# Efficiency Assessment of a Developed Sugarcane Juice Extractor

P. C. Umeakuekwe [1]; S.V. Irtwange[2]; J.O. Awulu[3]; S. S. Igila[4]; O. H. Salaudeen[5]
[1,2,3,4,5] Joseph Sarwuan Tarka University Makurdi Benue State Nigeria

**Abstract:- The study assessed the efficiency of a prototype sugarcane juice extractor. The machine's performance was assessed under varying operational conditions, including different machine speeds (700 rpm, 900 rpm, and 1100 rpm) and sugarcane weights (0.5 kg, 1 kg, and 1.5 kg). The investigation revealed that the weight of extracted sugarcane juice exhibited a range from 0.204 kg to 0.774 kg. The weight of sugarcane residue, known as bagasse, ranged from 0.21360 kg to 0.91549 kg, the operational time varied significantly with the shortest duration occurring at 1100 rpm machine speed with 0.5 kg sugarcane weight and the longest time observed at 700 rpm with 1.5 kg sugarcane weight. The operational time increased with higher sugarcane weights but decreased with higher machine speeds. Extraction efficiency ranged from 51.342% to 76% and increases as sugarcane weight decreases while the throughput capacity ranged from 11.844 kg/hr to 24.683 kg/hr, and the extraction rate varied from 6.005 kg/hr to 12.22 kg/hr. The analysis of variance (ANOVA) at a significant level of P<0.05 revealed that both machine speed and sugarcane weight significantly impacted the evaluated machine parameters. It is recommended that the sugarcane juice extractor be used in the extraction of juice from sugarcane.**

***Keywords:-*** *Sugarcane, Juice and Extractor.*

## I. INTRODUCTION

Sugarcane, classified within the Saccharum group of permanent grass in the Andropogoneae tribe, is a perennial plant that generates lateral shoots at its base, resulting in multiple stems reaching a typical height of 3 to 4 meters and a diameter of about 5 centimeters. These stems develop into cane stalks, constituting approximately 75% of the entire mature plant. The composition of mature sugarcane includes 69-75% water, 8-16% sucrose, 0.2-3.0% reducing sugar, 0.5-1.0% other organic matter, 0.2-0.6% inorganic compounds, 0.5-1.0% nitrogenous bodies, 0.3-0.8% ash, and 10.0-16.0% fiber (Rika, 2010). The cultivation of sugarcane is influenced by factors such as climate, soil type, irrigation, fertilizers, pests, disease control, varieties, and harvest timing. Cane stalk yields average 60–70 tonnes per hectare per year, with variations depending on cultivation practices, ranging from 30 to 180 tonnes per hectare (Saran, 2017). Sugarcane holds a crucial role in global sugar production, contributing approximately 62% of the world's sugar supply, while beet accounts for the remaining 38% (Wikipedia, 2010). It stands as the second-largest economically significant crop after cotton (Afghan et al., 2023), highlighting its immense economic and agricultural importance. Sugarcane serves as a primary source of sucrose for various products, including food items, cakes, candies, preservatives, soft drinks, and beverages (AGMRC, 2022), as well as pharmaceuticals (Afghan et al., 2023) and bioethanol production (Bušić et al., 2018; Amores et al., 2013; Mussato et al., 2010). Sugarcane juice is utilized in the production of white sugar, brown sugar (khand), and jaggery (gur) (Raza et al., 2018; Qureshi & Afghan, 2005). Beyond its role in sugar production, as a cash crop, and a food source, sugarcane also serves a significant function as fodder for livestock due to its fibrous nature. The stalks provide essential nutrients and energy to livestock during periods of fodder scarcity or drought, contributing to the health and productivity of livestock populations (Afghan et al., 2023).

The key processes in the sugarcane industry, including cane preparation for milling, juice extraction, sugar boiling, and crystal separation, have been identified as areas of significant demand (Olaoye, 2011). Mechanical energy is predominantly required in these processes, with the exception of sugar boiling and juice concentration, which involve heat (Abamaster, 2010). The milling of sugarcane, a crucial unit operation for making sugarcane juice available for various applications, involves juice extractors categorized into small-scale, intermediate, and advanced levels based on their operational complexity. Intermediate and advanced extractors typically consist of 2 to 3 sets of rollers with shredders, and warm water is sprayed on the fiber between the rollers to extract maximum juice from the cane (Boyle, 2019). In contrast, small-scale juice extractors utilize a single set of rollers without imbibition, proving particularly useful in developing countries like Nigeria, where extensive sugarcane farming is not yet widespread, and complex large equipment imported from developed countries poses maintenance challenges and lacks local spare parts (Soetan, 2018). Sugarcane-derived sugar, as a natural sweetener, holds a pivotal role in various everyday products, underscoring its significance in the global market (Arshad et al., 2022; Clemens et al., 2016). This highlights the importance of advancing sugarcane processing technologies to meet the growing demand for this essential commodity.

In Nigeria, challenges in sugarcane production and processing include small-scale farms, farm disintegration, land tenure systems, inadequate transportation infrastructure, and a lack of appropriate technologies for micro, small, and medium-scale processing. Additional issues involve poor storage facilities for harvested canes and extracted juice, hindering further processing into sugar (Olaniyan and Babatunde, 2012). Addressing these challenges is crucial, and the development of a simple, low-cost, portable machine for small-scale sugarcane processing in rural communities can significantly benefit farmers, ensuring a steady supply of sugarcane juice to cottage sugar factories and creating employment opportunities. The traditional method of extracting sugarcane juice presents challenges, including potential damage to gums and discomfort to human teeth due to excessive force during extraction. Moreover, the quantity of juice obtained through traditional methods is often insufficient to meet demand. Consequently, there is a compelling need to design an efficient sugarcane juice extraction machine capable of providing ample juice yield without subjecting the machine to excessive strain. The primary objective of this study is to evaluate the efficiency of a developed sugarcane juice extracting machine.The main objective of the study is to assess the efficiency of a developed sugarcane juice extracting machine.

## II. MATERIALS AND METHODS

### *A. General*

A sugarcane juice extractor was designed fabricated, and performance of the machine evaluated. The sugarcane size and weight were determined. The machine was evaluated using 700rpm, 900rpm and 1100rpm at different sugarcane weight of 0.5kg, 1kg and 1.5kg.

The efficiency of the machine, throughput capacity, extraction loss, operational time, the weight of the residue bargasse, weight of extracted juice, and extraction rate was determined. A randomized design (CRD) was adopted using 3 level of sugarcane weight and 3 level of speed was undertaken. ANOVA at P≤0.05 was carried out which shows the significant difference.

### *B. Design Parameters of Sugarcane Prototype*

➢ *Parameters Relevant to the Extraction of Sugarcane Juice*

In the design, machine parameters such as weight of sugarcane, speed of the machine, and the force required to crush the sugarcane, were all put into consideration.

- *Weight of Sugarcane:*

The sugarcane weight was measured using a weighing scale to determine the weight of the sugarcane which was used to carry out the performance evaluation of the sugarcane juice extractor.

- *Speed of the Machine:*

The speed of sugarcane juice extractor was varied at different speed level 700 rpm, 900rpm and 1100 rpm by conversely varying the size of the pulley during the performance evaluation of the machine.

- *Force Required to Crush the Sugarcane:*

The force required to crush the sugarcane was determined using the method as described by Tipler 2004.

➢ *Design Conception*

The sugarcane juice extraction machine consists of a crusher that supports crushing of the sugarcane, rollers that aid compression of the sugarcane, juice collector for collection of the extracted juice. The machine is electrically powered. The machine's frame acts as a support to every other component such as electric motor, pulleys, belt, bearings etc. The sugarcane juice extraction machine is presented in isometric view (Figure 1), Exploded view (Figure 2) and Orthographic view (Figure 3).

