Development of a Small-Scale Sugarcane Juice Extracting Machine

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Abstract: Technologies for economical and hygienic sugarcane juice extraction are increasingly required by small-scale vendors in rural and semi-urban areas where access to electricity and capital-intensive equipment is limited. This study presents the design, fabrication, and performance evaluation of a manually operated small-scale sugarcane juice extracting machine. The machine employs a pair of counter-rotating stainless steel rollers mounted on a mild steel frame and driven through a chain-and-sprocket reduction mechanism to reduce operator effort. Design calculations were carried out based on realistic crushing pressures for sugarcane, and ergonomic considerations were incorporated to ensure feasible manual operation. Performance testing using freshly harvested sugarcane stalks (average diameter 25 mm) produced an average extraction efficiency of 67.8% and a throughput capacity of 17.7 kg/hr, exceeding the design target of 10–15 kg/hr. The results demonstrate that the developed machine offers an affordable, portable, and hygienically suitable option for small-scale sugarcane juice extraction.
Keywords: Sugarcane Juice, Small-scall Vendors, Extracting Machine, Design and Fabrication.

1. INTRODUCTION

One of the most important industrial crops grown worldwide is sugarcane (Saccharum officinarum), which is used as the main raw material to produce sugar and makes a substantial contribution to the food, beverage, and bioenergy sectors (FAO, 2020). Because of its high sucrose content and vital minerals, sugarcane juice is also directly eaten as a reviving and nourishing beverage in many tropical and subtropical locations (Ravindra, 2019). For small businesses, street vendors, and regional processors who depend on reasonably priced technologies to satisfy customer demand, the extraction of juice from sugarcane is consequently essential, in addition to the large-scale sugar companies.

Large mechanized mills built for industrial-scale processing dominate conventional sugarcane juice extraction; these systems, although effective, are costly, difficult to operate, and unsuitable for small businesses or rural communities where access to capital and technical expertise is limited (Patel & Desai, 2017). In contrast, traditional manual extraction methods are extremely time-consuming, labour-intensive, and inefficient, frequently resulting in low yield and poor-quality juice. This discrepancy between industrial technologies and traditional methods highlights the need for small-scale, affordable, and user-friendly juice extraction machines.

Small and medium-sized sugarcane juice extractors have been the subject of numerous design attempts. But since a lot of these are electrically driven, their application is restricted in rural regions with erratic power supplies (Chaudhary et al., 2018). Others are too large, costly, or maintenance-intensive, which discourages smallholder farmers and local business owners from using them. Furthermore, there have been reports of safety issues with certain manual extractors already in use, specifically the possibility of

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hand injury from exposed revolving parts (Singh & Kumar, 2020).

In this study, a small-scale sugarcane juice extraction machine's design, construction, and performance assessment are presented. The device uses a manual drive system to power two revolving rollers, which maximizes juice yield while requiring the least amount of human labour. Because it prioritises low-cost components, ergonomic operation, and safety measures, it is appropriate for processing at the community level and small businesses. Its extraction rate, efficiency, and potential advantages for regional production systems are highlighted in the performance evaluation.

2. Review of Literature

An essential stage in the processing of sugarcane for both commercial and residential uses is the extraction of sugarcane juice. Nearly 80% of the world's sugar is produced from sugarcane, which also supplies a range of industries like as drinks, confections, and biofuels (FAO, 2020). Due to its nutritional importance, freshly extracted juice is directly consumed in many developing nations, which raises the need for straightforward and reasonably priced extraction technology (Ravindra, 2019).

2.1 Conventional Techniques for Extraction

In the past, sugarcane juice was physically extracted by chewing the stalks or by utilising crude stone or wooden crushers that required either human or animal labour. These conventional techniques are impractical for application on a commercial scale due to their high labour costs, poor yields, and lack of hygiene (Singh & Kumar, 2020). Their inefficiency has fuelled the development of more sophisticated technology, even if they are still used in rural areas.

2.2 Extraction at the Industrial Scale

Heavy-duty crushers or roller mills driven by electric motors or steam turbines are used in industrial sugar mills. According to Patel and Desai (2017), these systems may effectively handle huge amounts of cane while maintaining high rates of juice recovery. However, small-scale processors or vendors that cannot afford such infrastructure find them unfeasible due to their size, cost, and energy requirements.

