is crucial to ensure ease of use, maintenance, and repair by local artisans, making these machines more sustainable and adaptable to rural settings [7]. Manual juice extractors have been reported to be effective in low-resource settings where electricity is scarce [8], while motorized versions enhance processing speed and reduce labor [9].

Advancements in local engineering design have enabled significant innovations in extractor mechanisms, from screw press systems to rotary blade pulpers [10, 11]. These innovations have led to improved juice yield, higher processing efficiency, and better product quality. Machines developed for banana fiber extraction and oil pressing have informed design choices for juice extractors, particularly in component arrangement and pressure application [12, 13]. Additionally, the reuse of agricultural waste, such as fruit pulp and peels, for animal feed or bio-refinery applications aligns with circular economy principles [14]. Design considerations include the type of fruit, desired juice quality, ease of cleaning, and prevention of contamination. Motorized citrus juice extractors, for example, are designed with stainless steel contact surfaces to ensure hygiene and corrosion resistance [15]. Similarly, machines for extracting juice from fibrous fruits like mangoes and bitter leaves are constructed to handle pulp viscosity and solid residue efficiently [16, 17]. Several studies have demonstrated successful fabrication of machines capable of extracting juice from multiple fruit types using locally sourced materials and tools [18, 19]. While commercial juice machines are often complex and costly, locally made extractors prioritize affordability and modular design. This approach facilitates community-level manufacturing and skill transfer, encouraging local entrepreneurship [20, 21]. Semi-automated designs have been developed to strike a balance between manual labor and motorization, optimizing performance without incurring high energy costs [22].

Technological adaptations such as vending capabilities, automation, and programmable controls have also been integrated into some locally fabricated extractors aimed at commercial uses [23]. In industrial applications, extractors must accommodate large volumes of produce and ensure continuous operation. Although such high-capacity systems are common in developed countries, innovations have been replicated on a smaller scale in developing regions [24]. Design tools such as SOLIDWORKS™ have further enhanced precision in modeling extractor components, reducing material wastage during fabrication and improving structural integrity [25]. Complementary devices like fruit peelers and harvesters also support efficient juice production by reducing preparatory labor [26-28]. Ultimately, the design and fabrication of fruit juice extractors must consider socio-economic and environmental factors. The machine should be accessible to small-scale farmers and processors, contribute to food security, and reduce post-harvest losses. Recent studies continue to emphasize the importance of user-centered design in fabricating appropriate technology for local needs [29-32].

In conclusion, the development of locally made fruit juice extractors is a transformative innovation in the agro-processing sector. It bridges the gap between manual labor and industrial automation, empowers rural communities, and promotes sustainable economic development. Continuous research and development, coupled with policy support, are essential for scaling these innovations and ensuring their long-term viability.

2. MATERIALS AND METHODS

2.1. Design Considerations

The successful design and fabrication of a locally made fruit juice extractor require a strategic approach that ensures the machine is efficient, durable, user-friendly, and cost-effective. The following key factors were carefully considered during the design phase:

i. Availability and Cost of Local Materials: The use of locally available materials was prioritized to reduce cost and ensure easy maintenance and repair. Mild steel was selected for the frame due to its good weldability, affordability, and sufficient mechanical strength. Stainless steel was used for the juice chamber and filtering components to ensure hygiene and resistance to corrosion. This approach is supported by Abdullahi et al. [1], who emphasized the importance of local material selection in the design of small-scale agro-processing machines to enhance sustainability and reduce dependency on imported components.

ii. Type of Fruits to Be Processed: The machine was designed to process a variety of soft and semi-hard fruits commonly available in tropical regions, such as oranges, pineapples, mangoes, and guavas. These fruits have relatively low compressive strengths, which informed the calculation of the pressing force required. According to Adeodu et al. [2], fruit juicers intended for multipurpose extraction must consider the texture, fiber content, and juice yield potential of each fruit type to optimize performance and minimize clogging or mechanical failure.

iii. Ease of Operation and Maintenance: The extractor was designed for semi-automated and manual operation, allowing users to either power it using a 1.5 kW electric motor or a manually operated handle. This hybrid system ensures flexibility in use, especially in rural or off-grid areas. Furthermore, modular assembly was adopted to enable quick disassembly for maintenance. Faluyi et al. [9] highlight the relevance of user-friendly and maintainable designs in rural technology deployment to promote adoption and longevity.

iv. Juice Yield Efficiency: Maximizing juice yield was a critical design goal. The machine employs a compression-based extraction mechanism with optimal force application, leading to juice extraction efficiencies of up to 88.3%, depending on the fruit type and feed volume. This is consistent with research by Soomro and Rossi [25], who reported that extraction efficiency directly correlates with pressing force, contact area, and juice chamber design.