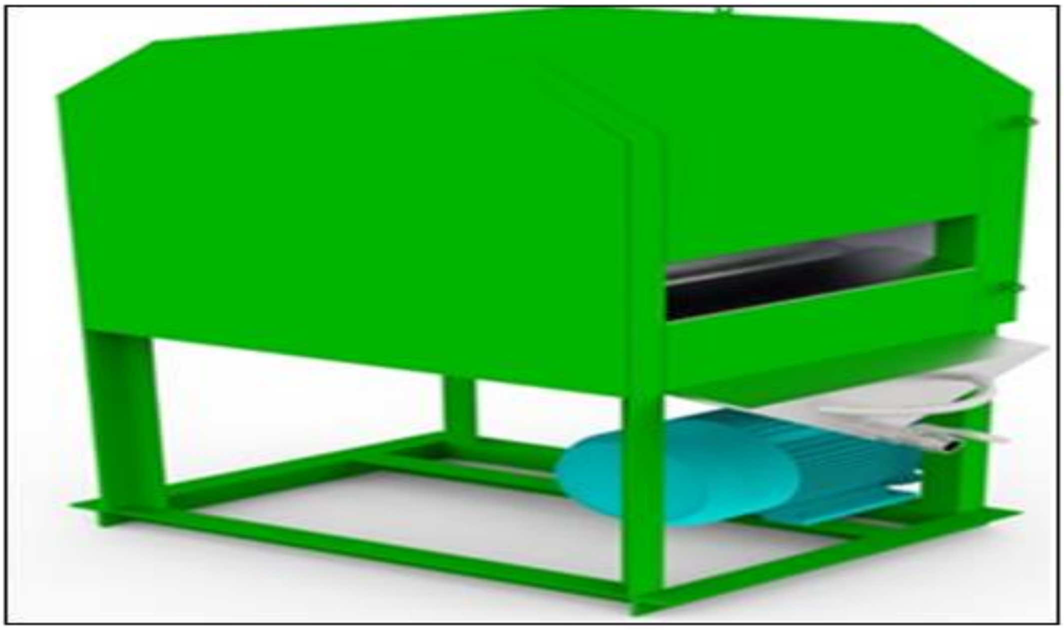

Fig 1 Sugarcane Juice Extractor

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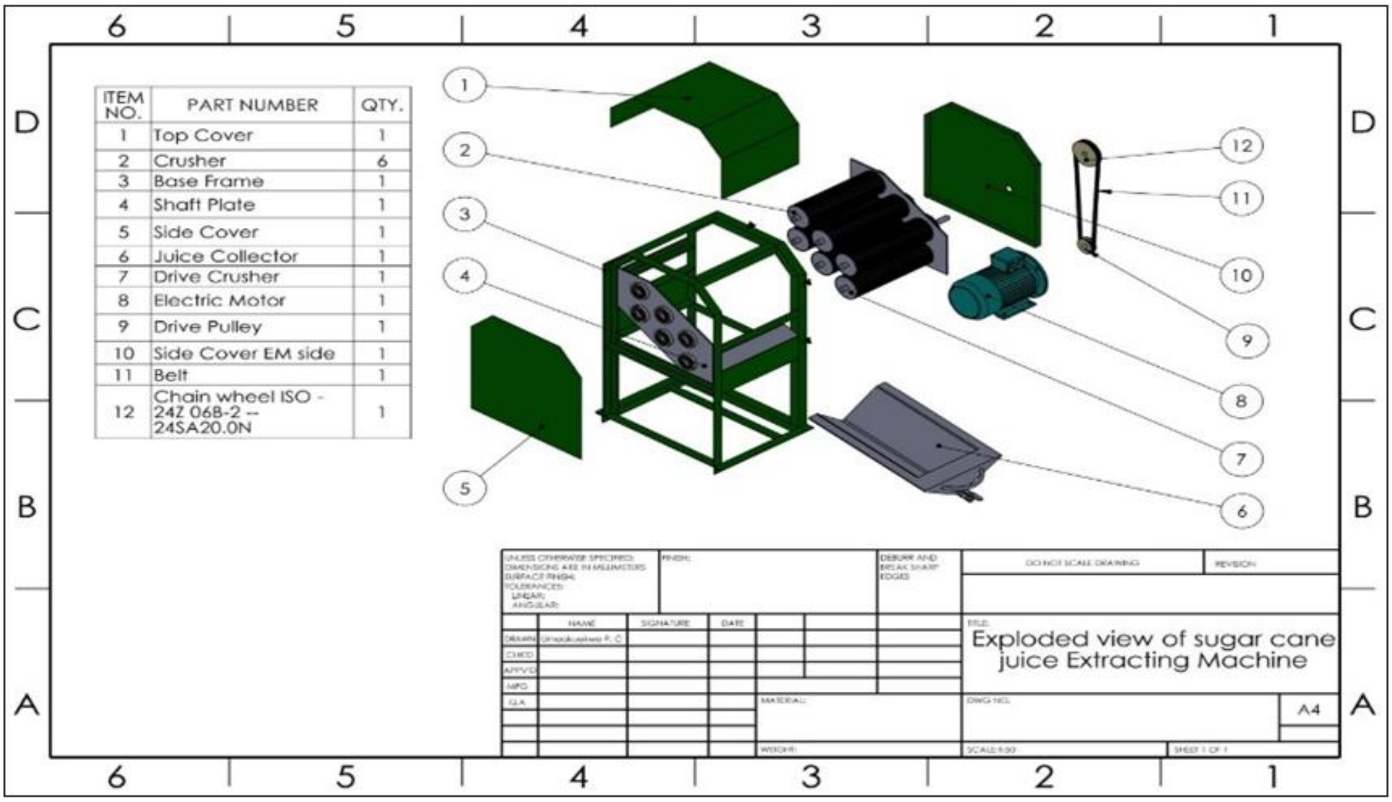


Fig 2 Exploded View of Sugar Cane Juice Extractor

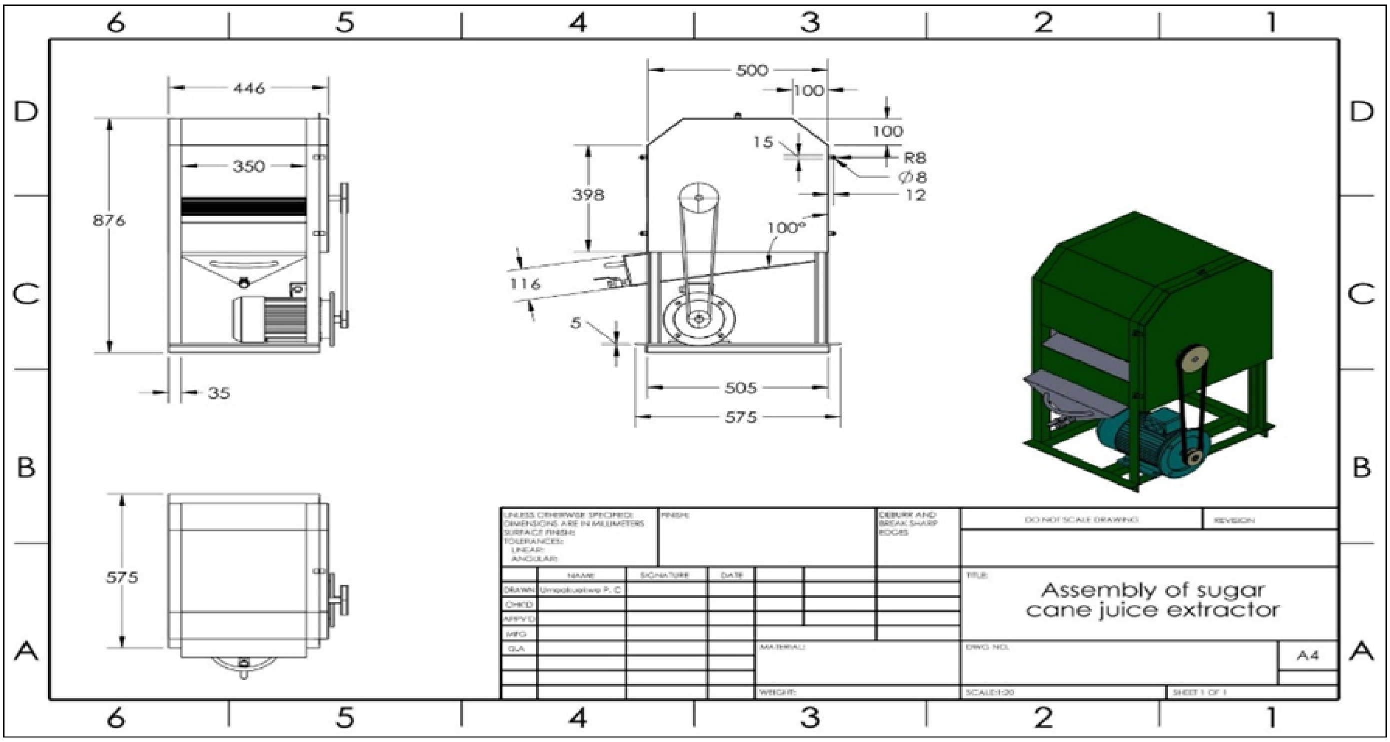


FiG 3 Orthographic and Assembly Projection of Sugarcane Juice Extractor

➢ *Design Considerations*

Several factors were taken into account to ensure the successful design and operation of the juice extractor:

- Strength, Rigidity, and Material Simplicity: The materials used in construction were chosen for their strength, rigidity, and simplicity to enhance the overall robustness of the extractor.
- Expression Pressure: The expression pressure was optimized to ensure a high level of extraction deemed acceptable for efficient operation.

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- Belt Alignment: Proper alignment of the transmission belt was ensured to facilitate easy rotation of the shaft during the extraction process.
- Power Shaft Integrity: The power shaft was designed to be rigid enough to withstand combined bending and tension stresses encountered while transmitting power under various operating and loading conditions.
- Force Requirements: The force necessary for expelling juice was carefully calculated and incorporated into the design.
- Portability: Considerations for the machine's portability were integrated into the design to enhance its practicality and versatility.
- Inspection, Serviceability, and Maintenance: The design prioritized easy inspection, serviceability, and maintenance of the machine to facilitate smooth and efficient operation.
- Durability: Emphasis was placed on the durability of the machine, ensuring a long lifespan and sustained functionality.

