
*Asian Research Journal of Agriculture*

***11(4): 1-8, 2019; Article no.ARJA.51056***
***ISSN: 2456-561X***

# Design and Construction of a Small Scale Sugarcane Juice Extractor

**N. Oji[1], M. A. Gwarzo[1], U. S. Mohammed[1], I. Abubakar[2*], J. K. Agunsoye[1], A. Zakariyah[1] and E. I. Adamu[3]**

*[1]Department of Agricultural and Bioresources Engineering, Ahmadu Bello University, Zaria, Nigeria.*
*[2]Department of Agricultural and Bo-Environmental Engineering, Waziri Umaru Federal Polytechnic, Birnin Kebbi, Nigeria.*
*[3]Department of Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria.*

***Authors' contributions***

*This work was carried out in collaboration among all authors. Authors NO, MAG and USM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors IA and JKA managed the analyses of the study. Authors AZ and EIA managed the literature searches. All authors read and approved the final manuscript.*

***Article Information***

DOI: 10.9734/ARJA/2019/v11i430064
*Editor(s):*
(1) Dr. Rusu Teodor, Department of Technical and Soil Sciences, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Romania.
(2) Dr. Afroz Alam, Department of Bioscience & Biotechnology, Banasthali University, Rajasthan, India.
(3) Dr. Tancredo Souza, Centre for Functional Ecology, Department of Life Sciences, University of Coimbra, Portugal.
*Reviewers:*
(1) T. Krishnakumar, ICAR-Central Tuber Crops Research Institute, India.
(2) Felicia Engmann, Ghana Institute of Management and Public Administration (GIMPA), Ghana.
Complete Peer review History: https://sdiarticle4.com/review-history/51056

***Original Research Article***

***Received 01 July 2019***
***Accepted 24 September 2019***
***Published 16 October 2019***

## ABSTRACT

The production of sugarcane is increasing in Nigeria nowadays. Juice extracted from sugarcane can be used extensively in manufacturing brown sugar, industrial sugar and bioethanol fuel through the process of fermentation; hence, the need to develop a machine that can extract juice from sugarcane effectively. This work involves the design, fabrication and performance evaluation of sugarcane juice extractor. The machine was designed to extract juice from sugarcane at small scale level suitable for small and medium scale sugarcane processors. The prototype machine was designed, fabricated and assembled in the Department of Agricultural and Bio-resources Engineering, Ahmadu Bello University, Zaria. The machine consists of rollers, gears, cane guide, juice collector, frame, and prime mover. The developed machine was evaluated using *koma* variety

_____________________________________

**Corresponding author: E-mail: ibrahimabib6@gmail.com;*

of cane and obtained an output capacity of 148.2 kg/h and extraction efficiency of 67.44%, respectively at a speed of 30 rpm. The production cost stood at ₦ 90,000 which is affordable and therefore recommended for small scale processors.

*Keywords: Design; sugarcane juice; mechanical properties; extractor; processing.*

## 1. INTRODUCTION

Sugarcane provides a high amount of energy for the nutritional requirement of both livestock and humans. Based on its land-use factor, its value of calories per unit area is highest for any plant [1]. Furthermore, the content of sugarcane (70% water, 14% fibre, 13.3% *saccharose* (about 10 – 15% sucrose), and 2.7% soluble impurities) it can be said that 60% of the world's sugar production while the rest is provided by sugar beet [2].

According to Food and agricultural organization statistics (FAOSTAT) [3], it was estimated that sugarcane was cultivated on about 26.0 million hectares, in over 90 countries, with a worldwide harvest of 1.83 billion tons. Brazil is the largest producer of sugarcane in the world. The next five major producers, in increasing order of the amount of production, were Mexico, Pakistan, Thailand, China and India. The cane producing countries in tropical Africa include Mauritius, Kenya, Sudan, Zimbabwe, Madagascar, Cote Divoire, Ethiopia, Malawi, Zambia, Tanzania, Nigeria, Cameroon and Zaire. Nigeria, being one of the most important producers of sugarcane has a land potential of more than 500,000 hectares of a suitable cane field. Nigeria has vast human and natural resources (land and water), to produce enough sugarcane, not only to satisfy the country's requirement for sugar and biofuels but also for export [4]. The crop is mostly cultivated in the Northern states of Nigeria, where irrigation water is readily available.