v. Safety and Hygiene: Incorporating food-grade materials in the juice-contacting parts of the machine was essential to ensure hygiene and user safety. Stainless steel was selected for the juice chamber and filtering mesh to resist corrosion and prevent contamination. The machine frame was treated with anti-rust paint and enamel coating for safe operation. Proper shielding of moving parts and electric components was also implemented to prevent accidents. As noted by Ugwu et al. [29], ensuring food safety in agro-processing machines is crucial for compliance with public health standards and consumer confidence.

vi. Durability and Corrosion Resistance: Given the acidic nature of fruit juice and the humid working conditions, corrosion resistance was a major factor in material selection. Stainless steel and mild steel were chosen for their durability, with all exposed surfaces adequately coated. Ugwu et al. [29] emphasized the importance of corrosion-resistant materials in agricultural machinery, especially when in contact with organic fluids like fruit juice.

2.2. Selection of Materials

Material selection is a critical aspect of the design and fabrication process of the locally made fruit juice extractor. The materials used must satisfy several criteria such as mechanical strength, corrosion resistance, availability, cost-effectiveness, and hygienic properties, particularly because the machine processes food-grade materials. Table 1 presents the key components of the juice extractor alongside the materials selected and the rationale behind each choice.

Table 1. Component and Selected Materials

Component	**Material**	**Reason for Selection**
Frame	Mild Steel	High strength, local availability, low cost [1]
Crushing Unit	Stainless -Steel	High corrosion resistance, non-reactive to juice, hygienic [2, 5]
Juice Tray	Stainless Steel	Easy to clean, hygienic surface, rust resistance [7]
Shaft & Bearings	Mild Steel & Bronze	Strength for torque transfer and wear resistance for bearings [6]
Bolts and Nuts	Steel	Readily available, facilitates assembly and disassembly [9]

Mild steel was selected for the frame and shaft due to its excellent mechanical properties and affordability, making it suitable for structural and rotating parts. It has a tensile strength ranging from 370–700 MPa, adequate for supporting the operational loads of the extractor [1, 2]. Moreover, its wide availability in local markets makes procurement and replacement easy. For the crushing unit and juice tray, stainless steel was chosen due to its corrosion resistance, durability, and non-toxicity, which are critical for maintaining food safety standards. Stainless steel prevents contamination of juice by metallic residues and ensures that hygiene is maintained throughout the extraction process [5, 8]. The bearings are subject to rotational loads and wear; thus, a combination of bronze (for low friction and wear resistance) and mild steel (for the shaft) was selected. Bronze is well known for its anti-seizing properties and long service life, particularly in conditions involving intermittent lubrication [7, 9]. Steel bolts and nuts of standard sizes were chosen to simplify the assembly and disassembly process. These fasteners are easy to procure and replace, and they offer sufficient tensile strength for the loads expected during machine operation [14]. This selection of materials ensures that the juice extractor is not only robust and durable but also affordable and easy to maintain within local contexts, enhancing its adoption in small-scale fruit juice production industries.

2.3. Design Calculations

This section outlines the engineering principles and key design considerations used in developing the fruit juice extractor. These calculations, although not explicitly detailed here, guided the sizing, selection, and integration of each component to ensure mechanical efficiency, structural stability, and user-friendly operation.

2.3.1. Crushing Force Estimation

The required force for crushing soft fruits such as oranges, pawpaw, and pineapples was estimated using average compressive strength values obtained from existing literature. This force estimation informed the structural design of the pressing mechanism, ensuring it can generate adequate pressure for juice extraction without damaging the machine.

2.3.2 Torque Requirement

To determine the effort needed for manual operation, the torque required to rotate the pressing shaft was analyzed. This involved considering the force applied at the handle and its distance from the shaft. The result influenced the handle length, shaft diameter, and gear mechanism to provide sufficient mechanical advantage.

2.3.3 Power Requirement for Motorized Operation

For the optional motorized configuration, power requirements were calculated based on the estimated torque and operational speed of the shaft. This calculation was used to select an appropriate electric motor capable of handling the expected mechanical load without overheating or stalling.

2.3.4 Shaft Design Considerations

The shaft design accounted for torsional and bending stresses that may arise during operation. Material properties such as allowable shear stress were considered in selecting a suitable shaft diameter. The final shaft size was chosen to ensure rigidity, minimal deflection, and long-term reliability.

2.3.5 Pulley and Belt Transmission System

To connect the electric motor to the pressing mechanism, a pulley and belt system was adopted. Calculations focused on selecting pulley diameters, belt velocity, and the required belt tension. A suitable V-belt type was chosen based on the expected load and operational speed, ensuring efficient power transmission and minimal slippage.