➢ *Economic Factors and Safety Considerations*

Construction materials were selected with a focus on economic factors and safety considerations, taking into account:

- Availability and Cost: Construction materials were chosen based on their availability and cost-effectiveness to ensure economic viability.
- Durability and Strength: Materials were selected for their durability and strength, aligning with safety standards and ensuring a reliable and secure operation.
- Manufacturing/Fabrication Methods: The methods employed in construction were evaluated for their efficiency and adherence to safety protocols.
- Extraction Efficiency and Juice Contamination: The materials and design aimed at optimizing extraction efficiency while minimizing the risk of juice contamination.
- Corrosion Resistance: Corrosion-resistant properties were considered in material selection to enhance the longevity of the extractor and maintain its operational integrity over time.

### C. *Design Calculations*

➢ *Weight of Crushing Rollers*

The weight of the crushing roller was estimated from the expression

$$W = \rho V g \quad (1)$$

Where: W = weight of crushing roller, N

ρ = density of the crushing roller material, 7840 kg/m$^3$

V = volume of the roller material, m$^3$

V= [volume of the two circular plate + volume of the hollow pipe]

$$v = 2\pi r^2 t + \pi dlt \quad (2)$$

r = radius of the circular plate = 59.5mm

t = thickness of the circular plate = 1.5mm

Volume of the two circular plates $V_c = 2 \times \pi \times 75.6^2 \times 1.5 = 0.0000539 m^3$

Volume of the rolled steel $V_r = \pi dtl$

d = diameter of the pipe steel, 151.2mm

l = length of the roller, 300mm

t = thickness of the pipe steel, 3mm

$V_r = 3.142 \times 151.2 \times 300 \times 3 = 0.000428 m^3$

The total volume of the roller becomes,

$V = 0.0000539 + 0.000428 = 0.0004873 m^3$

Substituting into equation (1)

$$W = 7860 \times 0.0004873 \times 9.81 = 37.57 \approx 38N$$

➢ *Size of Crushing Roller*

The size of the crushing roller was determined using the equation (3)

$$F_c = M_g \omega^2 r \quad (3)$$

(Ugye and Kolade, 2019)

$F_c$ = crushing force of sugarcane = 387.6N

ω = roller angular velocity rad/sec

$$F_c = M_f \times S_f \quad (4)$$

$(Tipler, 2004)$

Where: $M_f$ = mass of rollers =228N

$S_f$ = factor of safety 1.7 (Kehinde *et al.*, 2015)

$$F_c = 228 \times 1.7 = 387.6N$$

$$\omega = \frac{2 \times \pi \times 1800}{60} = 188.52\, rad/sec$$

$M_g$ = average mass of sugarcane, Kg =0.15kg

r = radius of the roller, m

$$r = \frac{387.6}{188.52^2 \times 0.15} = 0.0727m = 72.7mm$$

Thus, the diameter of the roller was estimated to be 145.4mm (0.1454m). a roller diameter of 150mm was used in the design.

- *Crushing Torque*

The crushing torque on the roller was estimated by the equation

$$T = F_c \times r \quad (5)$$

Where: T= crushing torque on the shaft Nm

$F_c$ = crushing force of sugarcane, 387.6N

r = radius of the roller, 0.075 m

Thus, the crushing torque was calculated to be;

$$T = 387.6 \times 0.075 = 29.1Nm$$

- *Power Required to Drive the Crushing Roller*

The power required to drive the crushing roller was calculated using equation (6)

$$P = T\omega \quad (6)$$

Where: P = power to drive the crushing roller, Kw

T = crushing torque on the shaft, 29.1Nm

ω = angular velocity of the crushing roller shaft, rad/s

But

$$\omega = \frac{2\pi N}{60} \quad (7)$$

N = roller speed, rpm

$$\omega = \frac{2 \times \pi \times 1800}{60} = 188.52\, rad/s$$

Hence,

$$P = 29.1 \times 188.52 = 5480.28Kw$$

Thus, the power required to drive the crushing rollers was calculated to be 5.4hp but a 5hp motor was used.

- *Crusher Length*

The length is a function of the angle of twist t, the length was obtained from;

$$\theta = \frac{584 M_t L}{G d^4} \quad (8)$$

Where: Θ = angle of twist deg

L = length of shaft, m

$M_t$ = torsional moment, Nm

G = torsional modulus of elasticity

d = diameter

$$M_t = \frac{9550 \times P}{N} Nm \quad (9)$$

Where P= power transmitted, 5480.2764

N=speed of the shaft, which is 1800 rpm

$$M_t = \frac{9550 \times 5.4}{1800} = 28.65KNm$$

The amount of twist permissible depends on the application and varies about 0.3 deg/m for machine tools shafts to 3 deg/m.

G = 80 X $10^9$ N/m (for steel)

d = 0.15 m

Hence:

$$\theta = \frac{584 \times 28.65 \times L \times 10^3}{80 \times 10^9 \times 0.15^4}$$

$$L = 2.42\theta$$

Therefore, Θ increases as length increases.

$$\theta \propto L$$

Assuming a machine tool shaft

When Θ=0.6 degree

$$L = 2.42 \times 0.6 \quad = 1.45$$

When Θ=0.9

$$L = 2.42 \times 0.9 \quad = 2.18$$

Substituting L & Θ

$$K = \frac{\theta}{L} = \frac{0.6}{1.45}\, at\, 0.6^\circ \; = \; 0.41$$

Where K = torsional stiffness

Using a length of 300mm (0.3m) in the design,

$\theta = 2.42 \times 0.3 \quad = \quad 0.73$ (maximum torsional deflection)

- *Actual Motor Pulley Power*

Motor power = 5480.2764Kw

The efficiency of motor speed selected from table = 93 % (Chemilevsky 1984)

Actual power due to efficiency = 93% (Pm)

$$P_m = 0.93 \times 5480.2764\text{Kw} = 5096.66\text{Kw}$$

- *Actual Motor Torque (Tm)*

The angular velocity of motor ω=188.52 rad/s

$$T_m = \frac{\text{motor power}(\text{P}_\text{m})}{\text{angular velocity}(\omega)} \quad (10)$$

$$T_m = \frac{5096.66\text{Kw}}{188.52} = 27.04\text{Nm}$$

- *Design of Motor Pulley Diameter*

Applying equation

$$D_m = 58\text{T}_\text{m}{}^{1/3}(mm) \quad (11)$$

$$D_m = 58 \times 27.04^{1/3} = 174.1\text{mm}$$

Rounding off to the nearest standard value for cast iron pulley $D_m$=175mm

- *Selection of Roller Shaft Pulley*

A velocity ratio of 2.5 is chosen to provide for speed reduction of the 1800rpm 5hp motor selected for suitable speed for the crushing rollers.

$$Speed\ of\ pulley = \frac{speed\ of\ motor}{Velocity\ Ratio} = \frac{1800}{2.5} = 720rpm$$

Substituting into the equation below;

$$D_2 = \frac{D_1\omega_1}{\omega_2} \quad (12)$$

$D_1$= diameter of motor pulley

$D_2$=diameter of roller pulley

$\omega_1$=angular velocity of motor shaft

$\omega_2$ = angular velocity of roller shaft

$$D_2 = \frac{174.1 \times 1800}{720} = 435.25mm$$

The diameter of the roller shaft pulley was determined to be 435.25mm. But pulley diameter of 400mm was used in the design.

- *Design of Shaft*

- *Allowable Shear Stress*

The required allowable shear stress was calculated using equation (13) (Khurmi & Gupta 2010)

$$\tau = \frac{\tau_u}{F_s} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (13)$$

Where

τ =is the stress

$\tau_u$ is the Ultimate Shear Stress for mild Steel is 350 MPa

$F_s$ is the Factor of Safety is 8

$$\tau = \frac{360}{8} \qquad = \ 45\ N/mm$$

- *Shaft Diameter*

The diameter of the solid shaft was calculated using equation (14) (Khurmi & Gupta 2010)

$$T_e = \frac{\pi}{16} \times \tau \times d^3 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (14)$$

Where

τ is the Shear Stress, which is 45 N

$T_e$ is the Twist moment

d is the diameter

$$22.36 \times 10^3 = \frac{3.142}{16} \times 45 \times d^3$$

$$d^3 = \frac{22.36 \times 10^3}{8.84}$$

The diameter of the solid shaft is 13. 63 mm Shaft diameter, d is 14 mm

- *Belt Design*

- *Tension in the Belt*

For a V-belt, the relationship between $T_1$ and $T_2$ is given as

$$2.3log\left(\frac{T_1}{T_2}\right) = \mu\theta cosec\beta \dots\dots\dots\dots\dots\dots (15)$$

Where;

$T_1$ = tension in the tight side (N)

$T_2$ = tension in the slack side (N)

μ= coefficient of friction between the belt and side of groove = 0.25

β= half angle of groove =17.5°

θ= angle of contact of the smaller pulley

Angle of contact on the smaller pulley can be calculated from the relationship;

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$$sin\alpha = \frac{O_2M}{O_1O_2} = \frac{r_2 - r_1}{x} = \frac{d_2 - d_1}{2x} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(16)$$

Where; $d_2$ and $r_2$ = diameter and radius of the driven pulley respectively

$d_1$ and $r_1$ = diameter and radius of the driving pulley respectively

x = center distance between pulleys

α= angle of contact

Figure 4 shows the belt and pulley arrangement.