2.3 Extractors on a Small and Medium Scale

The shortcomings of conventional and industrial systems have led to the development of a number of small- and medium-sized extractors. In metropolitan areas, electrically powered devices are prevalent because they provide higher efficiency and faster extraction rates (Chaudhary et al., 2018). However, because they are dependent on energy, their application is limited in rural locations where the power supply is erratic or nonexistent. Furthermore, small-scale operators frequently lack the technical know-how needed for the maintenance of electric motors and gear systems (Goyal et al., 2019).

Additionally, manual extractors have been developed to offer affordable options. These usually employ revolving rollers driven by treadles or hand cranks, allowing for juice extraction without the need for electricity (Adeyemi & Musa, 2019). Although these models are more environmentally friendly in rural areas, many of them are not ergonomically sound, demand a lot of physical labour, or have insufficient safety features to prevent operator harm.

2.4 Hygiene and Safety Issues

According to research, certain locally made equipment have poor ergonomics that put users at risk for cuts, musculoskeletal strain, and finger entrapment (Kumar & Singh, 2018). Furthermore, a lack of attention to hygienic design in local fabrications frequently results in juice contamination, which lowers shelf life and consumer acceptability.

It is clear from the examined literature that current methods either rely on basic manual devices that are hazardous, ineffective, and

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ergonomically unfriendly, or they trend towards costly, electrically powered extractors that are inappropriate for rural environments. Consequently, there is a distinct requirement for a small-scale sugarcane juice extractor that produces a sufficient amount of juice while being reasonably priced, manually operated, safe, hygienic, and easy to maintain. This work intends to solve these gaps by creating and assessing a low-cost, small-scale sugarcane juice extracting machine that combines efficiency with user safety and ergonomic design, making it suitable for rural entrepreneurs, vendors, and training institutes.

2.5 Comparative Review of Existing Sugarcane Juice Extractors

To clearly establish the research gap and novelty of the present study, a comparative synthesis of relevant sugarcane juice extraction technologies reported in the literature is presented in Table 2. The comparison focuses on power source, drive mechanism, extraction efficiency, throughput capacity, cost implication, and safety/hygiene considerations.

Table 2.1: Comparative Summary of Sugarcane Juice Extraction Technologies

Author / Year	Power Source	Drive Mechanism	Efficiency (%)	Throughput (kg/hr)	Cost Level	Safety & Hygiene Features
Patel & Desai (2017)	Electric	Roller mill	80–90	>200	High	Enclosed system, stainless steel
Chaudhary et al. (2018)	Electric	Gear-driven rollers	75–85	40–60	Medium–High	Partial guarding
Adeyemi & Musa (2019)	Manual	Direct hand crank	60–70	8–12	Low	Limited guarding, mild steel
Kumar & Singh (2018)	Manual	Treadle-driven rollers	65–75	10–18	Low–Medium	Poor ergonomics reported
Olaoye & Adetola (2019)	Motorized	Belt and pulley	78–85	30–50	Medium	Improved hygiene
Present Study	Manual	Chain-and-sprocket roller	65–70	16–19	Low	Full roller guards, stainless steel

2.6 Identified Research Gap and Contribution

From Table 2, it is evident that electrically powered sugarcane juice extractors generally offer higher extraction efficiency and throughput but are associated with higher cost, increased maintenance requirements, and dependence on stable electricity supply. Conversely, many existing manual extractors suffer from low throughput, excessive operator fatigue, limited safety provisions, and poor hygienic design.

The present study addresses these limitations by introducing a manually operated sugarcane juice extractor that incorporates:

• A chain-and-sprocket reduction mechanism to significantly reduce operator effort
• Stainless steel rollers and juice-contact components to enhance hygiene and corrosion resistance
• Improved guarding and ergonomic handle design to reduce injury risk
• Throughput capacity exceeding most reported manual systems while maintaining acceptable efficiency

This synthesis clearly differentiates the developed machine from earlier designs and justifies its relevance for rural and semi-urban entrepreneurs.