2.3.6 Bearing Load Capacity

Bearings were selected to support the rotating shaft while minimizing friction and wear. Load distribution was assumed to be equal across both bearings. The choice of bearing type and size was guided by the combined effects of radial and axial loads expected during operation.

2.3.7 Juice Chamber Volume and Filtering Surface

The juice chamber was designed to hold a sufficient volume of fruit pulp during each batch operation. Its shape and dimensions were selected to maximize capacity while maintaining a compact design. A filtering mesh with an appropriate surface area was included to separate juice from solid residues efficiently.

2.3.8 Manual Handle Design

The handle length and orientation were determined to ensure the operator can comfortably generate the required torque with minimal effort. The design incorporated ergonomic considerations and material strength to withstand repeated manual operations without deformation or failure.

2.3.9 Mechanical Efficiency

Mechanical efficiency was considered in the selection and alignment of components, aiming to reduce energy losses due to friction and component misalignment. Although the exact efficiency values are not detailed here, the design prioritized smooth motion and minimal resistance throughout the transmission system.

2.3.10 Juice Extraction Efficiency

Although numerical results are excluded, the juice extraction mechanism was evaluated for its capacity to recover a high percentage of juice from the processed fruits. Factors such as pressing force, pulp compaction, and filtration effectiveness were considered to optimize performance.

2.4. Fabrication Process

The fabrication of the locally made fruit juice extractor was systematically carried out through a series of interrelated stages to ensure structural integrity, operational efficiency, and durability. The entire process adhered to standard workshop practices and engineering principles as recommended by Abdullahi et al. [1] and Ukwu et al., [20]. The major steps involved are outlined below:

2.4.1 Measurement and Cutting

The fabrication process commenced with precise measurement and marking out of the various components, including the mild steel shaft, angle iron frame members, juice chamber sheet metal, and supporting plates. These materials were then cut to their required lengths and shapes using a power hacksaw and angle grinder. High attention was paid to dimensional accuracy to prevent assembly misalignment. This step is critical, as errors in measurement or cutting can propagate through the entire assembly [17, 22].

2.4.2 Welding and Assembly

Following cutting, the individual frame members and supporting parts were joined using shielded metal arc welding (SMAW) with E6013 electrodes. Arc welding was chosen for its strong joint formation and availability in local workshops. Proper jigs and clamps were employed to hold components in position during welding to ensure squareness and angular conformity. The juice chamber housing, shaft mounts, and base supports were also integrated during this stage. According to Eyeowa et al. [8], the integrity of welded joints directly impacts the mechanical strength and vibration stability of food processing machines.

2.4.3 Machining Operations

Key machining processes were undertaken on critical rotating components. The shaft underwent turning operations on a lathe machine to achieve uniform diameter, chamfered edges, and bearing seat grooves. Drilling operations were carried out to create bolt holes for the motor base, handle mounting, and filter mesh support. The tolerances maintained during these operations were within ±0.05 mm to allow for proper fit and rotation of moving parts, in line with standards reported by Ahmed et al. [3].

2.4.4 Finishing

All fabricated parts were subjected to finishing operations to enhance aesthetic value and prevent corrosion. Sharp edges were filed and deburred manually using hand files. Metal surfaces were cleaned, primed, and painted using rust-inhibitive enamel paint. Stainless steel parts such as the juice chamber and mesh tray were polished using abrasive compounds to achieve a smooth, food-grade finish. Surface finishing plays a dual role in hygiene maintenance and prolonging service life [14, 18].

2.4.5 Installation of Moving Components

In this stage, the functional components—shaft, bearings, pulley, and drive belt—were carefully installed. The bearings were press-fitted into their respective housings, and the shaft was aligned and seated to minimize eccentricity. The pulley and belt transmission system was adjusted to maintain optimal tension for efficient power transfer from the motor. Additionally, the manual handle was fixed for alternate operation. All moving components were lubricated using food-safe grease to reduce friction and wear. Proper installation and alignment of these components are crucial to operational efficiency and mechanical reliability [7, 11]. Overall, the fabrication process was conducted using available local materials and tools, ensuring the design remains cost-effective and replicable in rural or semi-urban settings without compromising functionality.

3.5 Testing and Evaluation

The fabricated fruit juice extractor underwent a comprehensive evaluation to determine its performance across key parameters, including juice extraction efficiency, ease of operation, processing time per batch, operational safety and stability, as well as ease of cleaning and hygiene. The tests were conducted using various locally available fruits such as oranges, pineapples, and watermelons.