$\Theta_1$= angle of repose of contact on the smaller pulley

$$\theta_1 = 180 - 2\alpha \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(17)$$

$$sin\alpha = \frac{400 - 175}{2 \times 420} = 0.2678°$$

$$\alpha = 15.53°$$

Substituting into equation 17;

$$\theta = 180 - 2(15.53) = 148.94° = 3.1\,rad$$

From equation 15;

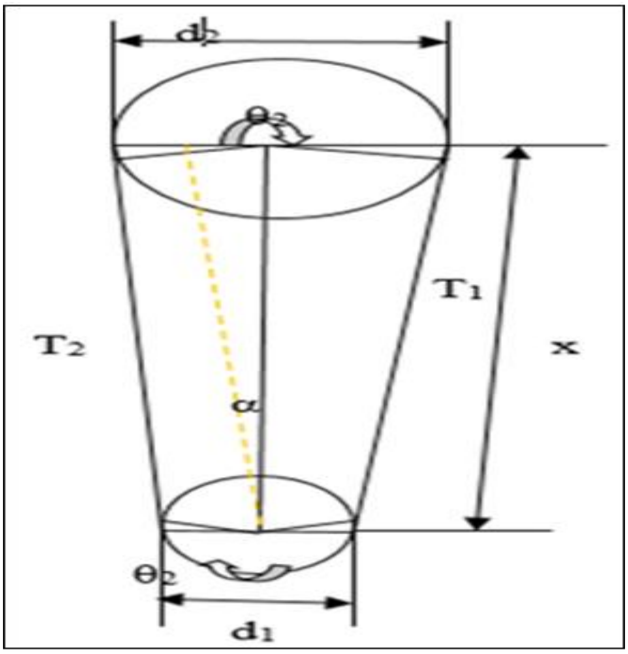

Fig 4 Belt and Pulley Arrangement

$$T_1 = 1.12T_2$$

Tension transmitted is given by

$$T = (T_1 - T_2)R_1 \ldots\ldots\ldots\ldots\ldots\ldots(18)$$

Where;

T = torque transmitted = 29.1 Nm

R = radius of pulley = 87.5 mm = 0.875 m

From equation 18;

$$T_2 = \frac{29.1}{0.12 \times 0.875} = 277.14\,N$$

Therefore, $T_1 = 1.12 \times 277.14 = 310.4\,N$

- *Belt length*

The belt length to be used to transmit the power from the motor to the juice extracting unit was determined using the equation;

$$length\ of\ belt\ (L)$$

$$= \frac{\pi}{2}(d_1 + d_2) + 2x + \left(\frac{d_1 - d_2}{4x}\right)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(19)$$

Where;

$d_1$ =diameter of the smaller pulley = 175 mm

$d_2$ = diameter of the larger pulley 400 mm

x = distance between the two pulleys =420 mm

Substituting into equation 24

$$L = \frac{3.142}{2}(175 + 400) + 2(420) + \left(\frac{175 - 400}{4 \times 420}\right)^2$$

$$= 1743.34\,mm = 1.74\,m$$

Therefore, the belt length from the extracting unit to the motor was determined to be 1.74 m.

*D. Description of Sugarcane Juice Extractor*

The sugarcane juice extracting machine consists mainly of the driving motor, frame, rollers, pulley, juice collector, belt drive, bearings, and shafts. The machine operates under the principle of rolling and crushing impact. The belt transmits power from the motor through the pulleys to the crushing unit. The sugarcane is feed into the machine through the inlet to the crushing unit where the sugarcane is been crushed through rotary impact of the rollers. The sugarcane juice fall by gravity into the juice collector unit and collected through the orifice in a container. The residual bargasse is then collected at the outlet of the machine. Figure 5 shows the flowchart of the design steps carried out.

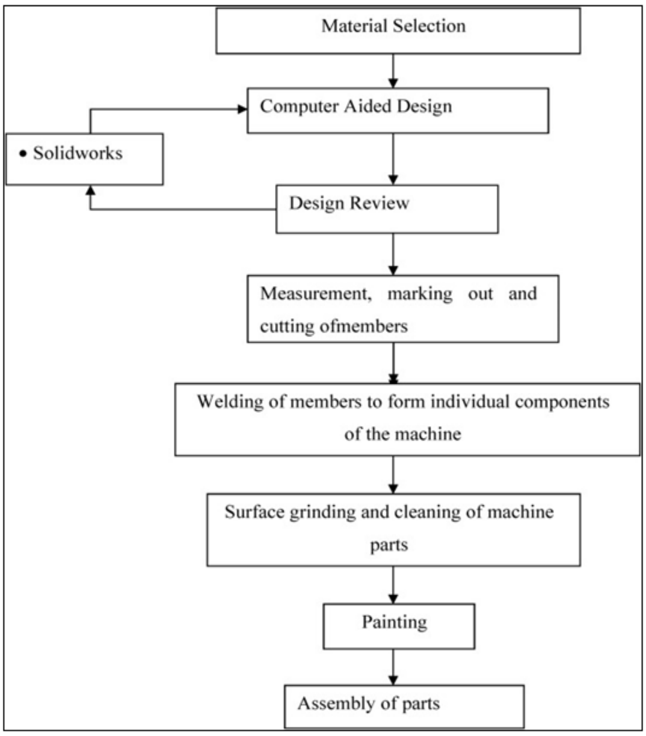


Fig 5 Flowchart of Design Steps

*E. Performance Evaluation of the Machine*

A performance evaluation was carried out after the design and construction of the machine, to determine the throughput capacity, extraction efficiency, extraction loss, extraction yield and extraction rate using "Kantoma" (*Saccharum officinarum*) variety of sugarcane as affected by sugarcane weight (0.5kg, 1kg and 1.5kg) and machine speed (700 rpm, 900 rpm and 1100 rpm)

➢ *Determination of the Rate of Operation (Throughput Capacity)*

This represents the machine's capacity in terms of the number of sugarcane it can process in a given amount of time. Using the relationship described by Adesoji *et al.* (2013), it was measured as follows:

$$O_R = \frac{W_{FS}}{T} \quad (20)$$

Where: $O_R$=rate of operation (kg/hr),

Wfs= weight of fed sample (kg),

T=Operation time (hr)

➢ *Determination of the Extraction Rate*

The machine's extraction rate is measured in terms of the amount or weight of juice it can produce in a given amount of time (Adesoji *et al.*, 2013).

$$E_R = \frac{W_o}{T} \quad (21)$$

Where: ER=extraction rate (kg/hr),

Wo=weight of juice extracted (kg),

T=Operation time (hr).

➢ *Determination of the Juice Yield*

The mass of the extracted juice to the mass of the crushed sugarcane sample was used to calculate the extraction yield as a percentage. Olaniyan and Oje (2007), Olaniyan and Oje (2011), and Adesoji *et al.* (2013) presented the following equation for calculating sugarcane juice yield:

$$O_Y = \frac{100\,W_{OE}}{W_{OE}+W_{RC}} \quad (22)$$

Where: OY=juice yield (%),

WOE=Weight of juice extracted (kg),

WRC=Weight of residual (kg).

➢ *Estimation of Extraction Efficiency*

By quantifying the amount of juice extracted as a percentage of the samples' total juice content, the machine's efficiency at extracting juice from sugarcane is assessed. Equation 28 was used to calculate this (Olaniyan and Oje, 2007; Olaniyan and Oje, 2011); (Adesoji *et al.*, 2013).

$$O_E = \frac{100\,W_{OE}}{XW_{FS}} \quad (23)$$

Where: OE=Extraction efficiency (%),

WOE=Weight of juice extracted (kg),

WFS=Weight of fed sample (kg), and

X= juice content of tigernut in decimal (Determined).

➢ *Determination of Extraction Loss*

The extraction loss is the ratio of the supplied sample to the unrecovered sample. Olaniyan and Oje (2007), Olaniyan and Oje (2011), and Adesoji *et al.* (2013) provided the following estimates:

$$E_L = \frac{100[W_{FS} - (W_{OF} + W_{RC})]}{W_{FS}} \quad (24)$$

Where: EL=Extraction loss (%),

WFS=weight of fed sample (kg),

WOE=Weight of juice extracted (kg),

WRC=Weight of residual (kg).

*F. Experimental Design*

The experimental design for this study was a Completely Randomized Factorial Design (CRD) having three levels of sugarcane weight (0.5 kg, 1 kg and 1.5 kg) and three levels of machine speed (700 rpm, 900 rpm and 1100 rpm) as factors each of six (5) replications.

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### *G. Cost Analysis*

The cost production of the sugarcane extractor was based on the present market value of the materials used in the construction of the machine. Table 1 shows the estimated cost analysis and the total expenditure in the production and evaluation of the sugarcane juice extractor.

### *H. Machine Specification*

Table 2 shows the summary of designed machine component and specifications of the sugarcane juice extractor.