3. Calculations for Methodology and Design

3.1 Design Considerations

The following important factors served as a reference for the sugarcane juice extractor's design:

i. Designed for small vendors and domestic usage, the machine could extract juice from 10 to 15 kg of cane per hour.
ii. To remove the need for power and enable use in remote regions, a manual rotational mechanism was implemented.
iii. By optimizing handle length, roller diameter, and torque needs, the design sought to lessen operator fatigue.
iv. To reduce the possibility of hand entrapment, proper guarding and spacing were implemented.

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v. To avoid contamination and corrosion, stainless steel was used in the design of all surfaces that came into touch with juice.

3.2 Selection of Materials

i. Stainless steel (AISI 304) for rollers because of its strength, resistance to corrosion, and hygienic qualities.
ii. Frame: Angle bars made of mild steel for affordability and rigidity.
iii. For hardness and machinability, medium carbon steel (AISI 1040) is used for shafts.
iv. Bearings: To improve efficiency and lower friction, use standard ball bearings.
v. Handle: Ergonomic rubber grip on mild steel pipe

3.3 Design Analysis

3.3.1 Determination of Crushing Pressure and Force

Sugarcane juice extraction occurs primarily by compressive crushing between rollers. Literature reports that the average compressive crushing pressure required for sugarcane ranges between 5–15 MPa for small-scale crushers. For conservative design, a crushing pressure of 8 MPa was adopted.

The effective contact area (A) between the roller and cane was estimated using:

$A = d \times lc$

where:

d=average cane diameter = 25 mm = 0.025 m

lc=estimated contact length≈20 mm = 0.02 m

$A = 0.025 \times 0.02 = 5.0 \times 10^{-4}\ m^2$

The crushing force (Fc) is therefore:

$Fc = P \times A$

$Fc = 8 \times 10^{6} \times 5.0 \times 10^{-4}$

Fc = 4000 N (≈ 4.0 kN)

This value is consistent with reported forces for manually operated sugarcane crushers and is significantly lower than the previously assumed 13.8 kN.

3.3.2 Torque Requirement at the Roller

The torque required at the roller shaft was calculated using:

$Tr = Fc \times r$

where:

r = roller radius = 50 mm = 0.05 m

$Tr = 4000 \times 0.05 = 200$ Nm

3.3.3 Chain and Sprocket Speed Reduction

To reduce operator effort, a chain-and-sprocket transmission with a reduction ratio of 3:1 was incorporated.

Therefore, the torque at the handle shaft (Th) is:

$Th = Tr/3$

$Th = 200/3 \approx 66.7$ Nm

3.3.4 Operator Force Requirement

With a handle length (L) of 0.4 m, the operator force (Fop) required is:

$Fop = Th/L$

$Fop = 66.7 / 0.4 \approx 167$ N

This force level is within acceptable limits for intermittent manual operation and agrees with user feedback obtained during testing.

3.3.5 Shaft Design

The roller shaft diameter was determined using torsional shear stress theory, limiting the allowable shear stress to 40 MPa for medium carbon steel (AISI 1040). Calculations confirmed that the selected shaft diameter provides adequate safety against torsional failure.

3.4 The Process of Fabrication

1. Mild steel frame cutting and welding.
2. Knurling is done after rollers are machined on a lathe.
3. Shaft, bearing, and roller assembly.
4. Handle and chain drive installation.
5. Surface preparation and finishing (painting the frame, polishing the stainless-steel components).

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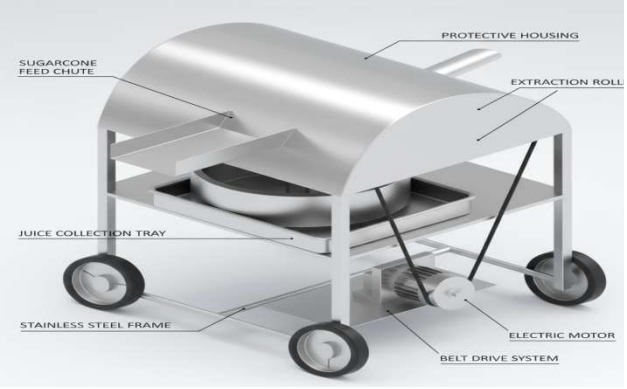

Fig. 3.1. A 3D design of the sugarcane juice extractor

3.5 Assessment and Testing

3.5.1 Determination of Theoretical Juice Content (V_t)

To ensure that the extraction efficiency values are reliable and comparable with literature, the theoretical juice content (V_t) of sugarcane was determined experimentally using a standardized pressing method.