Juice Extraction Efficiency: Juice extraction efficiency is a critical indicator of the machine's performance. It refers to the percentage of juice successfully extracted from the total juice content within the fruit. This parameter was assessed to ensure the machine's suitability for domestic and small-scale industrial use. According to Abdullahi et al. (2024), extraction efficiency plays a crucial role in determining the economic value and operational effectiveness of fruit processing machines.

Ease of Operation: The juice extractor was evaluated for its user-friendliness in terms of manual and motorized operation. The focus was on the ergonomic design of the handle for manual use and the responsiveness of the motor for automated operation. The goal was to ensure that the average user can operate the machine with minimal technical skill, consistent with the findings of Adeodu and Tamunoseipiriala [2], who emphasized the importance of simple interface design in local agro-processing equipment.

Time Required per Batch: Time efficiency is vital in determining the throughput of the machine. For this evaluation, the time taken to process a fixed quantity of fruit was measured and used to analyze the throughput capacity. As highlighted by Akram et al. [4], optimizing batch processing time can improve productivity and reduce operational fatigue in manual systems.

Safety and Stability: The machine's operational safety was assessed based on its structural stability, enclosure of moving parts, and risk of injury during use. A well-fabricated frame with a low center of gravity and adequate support ensured minimal vibration and tipping. Hmar et al., [13] stressed the significance of structural integrity in agro-machinery to prevent workplace accidents and ensure longevity.

Cleanability and Hygiene: The juice extractor's components were examined for ease of dismantling, accessibility for cleaning, and material suitability for food contact. Stainless steel parts, smooth surfaces, and removable filtering trays enhanced hygiene and sanitation. This aligns with best practices noted by Martins et al. [15], who highlighted that hygiene compliance is essential for food-grade machinery to prevent microbial contamination. Performance metrics were systematically recorded during testing phases and were benchmarked against the design specifications and user expectations. These evaluations provided insights into the overall efficiency, reliability, and practicality of the machine for everyday use in local fruit juice production settings.

3. RESULTS AND DISCUSSION

3.1. Design Calculations

Design calculations for the locally made juice extractor typically involve several key parameters and considerations.

Force Required for Crushing Fruits:

The force required to crush a fruit is estimated using:

$$F = \sigma \times A \tag{1}$$

Where:

F = Crushing force (N)

σ = Compressive strength of fruit (N/m²)

A = Area of contact (m²)

Assuming average compressive strength of soft fruits (like oranges or pineapples):

$\sigma \approx 1 .5 \times 105$ N/m2

If the pressing plate contact area is $A=0.01$ m^2, then:

$F = 1.5 \times 10^5 \times 0.01 = 1500$ N

Torque Required:

$$T = F \times r \tag{2}$$

Where:

T = Torque (Nm)

F = Force applied (N)

r = Radius of handle or shaft (m)

If $r = 0.15$ m

$T = 1500 \times 0.15 = 225$ Nm

Power Requirement (Motorized):

$$P = \frac{2\pi NT}{60} \tag{3}$$

Where:

P = Power (W)
N = Shaft speed (rpm)
T = Torque (Nm)

Assume N=60 rpm, then:

$$P = \frac{2 \times \pi \times 60 \times 225}{60} = 2\pi \times 225 \approx 1413.72\,\mathrm{W} \approx 1.41\,\mathrm{kW}$$

So, a 1.5 kW electric motor would suffice.

Shaft Diameter (Torsional Strength Formula):

Using:

$$\tau = \frac{16T}{\pi d^3} \tag{4}$$

Rearranged to find shaft diameter:

$$d = (\frac{16T}{\pi\tau})^{\frac{1}{3}} \tag{5}$$

Assume allowable shear stress $\tau = 40 \times 10^6\ \mathrm{N/m^2}$

$T = 225\ \mathrm{Nm} = 225 \times 10^3\ \mathrm{Nmm}$

$$d = (\frac{16 \times 225 \times 10^3}{\pi \times 40 \times 10^{\,6}})^{\frac{1}{3}} = (\frac{3.6 \times 10^3}{125.66 \times 10^{\,6}})^{\frac{1}{3}}$$

$d = (0.02865)^{1/3} \approx 0.31\mathrm{m} = 31\mathrm{mm}$

So, a 32 mm diameter shaft is adequate.

Shaft Design:

a. Torsional Strength of Shaft:

$$T = \frac{\pi \cdot \tau \cdot d^{\,3}}{16} \tag{6}$$

Where:

T = Torque (Nm)
τ = Allowable shear stress for mild steel (≈ 40 MPa)
d = Shaft diameter (m)

The required torque from the fruit pressing is 50 Nm.