Table 1 Cost Analysis for the Design, Construction and Performance Evaluation of Sugarcane Juice Extractor

| S/N | Material description | Quantity | Rate | Amount |
|---|---|---|---|---|
| 1 | Shaft screw | 6 | 1500 | 9,000 |
| 2 | Belt | 3 | 1000 | 3,000 |
| 3 | Rollers | 6 | 2000 | 12,000 |
| 4 | Cutting blades | | | 5000 |
| 5 | Galvanize sheet | 2 | 11000 | 22,000 |
| 6 | Stainless square pipe | 1 | 5000 | 5000 |
| 7 | Bolt and nut | 50 | 200 | 10,000 |
| 8 | Angle bar | 1 | 6000 | 6000 |
| 9 | Electrodes | 100 | 30 | 3000 |
| 10 | Paint | 1 | 1500 | 1500 |
| 11 | Workmanship | | | 15,000 |
| 12 | Bearings | 6 | 1000 | 6000 |
| 13 | Sprockets | 3 | 2000 | 6000 |
| | | | Grand total | 103,500 |

Table 2 Machine Specification of Sugarcane Juice Extractor

| S/N | Designed Component | Design Specification |
|---|---|---|
| 1 | Electric motor | 5hp |
| 2 | Crushing Rollers | Φ 150 mm |
| 3 | Motor pulley | Φ 175 mm |
| 4 | Shaft pulley | Φ 400 mm |
| 5 | Shaft | Φ 40 mm |
| 6 | Belt | 1743mm |
| 7 | Frame | Height=840mm<br>Width=305 mm<br>Breadth=350mm |

## III. RESULTS AND DISCUSSION

The performance evaluation of the developed sugarcane juice extractor was carried as affected by the machine speed (MS) and sugarcane weight (SW) The raw performance evaluation results and the descriptive statistics are presented in Table 3. The pictorial views of the evaluation process are presented in plate 1 to plate 6 respectively.

Table 3 Analysis of Variance Result of the Effect of Machine Speed and Sugarcane Weight on the Performance of the Developed Sugarcane Juice Extractor

| Source | Dependent Variable | Type III Sum of Squares | Df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Corrected Model | Weight of Residue | 2.749[a] | 8 | .344 | 43431.744 | <.001 |
| | Weight of Juice | 1.508[b] | 8 | .189 | 8289.373 | <.001 |
| | Operational Time | .004[c] | 8 | .001 | 95.400 | <.001 |
| | Extraction Rate | 213.513[d] | 8 | 26.689 | 145.621 | <.001 |
| | Efficiency | 4218.582[e] | 8 | 527.323 | 967.353 | <.001 |
| | Juice Yield | 2262.187[f] | 8 | 282.773 | 1348.822 | <.001 |
| | Extraction Loss | 36.597[g] | 8 | 4.575 | 31.365 | <.001 |
| | Throughput Capacity | 1520.883[h] | 8 | 190.110 | 263.703 | <.001 |
| Intercept | Weight of Residue | 14.158 | 1 | 14.158 | 1789629.441 | <.001 |
| | Weight of Juice | 8.389 | 1 | 8.389 | 368818.799 | <.001 |
| | Operational Time | .103 | 1 | .103 | 19384.557 | <.001 |
| | Extraction Rate | 3402.311 | 1 | 3402.311 | 18563.679 | <.001 |
| | Efficiency | 154681.900 | 1 | 154681.900 | 283757.865 | <.001 |
| | Juice Yield | 88372.016 | 1 | 88372.016 | 421532.401 | <.001 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Extraction Loss | 33.282 | 1 | 33.282 | 228.190 | <.001 |
| | Throughput Capacity | 18561.813 | 1 | 18561.813 | 25747.155 | <.001 |
| Machine Speed | Weight of Residue | .133 | 2 | .066 | 8390.834 | <.001 |
| | Weight of Juice | .156 | 2 | .078 | 3440.120 | <.001 |
| | Operational Time | .001 | 2 | .001 | 107.579 | <.001 |
| | Extraction Rate | 4.029 | 2 | 2.015 | 10.992 | <.001 |
| | Efficiency | 2961.236 | 2 | 1480.618 | 2716.136 | <.001 |
| | Juice Yield | 1547.491 | 2 | 773.745 | 3690.747 | <.001 |
| | Extraction Loss | 20.560 | 2 | 10.280 | 70.484 | <.001 |
| | Throughput Capacity | 194.809 | 2 | 97.405 | 135.110 | <.001 |
| Weight of Sugarcane | Weight of Residue | 2.592 | 2 | 1.296 | 163833.357 | <.001 |
| | Weight of Juice | 1.330 | 2 | .665 | 29229.627 | <.001 |
| | Operational Time | .003 | 2 | .001 | 267.002 | <.001 |
| | Extraction Rate | 207.579 | 2 | 103.789 | 566.295 | <.001 |
| | Efficiency | 1194.939 | 2 | 597.469 | 1096.034 | <.001 |
| | Juice Yield | 687.751 | 2 | 343.876 | 1640.279 | <.001 |
| | Extraction Loss | 5.628 | 2 | 2.814 | 19.294 | <.001 |
| | Throughput Capacity | 1303.204 | 2 | 651.602 | 903.839 | <.001 |
| Machine Speed * Weight of Sugarcane | Weight of Residue | .024 | 4 | .006 | 751.393 | <.001 |
| | Weight of Juice | .022 | 4 | .006 | 243.873 | <.001 |
| | Operational Time | 7.441E-5 | 4 | 1.860E-5 | 3.510 | .016 |
| | Extraction Rate | 1.905 | 4 | .476 | 2.599 | .052 |
| | Efficiency | 62.407 | 4 | 15.602 | 28.621 | <.001 |
| | Juice Yield | 26.944 | 4 | 6.736 | 32.131 | <.001 |
| | Extraction Loss | 10.409 | 4 | 2.602 | 17.842 | <.001 |
| | Throughput Capacity | 22.870 | 4 | 5.718 | 7.931 | <.001 |
| Error | Weight of Residue | .000 | 36 | 7.911E-6 | | |
| | Weight of Juice | .001 | 36 | 2.274E-5 | | |
| | Operational Time | .000 | 36 | 5.300E-6 | | |
| | Extraction Rate | 6.598 | 36 | .183 | | |
| | Efficiency | 19.624 | 36 | .545 | | |
| | Juice Yield | 7.547 | 36 | .210 | | |
| | Extraction Loss | 5.251 | 36 | .146 | | |
| | Throughput Capacity | 25.953 | 36 | .721 | | |
| Total | Weight of Residue | 16.907 | 45 | | | |
| | Weight of Juice | 9.898 | 45 | | | |
| | Operational Time | .107 | 45 | | | |
| | Extraction Rate | 3622.422 | 45 | | | |
| | Efficiency | 158920.107 | 45 | | | |
| | Juice Yield | 90641.750 | 45 | | | |
| | Extraction Loss | 75.130 | 45 | | | |
| | Throughput Capacity | 20108.649 | 45 | | | |
| Corrected Total | Weight of Residue | 2.749 | 44 | | | |
| | Weight of Juice | 1.509 | 44 | | | |
| | Operational Time | .004 | 44 | | | |
| | Extraction Rate | 220.111 | 44 | | | |
| | Efficiency | 4238.206 | 44 | | | |
| | Juice Yield | 2269.734 | 44 | | | |
| | Extraction Loss | 41.848 | 44 | | | |
| | Throughput Capacity | 1546.837 | 44 | | | |
| A. R Squared = 1.000 (Adjusted R Squared = 1.000) | | | | | | |
| B. R Squared = .999 (Adjusted R Squared = .999) | | | | | | |
| C. R Squared = .955 (Adjusted R Squared = .945) | | | | | | |
| D. R Squared = .970 (Adjusted R Squared = .963) | | | | | | |
| E. R Squared = .995 (Adjusted R Squared = .994) | | | | | | |
| F. R Squared = .997 (Adjusted R Squared = .996) | | | | | | |
| G. R Squared = .875 (Adjusted R Squared = .847) | | | | | | |
| H. R Squared = .983 (Adjusted R Squared = .979) | | | | | | |

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Plate 1 Extraction Process


Plate 2 Fabricated Sugarcane Extractor


Plate 3 Residual (Bargasse)


Plate 4 Weighing of the Residual (Bargasse)