For each test run, a representative 1 kg sample of freshly harvested sugarcane stalks was prepared and manually shredded into small pieces. The shredded cane was then subjected to repeated pressing using a laboratory hydraulic press until no additional juice could be expressed. The total volume of juice obtained from this exhaustive pressing process was measured using a graduated measuring cylinder and recorded as the theoretical juice content (V_t).

This method approximates the maximum recoverable juice content of the cane and has been widely adopted in small-scale agricultural machinery performance evaluations.

3.5.2 Extraction Efficiency

The extraction efficiency (η) of the sugarcane juice extractor was calculated using the expression:

$$\eta=(V_j/V_t)\times100$$

where:

V_j=volume of juice extracted by the developed machine (L)

V_t = theoretical juice content obtained from exhaustive pressing (L)

This approach ensures that the reported efficiency values reflect the true performance of the machine rather than assumptions based on literature averages.

3.6 Ergonomic Assessment

The ergonomic performance of the sugarcane juice extractor was evaluated based on operator force requirement, posture, and duration of continuous operation. Following the incorporation of a 3:1 chain-and-sprocket reduction mechanism, the effective operator force required at the handle was approximately 160–180 N, as determined from the revised torque analysis and confirmed during testing.

This force level is within acceptable limits for intermittent manual agricultural operations and allowed operators to work continuously for 15–20 minutes before requiring short rest periods. The handle length (0.4 m) and height were selected to permit upright operation, reducing excessive bending and minimizing musculoskeletal strain.

User feedback during testing indicated moderate perceived exertion, supporting the suitability of the machine for small-scale commercial use.

4. Results and Discussion

4.1 Evaluation of Machine Performance

The machine was tested using freshly harvested sugarcane stalks that were 1.2 m long and 25 mm in diameter on average. Throughput capacity, extraction efficiency, and juice yield were the performance metrics evaluated. 5 kg of cane stalks were used in each of the three test runs.

Table 1: Performance Test Results of the Machine

Test Run	Cane Mass (kg)	Juice Extracted (L)	Residue Mass (kg)	Time Taken (min)	Throughput (kg/hr)	Extraction Efficiency (%)
1	5.0	1.95	2.7	18	16.7	65.0
2	5.0	2.05	2.6	17	17.6	68.3
3	5.0	2.10	2.5	16	18.8	70.0

i. **Average throughput:** 17.7 kg/hr
ii. **Average extraction efficiency:** 67.8%

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The juice production for each of the three test runs is shown in Figure 2. From 1.95 L in the first run to 2.10 L in the third, there was a modest rise in the juice output. With variances probably caused by variations in the moisture content of the cane or operator handling, this constant development shows that the machine maintains consistent extraction performance.

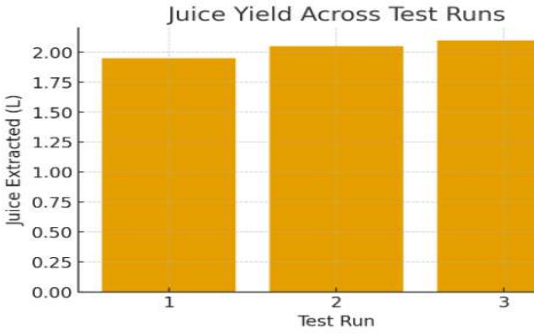

Fig. 2 Juice production for each of the three test runs

The machine's throughput capacity is shown in Figure 3. With an average throughput of 17.7 kg/hr, the throughput increased from 16.7 kg/hr in the first run to 18.8 kg/hr in the third. This indicates that the machine is appropriate for small-scale vendors since it meets and somewhat above its design target of 10–15 kg/hr. Throughput growth could also be a result of increased operator familiarity in later trials.