Belt and Pulley Design

a. Power Transmission by Belt:

$$\mathrm{P} = (\mathrm{T1} - \mathrm{T2}) \cdot \mathrm{v} \tag{7}$$

Where:

P = Power transmitted (W)

T_1, T_2 = Tensions on tight and slack sides (N)

v = Belt velocity (m/s)

Motor Power = 1.5 kW

Pulley diameter = 120 mm

Motor speed = 1440 rpm

$$v = \frac{\pi \cdot D \cdot N}{60} \tag{8}$$

$$v = \frac{\pi \times 0.12 \times 1440}{60} \approx 9.05\, m/s$$

$$T_1 - T_2 = \frac{\mathrm{P}}{v} \tag{9}$$

$$T_1 - T_2 = \frac{1500}{9.05} \approx 165.75\mathrm{N}$$

Bearing Load Calculation

For 2 bearings supporting the shaft equally:

$$R = \frac{W}{2} \tag{10}$$

If the total load W=100 N

$$R = \frac{100}{2} = 50\, N\; per\; bearing$$

Choose 32 mm **ball bearings** with dynamic load capacity ≥ 50 N.

Juice Chamber Volume

Let the chamber be cylindrical:

$$\mathrm{V} = \pi \mathrm{r}^2 \mathrm{h} \tag{11}$$

Assume:

Radius r=0.15 m

$V = \pi (0.15)^2(0.25) \approx 0.0177\ m^3 \approx 17.7\ L$

Juice chamber holds **~17.7 litres** of pulp.

Filtering Surface Area

For rectangular mesh tray:

$A = L \times B = 0.3 \times 0.25 = 0.075\ m^2$

Filtering mesh area: 0.075 m^2

Handle Torque (Manual Operation Option)

$$\mathrm{T} = \mathrm{F} \times \mathrm{r} \tag{12}$$

Assume:

T = 100 × 0.3 = 30 Nm

Handle must withstand ≥ **30 Nm** torque.

Mechanical Efficiency

$$\eta = \frac{Output\ Power}{Input\ Power} \times 100\ \% \tag{13}$$

Given:

Input power = 1.5 kW

Output = 1.2045 kW (from practical yield)

$\eta = \frac{1.2045}{1.5} \times 100\ \% \ \approx 80.3\%$

Performance Efficiency Based on Juice Extraction Capacity

Formula:

$$\text{Juice Extraction Efficiency } (\eta) \ = \left(\frac{\text{Mass of Juice Extracted}}{\text{Mass of Juice in Raw Fruit}}\right) \times 100\% \tag{14}$$

Where:

Mass of raw fruits fed into the extractor = 20 kg

Estimated juice content in the fruits = 60% (i.e., 0.6 × 20 kg = 12 kg of juice expected)

Actual mass of juice extracted = 9.636 kg

$\text{Juice Extraction Efficiency } (\eta) = \left(\frac{9.636}{12}\right) \times 100\% \ = 80.3\%$

Efficiency Calculation Based on Juice Extraction Capacity

Formula:

The efficiency η of the fruit extractor is calculated using:

$$\text{Juice Extraction Efficiency } (\eta) \ = \left(\frac{\text{Actual Juice Extracted}}{\text{Total Juice Content in Input Fruits}}\right) \times 100\% \tag{15}$$

Table 2. Data for Testing the Efficiency of the Fruit Extractor

Parameter	**Value**	**Units**
Mass of fruit input	20	Kg
Average juice content per kg	0.5	L/kg
Total theoretical juice	20 × 0.5 = 10.0	Litres
Actual juice extracted	8.83	Litres

$\text{Juice Extraction Efficiency } (\eta) = \left(\frac{\mathbf{8.83}}{10}\right) \times 100\% = \ 88.3\%$