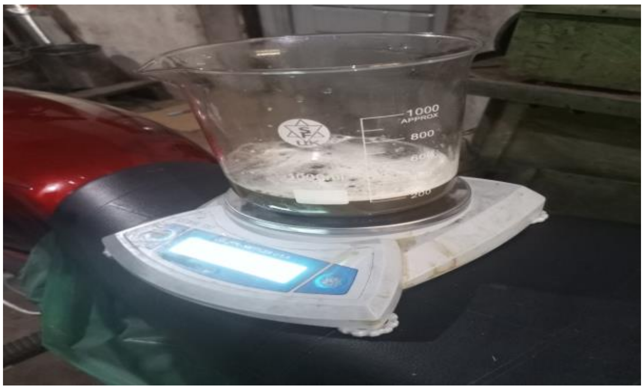

Plate 5 Weighing of the Extracted Juice


Plate 6 Extracted Juice

### A. *Weight of Sugarcane Residue*

In the investigation, the weight of the sugarcane residue exhibited a range between 0.21360 to 0.91540 kg. Notably, the minimum value of the residue was observed when the sugarcane weight was 0.5 kg and the machine speed was set at 700 rpm. Conversely, the highest value of residue was obtained when the sugarcane weight was 1.5 kg and the machine speed was set at 1100 rpm. These findings clearly demonstrate that as both the machine speed and sugarcane weight increase, the weight of sugarcane residue also increases accordingly. This relationship is visually depicted in the accompanying Figure 5. Furthermore, an analysis of variance was conducted to determine the significance of machine speed and sugarcane weight on the weight of the sugarcane residue. The results of this analysis, performed at a 95% confidence level, indicated that both the machine speed and sugarcane weight exert a significant impact on the weight of the sugarcane residue as shown in Table 3. The reason behind the increase in residue weight when the machine speed is higher can be attributed to the fact that higher speeds result in a more vigorous extraction process, which leads to a larger amount of residue being produced. Similarly, when the weight of the sugarcane itself is greater, the quantity of residue also increases. This relationship can be explained by the fact that a larger volume of sugarcane is being processed, resulting in a higher amount of residue being generated. The findings of this particular study align with previous research conducted on sugarcane residue. For example, Shen *et al.* (2016) conducted a study that indicated an increase in the weight of sugarcane residue with higher extraction speeds. Likewise, Ali *et al.* (2018) discovered that as the weight of sugarcane increased, the amount of residue also increased. These studies provide support for the idea that both the speed of the machine and the weight of the sugarcane have an influence on the weight of the residue produced. It is important to highlight that the weight of sugarcane residue holds significance for various applications. For instance, bagasse has been explored as a potential renewable energy source through biofuel production (Zhou *et al.*, 2020). Additionally, it can serve as a valuable raw material for the manufacturing of paper, board, and other biodegradable products (Lisboa *et al.*, 2020). Therefore, comprehending the factors that impact the weight of sugarcane residue is crucial for optimizing its utilization across different industries.

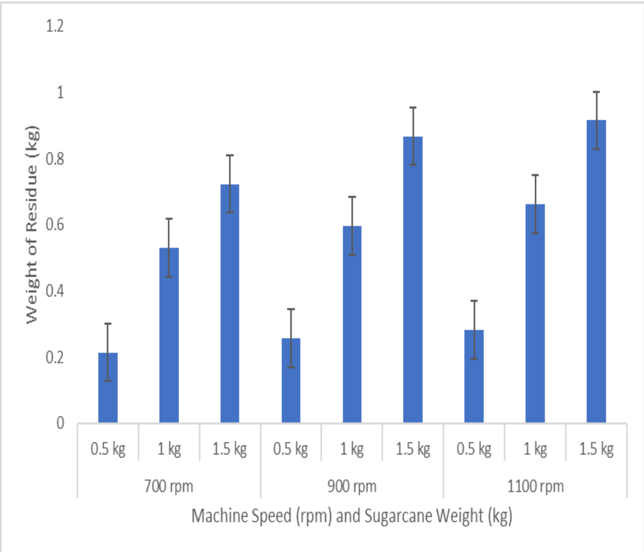


Fig 5 Graph of the Trend of the Results of the Weight of Residue as Affected by Machine Speed and Sugarcane Weight

## B. *Extracted Sugarcane Juice*

Regarding the weight of the extracted sugarcane juice, the results showed a range from 0.204 to 0.774 kg. Interestingly, the lowest value of juice extraction was recorded when the machine speed was set at 1100 rpm and the sugarcane weight was 0.5 kg. Conversely, the highest value was obtained at a machine speed of 700 rpm and a sugarcane weight of 1.5 kg. These findings indicate that the weight of the extracted juice increases as the weight of the sugarcane increases, but it decreases as the machine speed increases. This relationship is clearly illustrated in Figure 6. An analysis of variance was conducted to assess the impact of machine speed and sugarcane weight on the weight of the extracted juice. The results, at a 95% confidence level, revealed that both the machine speed and sugarcane weight have a significant influence on the weight of the extracted sugarcane juice as shown in Table 3. The influence of machine speed on the weight of sugarcane juice can be explained by the impact on the extraction process. Higher machine speeds generally lead to more efficient extraction, resulting in a greater weight of juice being obtained.

This finding is supported by the work of Jaiswal *et al.* (2019), who reported that increasing the machine speed led to higher extraction rates and improved juice yield. Similarly, the weight of the sugarcane itself has a direct impact on the weight of the extracted juice. As the sugarcane weight increases, more juice can be obtained, resulting in a higher weight of extracted juice. This relationship is consistent with the findings of a study by Saha *et al.* (2017), which demonstrated that increasing the sugarcane weight led to higher juice yield.

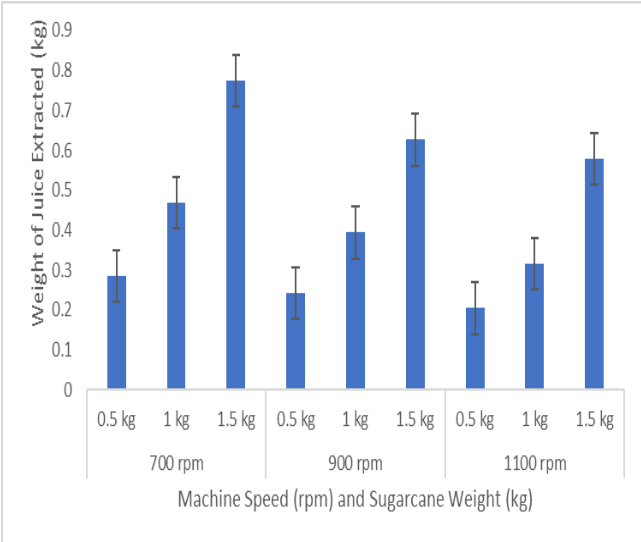


Fig 6 Graph of the Average Results of the Weight of Juice as Affected by Machine Speed and Sugarcane Weight

## C. *Operational Time of the Developed Machine*

The operational time of the machine during the experiment ranged from 0.034 to 0.0633 hours. Notably, the shortest operational time was observed when the machine speed was set at 1100 rpm and the sugarcane weight was 0.5 kg. Conversely, the longest operational time was obtained when the machine speed was 700 rpm and the sugarcane weight was 1.5 kg. These results indicate that the operational time increases as the weight of the sugarcane increases, but it decreases as the machine speed increases. The Figure 7 provides a visual representation of this relationship.

To determine the significance of machine speed and sugarcane weight on the operational time, an analysis of variance was performed at a 95% confidence level. The results revealed that both the machine speed and sugarcane weight have a significant impact on the operational time of the machine as shown in Table 3. The impact of machine speed on the duration of operations can be attributed to the inherent processing capacity of the machine. When the machine speed is higher, it generally leads to a faster processing rate, resulting in a reduction in the overall operational time. This correlation is supported by the research conducted by Raval *et al.* (2018), wherein they demonstrated that an increase in machine speed corresponded to shorter operational times and enhanced efficiency in the processing of sugarcane. Similarly, the weight of the sugarcane itself plays a role in determining the operational time required. When the sugarcane is heavier in weight, it necessitates more time for processing due to the larger volume of material that needs to be handled. This discovery aligns with the findings of a study conducted by Patel *et al.* (2019), which reported that an increase in sugarcane weight resulted in longer operational times during the extraction of sugarcane juice.

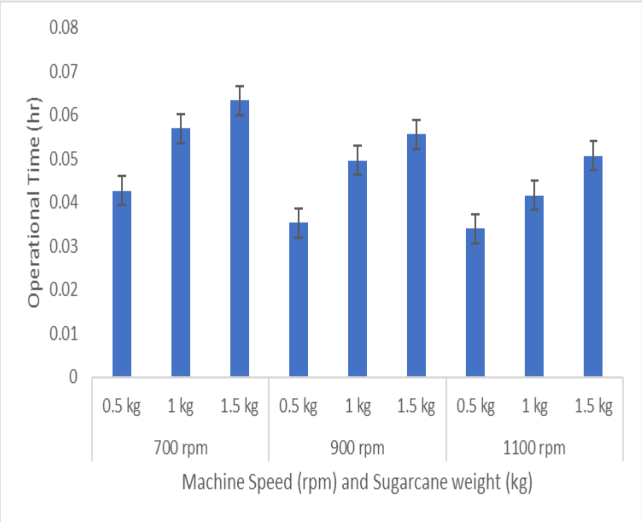


Fig 7 Graph of the Average Results of the Operational Time as Affected by Machine Speed and Sugarcane Weight

*D. Extraction Rate of the Developed Machine*

In terms of the extraction rate of the developed machine, the range observed was between 6.005 and 12.22 kg/hr. It is worth noting that the lowest extraction rate was recorded when the machine speed was set at 1100 rpm and the sugarcane weight was 0.5 kg. Conversely, the highest extraction rate was obtained at a machine speed of 700 rpm and a sugarcane weight of 1.5 kg. These findings indicate that the extraction rate increases as both the sugarcane weight and the machine speed increase. This relationship is visually depicted in Figure 8. To determine the significance of the machine speed and sugarcane weight on the extraction rate, an analysis of variance was conducted at a 95% confidence level. The results of this analysis indicated that both the machine speed and sugarcane weight have a significant impact on the extraction rate of the developed machine as shown in Table 3. The influence of machine speed on extraction loss can be attributed to the intensity of the extraction process. Higher machine speeds often result in more aggressive extraction, leading to increased mechanical forces that extract more juice and reduce the extraction loss This relationship is supported by the work of Farias et al. (2019), who reported that increasing machine speed resulted in lower extraction losses and improved juice recovery in sugarcane processing. The weight of the sugarcane directly affects the extraction loss. Heavier sugarcane weights require more thorough extraction to recover a greater amount of juice, resulting in lower extraction losses. This finding is consistent with the findings of a study by Khaparde *et al.* (2017), which demonstrated that increasing the sugarcane weight led to lower extraction losses and improved juice recovery efficiency. The analysis of variance performed in this study confirmed the statistical significance of both machine speed and sugarcane weight on the extraction loss. This suggests that controlling and optimizing these variables can have a substantial impact on reducing extraction losses and improving overall juice recovery efficiency.