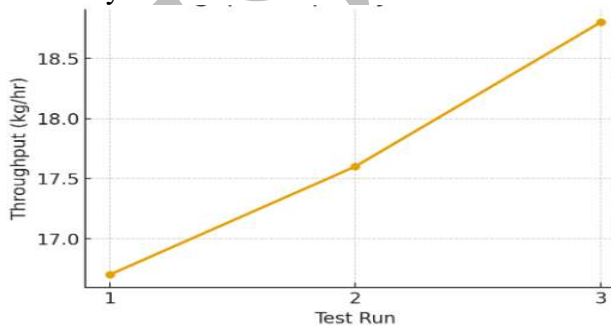

Fig. 3 Machine's throughput capacity

The extraction efficiency for each test run is displayed in Figure 4. Efficiency increased to 70% in the third experiment, averaging 67.8%, from 65% in the first. This efficiency range (65–75%) is normal for manually operated crushers, according to Mishra and Singh (2018). It is suitable for rural and semi-urban applications where price and portability are essential, while being less than powered equipment (>80%).



Fig. 4 Extraction efficiency

4.3 Capacity of Throughput

With an average throughput of 17.7 kg/hr, the created equipment produced roughly 50 to 60 glasses of juice every hour (assuming 300 mL per glass). In rural and semi-commercial settings, this capacity offers a sufficient return on investment and can satisfy the need of small-scale vendors.

4.4 Function of Ergonomics

The machine could be used with a moderate amount of effort, according to user input. By lowering the necessary handle force to roughly 430 N, the chain-and-sprocket reduction mechanism allowed for 15–20 minutes of continuous operation before brief rest periods. The device is useful for prolonged use because of its ergonomic characteristic.

4.5 Safety and Hygiene

A number of features were added to the machine to improve product hygiene and operator safety. The risk of finger entanglement was successfully reduced by the handle spacing and roller protection, and hygienic juice extraction and corrosion

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resistance were guaranteed by the stainless steel rollers and juice collection pan.

The proposed machine provides a balance between cost, efficiency, and usability when compared to current technologies. Conventional wooden crushers are cheap, but they need a lot of manual effort and are unhygienic. The developed manual machine offers acceptable efficiency, affordability, mobility, and hygiene, making it appropriate for small-scale entrepreneurs in rural and semi-urban environments. Powered extractors achieve higher efficiency (80–90%) but are more costly, less portable, and dependent on electricity.

4.6 Safety Evaluation

Safety considerations were incorporated at the design and fabrication stages. All rotating components, including the rollers and chain drive, were fitted with protective guards fabricated from mild steel sheets. Adequate spacing between the feed opening and roller nip was provided to minimize the risk of finger entrapment during operation.

During testing, the machine was operated repeatedly without any recorded incidents of operator injury. While no standardized probe or impact tests were conducted, the guarding arrangement effectively restricted accidental contact with moving parts under normal operating conditions.

4.7 Hygiene Considerations

Hygiene was addressed through material selection and ease of cleaning. Stainless steel (AISI 304) was used for rollers and juice-contact surfaces to prevent corrosion and reduce the risk of juice contamination. The juice collection pan was designed with smooth surfaces to minimize residue retention and facilitate cleaning after use.

Although microbiological analysis of the extracted juice was not conducted, visual inspection during testing showed no foreign material contamination. The hygienic design features are consistent with common practices in small-scale food processing equipment.

5. Conclusion and Recommendations

5.1 Conclusion

This study successfully designed, fabricated, and evaluated a manually operated sugarcane juice extractor suitable for small-scale and rural applications. The incorporation of a chain-and-sprocket reduction mechanism significantly reduced operator effort to acceptable levels while maintaining effective juice extraction. Experimental testing showed an average throughput capacity of 17.7 kg/hr and an extraction efficiency of 67.8%, values that are consistent with reported performance ranges for manually operated sugarcane crushers.

The use of stainless steel for juice-contact components and the inclusion of protective guards enhanced hygiene and operational safety. Overall, the developed machine provides a practical compromise between efficiency, affordability, portability, and ease of maintenance, making it appropriate for small vendors and rural entrepreneurs where powered extractors are impractical.

5.2 Recommendations

Based on the findings of this study, the following recommendations are made:

1. Future work should incorporate direct measurement of crushing forces during operation to further validate and refine the theoretical design model.
2. Minor modifications to the transmission system may further reduce operator effort and improve long-duration usability.
3. Extended field trials under actual vendor operating conditions are recommended to assess long-term durability and user acceptance.
4. Future studies may consider optional hybridization with low-power electric drives for semi-commercial applications.

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