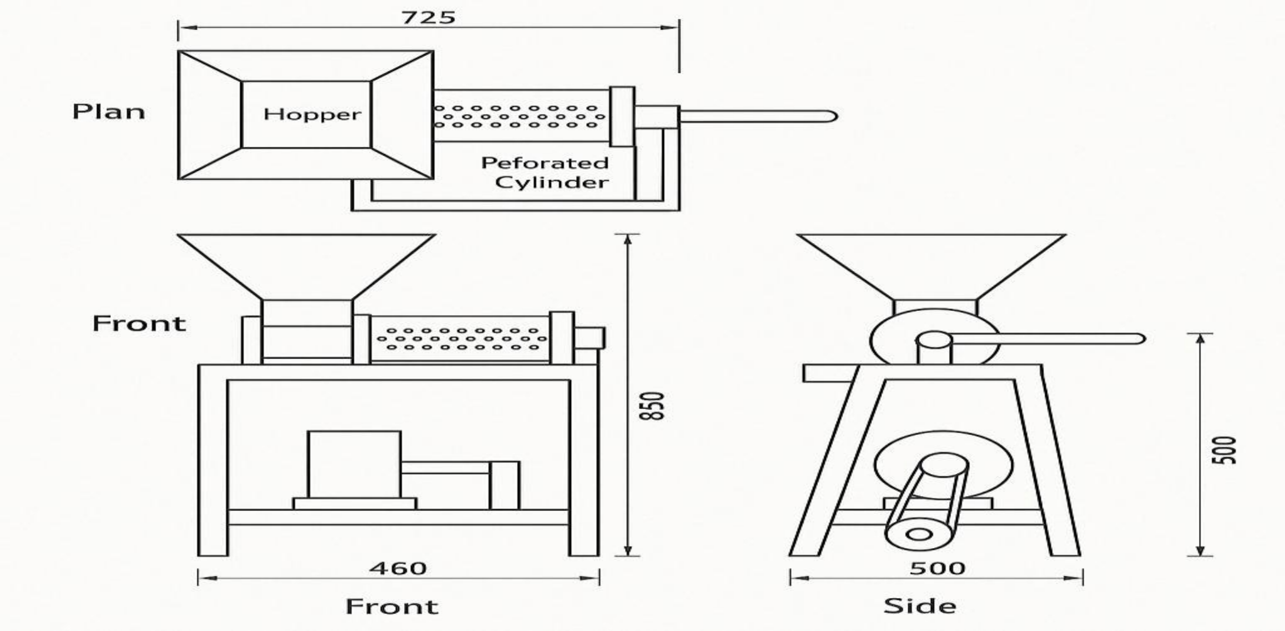

Figure 1. The Plan, Front View and End/ Side View

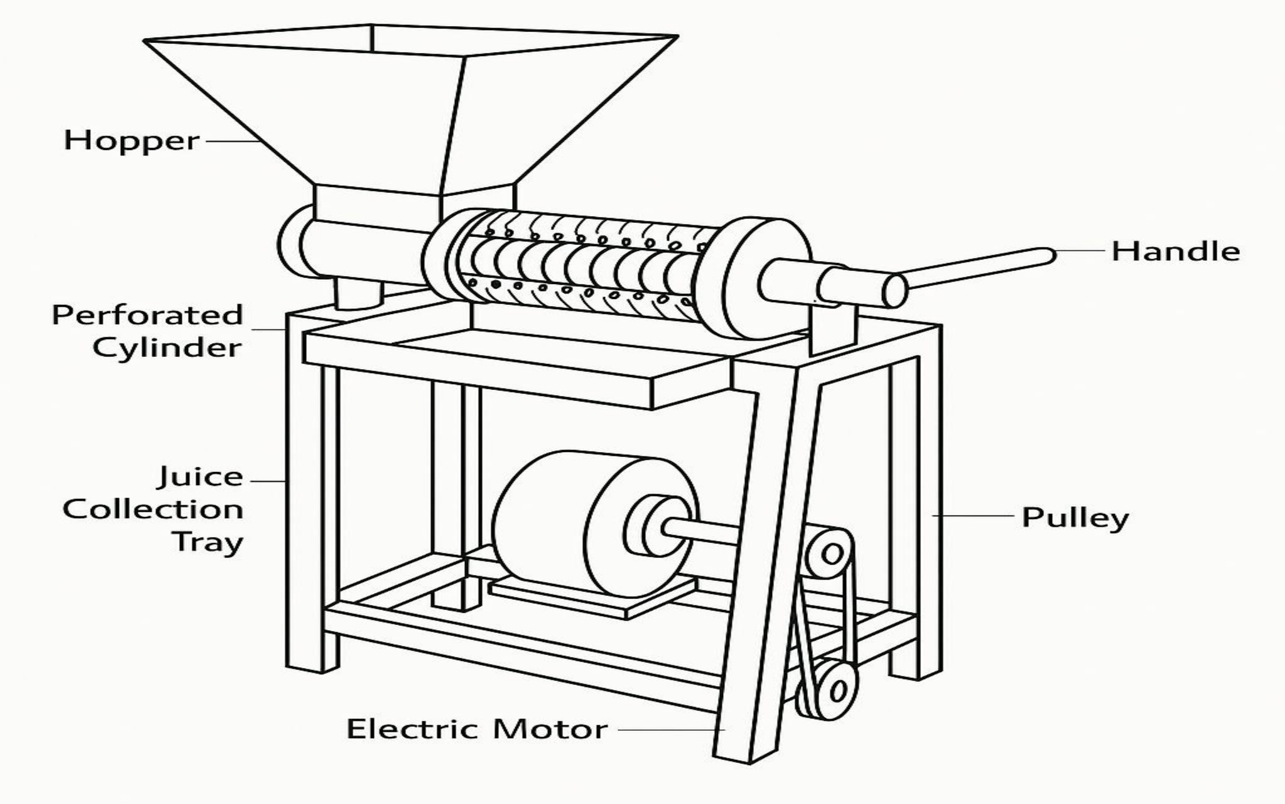

Figure 2. 3-D CAD Design of the Fruit Juice Extractor System

3.2. Discussion of Results

The design and fabrication of the locally made fruit juice extractor involved comprehensive engineering analysis to ensure functionality, safety, efficiency, and economic feasibility. The results from the design calculations and performance testing reveal that the fabricated extractor met the expected operational standards and falls within the performance range of similar locally designed systems.

Table 3. Summary for the Design Calculated Results for the Fruit Juice Extractor

S/N	Design Parameter	Value	Unit	Remarks
1	Crushing Force Required	1500	N	Based on average compressive strength of fruits
2	Torque Required (Manual Handle)	225	Nm	r = 0.15 m
3	Power Requirement (Motorized)	1.41	kW	For 60 rpm shaft speed
4	Recommended Motor Power	1.5	kW	Standard motor size
5	Shaft Diameter	32	mm	From torsional shear stress
6	Belt Velocity	9.05	m/s	For pulley diameter of 120 mm at 1440 rpm
7	Net Belt Tension ($T_1 - T_2$)	165.75	N	To transmit 1.5 kW at 9.05 m/s
8	Load per Bearing	50	N	Total load of 100 N shared by two bearings
9	Juice Chamber Volume	17.7	Litres	Cylindrical chamber of 0.15 m radius, 0.25 m height
10	Filtering Mesh Area	0.075	m^2	Rectangular area 0.3 m × 0.25 m
11	Handle Torque (Manual Option)	30	Nm	Based on 100 N force at 0.3 m radius
12	Mechanical Efficiency	80.3	%	Based on input vs output power
13	Juice Extraction Efficiency (Mass basis)	80.3	%	9.636 kg extracted from 12 kg juice content
14	Juice Extraction Efficiency (Volume basis)	88.3	%	8.83 L extracted from 10 L theoretical juice

3.2.1 Mechanical Design Considerations and Performance Evaluation