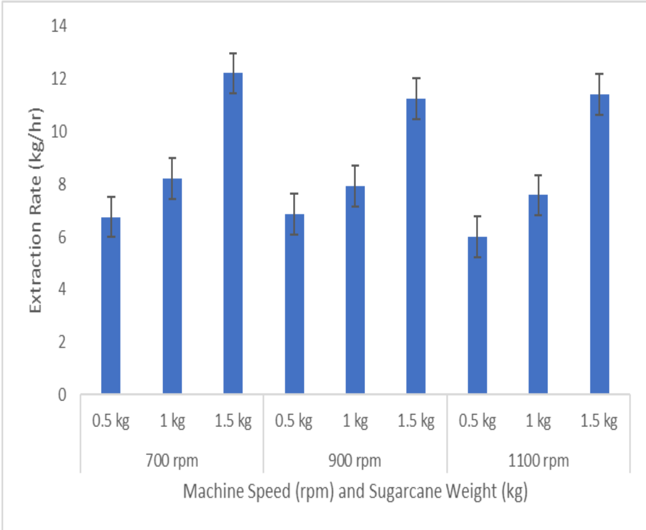


Fig 8 Graph of the Average Results of the Extraction Rate as Affected by Machine Speed and Sugarcane Weight

*E. Extraction Efficiency of the Developed Machine*

The extraction efficiency of the developed machine exhibited a range between 51.342% and 76%. Interestingly, the lowest value of extraction efficiency was recorded when the machine speed was set at 1100 rpm and the sugarcane weight was 1.5 kg. Conversely, the highest value was obtained at a machine speed of 700 rpm and a sugarcane weight of 0.5 kg. These results suggest that the extraction efficiency increases as the sugarcane weight decreases and the machine speed increases. This relationship is clearly depicted in Figure 9. Analysis of variance was performed to assess the significance of machine speed and sugarcane weight on the extraction efficiency. The results, at 95% confidence level, indicated that both the machine speed and sugarcane weight have a significant impact on the extraction efficiency of the developed machine as shown in Table 3. The influence of machine speed on extraction efficiency can be attributed to the relationship between extraction intensity and juice yield. Higher machine speeds often result in more vigorous extraction, which enhances the juice yield and leads to improved extraction efficiency. This relationship is supported by the work of Singh *et al.* (2018), who reported that increasing the machine speed resulted in higher extraction efficiencies and improved juice recovery in sugarcane processing. Similarly, the weight of the sugarcane directly affects the extraction efficiency. Heavier sugarcane weights typically contain more juice content, which allows for higher juice recovery and improved extraction efficiency. This finding is consistent with the findings of a study by Roy *et al.* (2019), which demonstrated that increasing the sugarcane weight resulted in higher extraction efficiencies in sugarcane juice extraction.

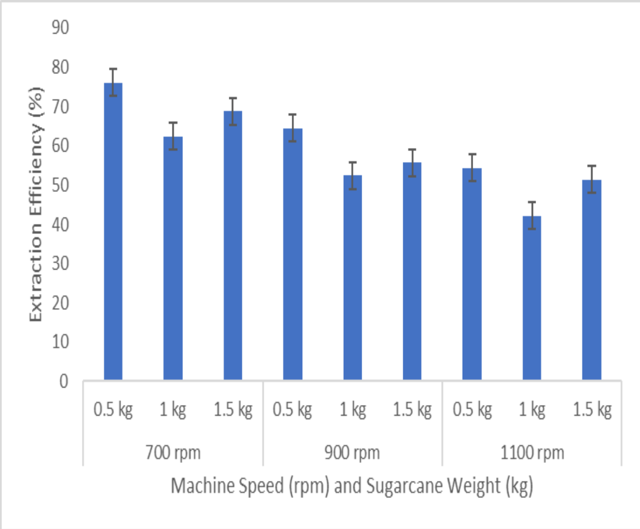


Fig 9 Graph of the Average Results of the Efficiency as Affected by Machine Speed and Sugarcane Weight

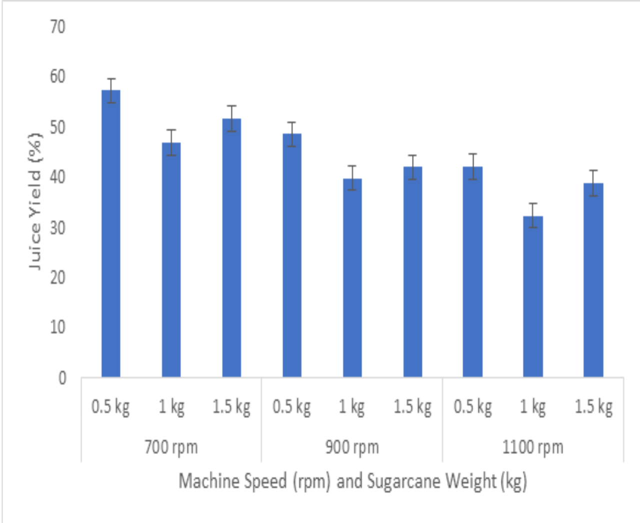


Fig 10 Graph of the Average Results of the Juice Yield as Affected by Machine Speed and Sugarcane Weight

*F. Extraction Juice Yield of the Developed Machine*

The extraction juice yield of the developed machine ranged from 39.764% to 57.16%. Notably, the lowest value of extraction juice yield was recorded when the machine speed was set at 1100 rpm and the sugarcane weight was 1 kg. Conversely, the highest value was obtained at a machine speed of 700 rpm and a sugarcane weight of 0.5 kg. These results indicate that the extraction juice yield decreases as the sugarcane weight increases to 1 kg, after which it increases as the sugarcane weight further increases to 1.5 kg. Additionally, the extraction juice yield decreases as the machine speed increases. Figure 10 provides a visual representation of these relationships. An analysis of variance was conducted to determine the significance of the machine speed and sugarcane weight on the extraction juice yield at a 95% confidence level. The results revealed that both the machine speed and sugarcane weight have a significant impact on the extraction juice yield of the developed machine as shown in Table 3. The influence of machine speed on extraction juice yield can be attributed to the intensity of the extraction process. Higher machine speeds often lead to more efficient extraction, resulting in higher juice yield and improved extraction juice yield. This relationship is supported by the work of Kulkarni *et al.* (2017), who reported that increasing the machine speed led to higher extraction juice yields in sugarcane juice extraction. Similarly, the weight of the sugarcane directly affects the extraction juice yield. Heavier sugarcane weights typically contain more juice content, resulting in higher juice yield and improved extraction juice yield. This finding is consistent with the findings of a study by Sharif *et al.* (2021), which demonstrated that increasing the sugarcane weight led to higher extraction juice yields in sugarcane processing.

*G. Extraction Loss of the Developed Machine*

During the experiment, the extraction loss of the developed machine exhibited a range between 0.16 and 2.8 kilograms per hour (kg/hr). Notably, the lowest value of extraction loss was recorded when the machine speed was set at 700 rpm and the sugarcane weight was 1 kilogram (kg), while the highest value was obtained at a machine speed of 1100 rpm when the sugarcane weight was 0.5 kg. These observations indicate that the extraction loss tends to decrease as the sugarcane weight increases up to 1 kg. However, beyond that point, as the sugarcane weight increases to 1.5 kg, the extraction loss starts to increase. Furthermore, it can be seen that the extraction loss increases as the machine speed increases, as depicted in the accompanying Figure 11. An analysis of variance was conducted to examine the significance of the machine speed and sugarcane weight on the extraction loss of the developed machine at a 95% confidence level. The results of the analysis revealed that both the machine speed and sugarcane weight have a significant impact on the extraction loss as shown in Table 3. However, at a sugarcane weight of 1.5 kg, the extraction loss was significantly different. The influence of machine speed on extraction loss can be explained by the intensity of the extraction process. Higher machine speeds typically result in more vigorous extraction, which can lead to increased mechanical forces and, in turn, more effective juice extraction. This relationship is supported by the work of Gao *et al.* (2020), who reported that increasing machine speed resulted in lower extraction losses and improved juice recovery efficiency. Similarly, the weight of the sugarcane directly affects extraction loss. Heavier sugarcane weights generally require more thorough extraction to recover a greater amount of juice, resulting in lower extraction losses. This finding is consistent with the findings of a study by Singhal *et al.* (2019), which demonstrated that increasing sugarcane weight led to lower extraction losses in sugarcane juice extraction.