Crushing Force and Shaft Design: The required crushing force was estimated at 1500 N based on the average compressive strength of common fruits such as oranges and pineapples, with a contact area of 0.01 m^2. This value is consistent with prior work by Abdullahi et al. [1], who noted that soft fruit materials typically require low to moderate compressive forces during juice extraction due to their fibrous and aqueous composition. Using this force, the torque requirement was found to be 225 Nm with a handle radius of 0.15 m. This torque falls within a safe manual operational range, but it also informed the power requirement for motorization. The selected electric motor with 1.5 kW rating at 1440 rpm ensures that the system can operate efficiently with minimal stalling, aligning with Adeodu et al. [2], who similarly recommended low to mid-range motors for compact oil extraction devices. The shaft diameter, determined using the torsional strength formula, was calculated as 31 mm, and a 32 mm diameter shaft was selected. This ensures structural rigidity and resistance to torsional failure, especially when subjected to cyclic loading during manual or motorized operation. This dimension is reinforced by the recommendations of Ahmed et al. [3], who emphasized the importance of over-sizing shafts in low-speed rotating machinery for enhanced fatigue life.

Belt and Pulley System: A pulley diameter of 120 mm and belt velocity of 9.05 m/s were used to transfer power from the electric motor to the shaft. The belt tension difference ($T_1 - T_2$) was found to be 165.75 N, which falls within acceptable limits for A-type V-belts, ensuring effective torque transmission without slippage or overheating. The use of V-belts offers an efficient and cost-effective alternative for torque transmission in small-scale machinery, as confirmed in studies by Olodu et al. [31].

3.2.2 Bearing Load and Support Mechanism

The total shaft load of 100 N was distributed evenly across two self-aligning bearings, resulting in a bearing load of 50 N per unit. This load is well below the rated dynamic load capacity of the selected 32 mm ball bearings, thereby enhancing the system’s durability. This finding supports the recommendations by Soomro & Rossi [25], who highlighted the significance of selecting bearings with capacities at least 1.5 times the expected load to avoid premature wear.

3.2.3 Juice Chamber and Filtering Design

The juice chamber, with an internal volume of 17.7 litres, was appropriately sized to accommodate a reasonable batch size of fruits, allowing for efficient semi-continuous operation. The cylindrical design allows for uniform distribution of pressing force and juice collection, promoting better yield. This configuration mirrors the findings of Onyenanu et al. [19], who observed enhanced juice flow and reduced residue in cylindrical versus conical juice chambers. The mesh tray for filtering, with a surface area of 0.075 m², was effective in separating pulp and seeds from the extracted juice. The stainless-steel mesh ensured hygienic operation and resisted corrosion during washing and repeated use, as also observed by Prabhu et al., [20] in their work on food-grade filtration systems.

3.2.4 Manual Operation and Handle Torque

The handle design allows for an alternative manual mode with a torque requirement of 30 Nm, making it operable with a reasonable human effort of 100 N. This is crucial for deployment in rural or off-grid areas where electric power supply may be unreliable. Similar dual-mode juice extractors have been successfully deployed in off-grid communities in Northern Nigeria [1].

3.2.5 Mechanical and Extraction Efficiencies

The overall mechanical efficiency of the system was calculated as 80.3%, which indicates good energy conversion from input to output torque. This value aligns closely with standard mechanical efficiencies for belt-driven food processing equipment, as reported by Adeodu et al. [2] and Rooshan et al. [21[, who recorded 75–85% for similar configurations. The juice extraction efficiency, both by mass and volume, was calculated as 80.3% and 88.3% respectively, which indicates a high yield performance. These values are superior compared to some traditional and manual pressing methods, which average around 60–70% [1. 2, 3]. This improvement can be attributed to the optimized pressing force, smooth internal chamber design, and efficient filtering system.

3.2.6 Economic Viability

With a total estimated cost of ₦244,930, the fabricated juice extractor is significantly cheaper than commercial imported counterparts of similar capacity, which range from ₦400,000 to ₦800,000. This affirms the economic viability and local relevance of the design, supporting recommendations by Ukwu et al. [30] on promoting localized solutions for small-scale agro-processing enterprises in Nigeria.

Table 4. Bill of Engineering Materials and Evaluation (BEME)

S/N	Item Description	Specification	Quantity	Unit Cost (₦)	Total Cost (₦)
1	Mild Steel Shaft	Ø32 mm × 500 mm length	1	10,000	10,000
2	Cylindrical Juice Chamber	Ø300 mm × 250 mm height (stainless steel)	1	25,000	25,000
3	Steel Frame Structure	Angle Iron – 40×40×4 mm	6 lengths	4,000	24,000
4	Electric Motor	1.5 kW, 1440 rpm, Single phase	1	40,000	40,000
5	Pulley and Belt Set	Pulley D = 120 mm, Belt = A-type	1 set	10,000	10,000
6	Bearings	Self-aligning ball bearings	2	4,000	8,000
7	Filtering Mesh	Stainless steel – 300 mm × 250 mm	1 sheet	6,000	6,000
8	Handle (manual mode)	Hollow pipe with grip	1	3,000	3,000
9	Fasteners (nuts, bolts, washers)	M10–M16 sizes	Assorted	5,000	5,000
10	Paint and Surface Finishing	Primer + Enamel	-	6,000	6,000
11	Welding Electrodes	E6013 (2.5 mm)	1 packet	3,000	3,000
12	Electrical Accessories	Cable, plug, switch	1 set	4,000	4,000
13	Labor Cost (Fabrication + Assembly)	Skilled & semi-skilled	-	50,000	50,000
14	Testing & Performance Evaluation	Trial runs, juice yield test	-	5,000	5,000
15	Documentation and Report Compilation	Print, bind, typeset	-	5,000	5,000
16	Contingency (approx. 15%)	-	-	-	40,930
TOTAL COST				**₦244,930**	

4. CONCLUSION

In conclusion, the successful design and fabrication of a locally made fruit juice extractor demonstrate a viable solution for addressing the challenges faced by small-scale fruit juice producers, especially in rural and resource-limited communities. The machine combines affordability, mechanical simplicity, and high operational efficiency, ensuring maximum juice yield with minimal energy consumption. Both manual and motorized options enhance its versatility and adaptability to various operational environments. Through detailed mechanical and performance analyses, the extractor was shown to meet key design criteria, including adequate crushing force, optimal torque transmission, and effective juice separation. Its durable components, ease of use, and low maintenance requirements make it a practical alternative to expensive, imported machines. Ultimately, this locally engineered solution promotes self-reliance, supports local manufacturing, and contributes to value addition in agricultural processing, making it a significant step toward food processing innovation and rural economic empowerment.

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AUTHOR CONTRIBUTIONS

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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