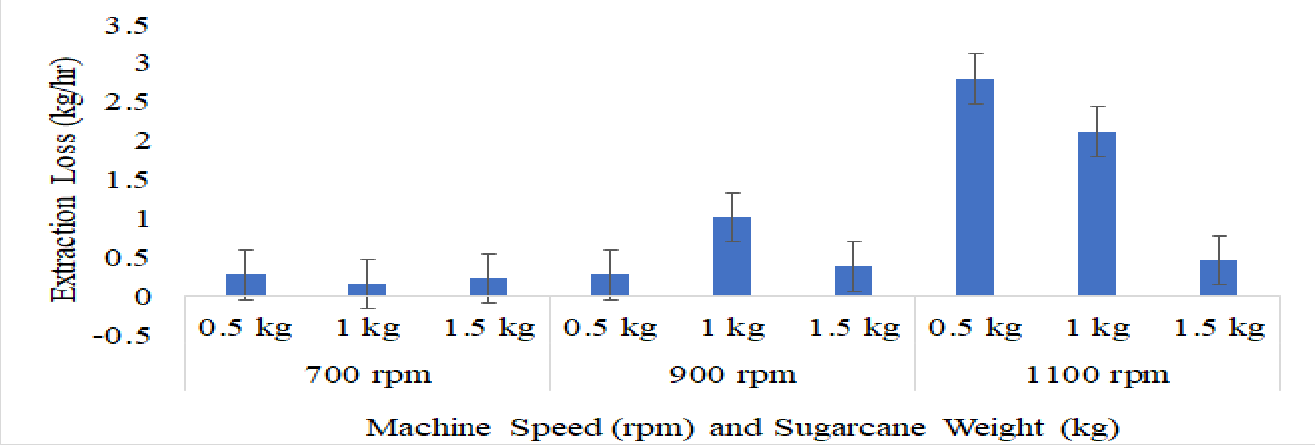


Fig 11 Graph of the Average Results of the Extraction Loss as Affected by Machine Speed and Sugarcane Weight

*H. Throughput Capacity of the Developed Machine*

In terms of the throughput capacity of the machine, the observed range was between 11.844 and 29.638 kg/hr. It was noted that the highest value of throughput capacity was obtained when the machine speed was set at 1100 rpm and the sugarcane weight was 1.5 kg, while the lowest value was recorded at a machine speed of 700 rpm when the sugarcane weight was 0.5 kg. These findings indicate that the throughput capacity tends to increase as both the weight of the sugarcane and the machine speed increase. This relationship is clearly illustrated in the Figure 12. To determine the significance of the machine speed and sugarcane weight on the throughput capacity, an analysis of variance was performed at a 95% confidence level. The results of the analysis indicated that both the machine speed and sugarcane weight have a significant impact on the throughput capacity of the developed machine as shown in Table 3. The influence of machine speed on the throughput capacity can be attributed to the processing efficiency and speed of the machine. Higher machine speeds often result in faster processing, allowing for a larger quantity of sugarcane or juice to be processed within a given time frame. This relationship is supported by the work of Subhadrabandhu and Wilasrusmee (2020), who reported that increasing the machine speed led to higher throughput capacities in sugarcane processing. The weight of the sugarcane directly affects the throughput capacity. Heavier sugarcane weights require more time for processing due to the larger volume of material to be handled. Consequently, this can affect the overall throughput capacity of the machine. This finding is consistent with the findings of a study by Anand *et al.* (2021), which demonstrated that increasing the sugarcane weight resulted in lower throughput capacities in sugarcane juice extraction.

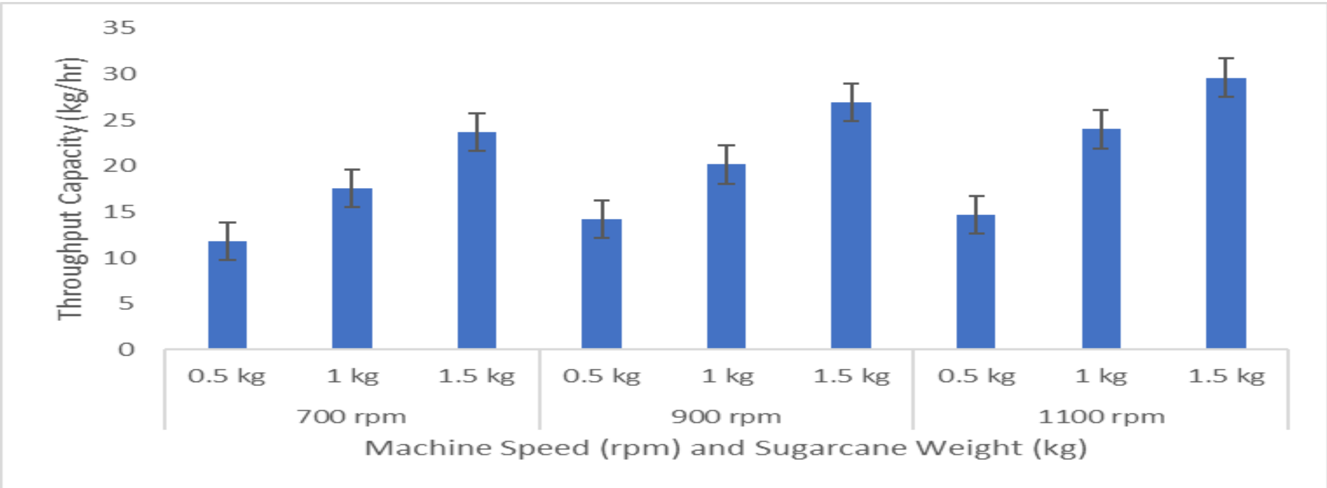


Fig 12 Graph of the Average Results of the Throughput Capacity as Affected by Machine Speed and Sugarcane Weight

## IV. CONCLUSIONS AND RECOMMENDATIONS

*A. Conclusion*

It can be concluded that the sugar cane juice extractor prototype was design, fabricated and performance evaluation carried out. The machine was evaluated using 700 rpm, 900 rpm, and 1100 rpm with varying weight of 0.5 kg, 1 kg and 1.5 kg of sugar cane.

At 0.5kg weight of sugarcane at 700 rpm, produced an average weight of extracted juice, operational time, extraction efficiency, extraction loss and throughput capacity of 0.285kg, 0.427hr, 76%,0.28% and 11.84419 Kg/hr respectively. At 1kg, produced 0.46820 kg, 0.05700hr, 62.42667%,0.16% and 17.55233 Kg/hr respectively. While 1.5 kg weight of sugarcane produced, 0.7736kg, 0.06333hr, 68.7644%, 0.22667% and 23.6973kg/hr respectively.

With the speed varied to 900 rpm, 0.5 kg sugarcane produced an average weight of extracted juice, operational time, extraction efficiency, extraction loss and throughput capacity of 0.2418 kg, 0.03533hr, 64.48%, 0.28%, 14.20815 kg/hr. 1 kg sugarcane produced, 0.3936 kg, 0.04967hr, 52.48%, 1.02% and 20.16558 kg/hr. And 1.5 kg recorded 0.6262kg, 0.05567hr, 55.6622%, 0.38667% and 26.95187 kg/hr respectively.

Conversely, at 1100rpm, 0.5 kg of sugarcane recorded an average weight of extracted juice, operational time, extraction efficiency, extraction loss and throughput capacity of 0.204kg, 0.034hr, 54.4%,2.8%, and 14.71429kg/hr. 1kg of sugarcane recorded 0.3158kg, 0.04167hr, 42.10667%,2.12% and 24.01538 kg/hr. And 1.5kg of sugarcane produced 0.5776kg, 0.05067hr, 51.34222%, 0.4667% and 29.63835kg/hr respectively.

The experiment followed a completely randomized factorial design and the generated data were subjected to analysis of variance (ANOVA) at a significant level of $P<0.05$. The analysis of variance (ANOVA) revealed that both machine speed and sugarcane weight significantly impacted the evaluated machine parameters. The Duncan test further confirmed that the varying levels of machine speed and sugarcane weight had noticeably difference on the performance of the machine.

### *B. Recommendations*

Based on the results obtained, the following recommendations will be relevant for future construction of the machine either as prototype or for large scale use;

- It is recommended that the sugarcane juice extractor be used in the extraction of juice from sugarcane.
- It is recommended that the sugarcane juice extractor be operated at 700rpm speed for high juice extraction efficiency.
- Further research and investigation can be carried out to explore the possibility of incorporating pre-processing techniques such as peeling or cleaning, adjustment mechanism to accommodate sugarcane stick of larger diameter and advanced engineering principles and technologies such as computational fluid dynamics.
- Conduct additional research to optimize the extraction process and enhance the overall efficiency of juice extraction. This can include investigating the effect of various factors such as sugarcane variety, cutting parameters, crushing mechanisms, and juice flow control systems on the extraction efficiency.

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