Sugarcane is produced and sold in many local government areas of Kaduna State, including Makarfi, Giwa and Kudan. In the year 2013, about 20,000 households cultivated sugarcane in the state [5]. Some of the problems associated with the traditional method of sugarcane juice extraction are the tedious nature involved in extracting the juice, high extraction losses, poor handling, poor hygiene and drudgery. Most of the traditional and animal operated crushers are very massive hence the difficulty in moving them from one place to the other. The commonly available sugarcane juice extractors require high energy with a sophisticated mechanism [6]. Some of these commonly available sugarcane juice extractors are for industrial applications which are out of reach of small scale and rural processors who are deeply involved in the processing of cane juice into brown sugar. This study aims to design and construct a small scale sugarcane juice extractor.

## 2. MATERIALS AND METHODS

Materials selected for various components of the machine were based on strength, durability, availability and cost. The materials are non-corrosive and hard enough to withstand wear. Mild steel was used for rollers, gear, shaft and frame while the juice collector was made of galvanized steel sheet. Cast iron was used for the pulley. The instruments used for measuring mass, speed and time were: Mettler Model (PN20001) top loading balance with the capacity of 2 kg and accuracy of 0.1 gram, Lutron Digital Photo Tachometer that can measure a range of 0.5 to 100,000 rpm and accuracy of 0.05% + 1 digit and digital stopwatch.

Some of the physical and mechanical properties of sugarcane were estimated as per the method of Olaoye JO [6]. The two varieties determined were: *Saccharum officinarum* and *Saccharum barberi.* The major diameters were 40 mm and 33 mm, respectively. This is important is chosen the clearance between the top roller and the two rollers that allows entry for crushing. While the mechanical properties rupture force at vertical and horizontal orientations were 11.15 N, 17.83 N and 28.90 N, 35.10 N, respectively. It is important in determining the force required to crush the sugar cane [7].

### 2.1 Design Consideration

The following factors were considered during the design of the sugarcane juice extractor:

i. Availability and relative cost of the material.
ii. The machine is to compose of three rollers.
iii. Roller diameter of 70 mm was used for effective force of compression.

iv. Length of the roller of 175 mm was used to accommodate three stalks of cane at a time.
v. The crushing speed was chosen as 30 rpm as given by Abamaster Incorporated [8].
vi. The cane is to be paired before crushing.

## 2.2 Design Calculations

### 2.2.1 Determination of the size of roller to accommodate the varying sizes of sugarcane

The maximum size of sugarcane stalks that can be fed into the extractor is determined using Equation (1) by [9];

$$x_1 = 2\left(\frac{\left(R+\frac{L}{2}\right)}{cos\theta} - R\right) \quad (1)$$

Where;

$x_1$ = maximum size of sugarcane that can be fed into the machi;ne
$R = \text{Radius of the roller, mm}$
$L =$
$\text{Clearance between the top and feed roller, mm}$
$2\theta = \text{Nip angle}$

The nip angle is a function of the coefficient of friction, µ, between the roller surface and the sugarcane surface, and the relationship between the nip angle and the coefficient of friction is such that;

$$\theta = tan^{-1}\mu$$

Where;

µ = coefficient of friction between the roll surface (mild steel) and the particle

### 2.2.2 Determination of weight of crushing rollers

The weight of the crushing roller was estimated from the expression as given by [10] in Equation (2).

$$W = \rho v g \quad (2)$$

Where;

W = weight of crushing roller, N
$\rho =$ The density of the crushing roller material, 7840 kg/m$^3$
$v$ = Material volume of the roller, m$^3$
$g =$ Acceleration due to gravity, 9.8 m/$s^2$

### 2.2.3 Determination of the size of crushing roller

The size of the crushing roller was determined using Equation (3) as given by [11]:

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

Where;

$F_c = \text{crushing force for sugarcane } (N)$
$M_s$ = average mass of sugarcane, kg
$\omega$ = roller angular velocity (rad/sec)
$r$ = radius of roller (m)

### 2.2.4 Determination of crushing torque

The crushing torque on the roller is expressed as given in Equation (4):

$$T = F_c r \quad (4)$$

Where;

$T$ =crushing torque on the shaft, Nm
$F_c$ = crushing force for sugar cane, N
r = radius of the roller, m
$F_c = R_f \times S_f$

Where;

$R_f$ = rupture force of sugar cane, N
$S_f$ = Factor of safety: 1.7 [12]

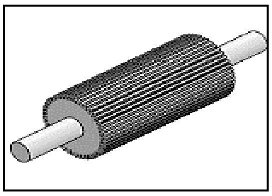

**Fig. 1. Roller**

### 2.2.5 Determination of power required to drive the crushing roller

The power required to drive the crushing roller is expressed as given in Equation (5):

$$P = T\omega \quad (5)$$

Where;

$P$ = power to drive the crushing roller, kW

$T =$ crushing torque on the shaft, Nm
$\omega =$ angular velocity of the crushing roller shaft, rad/s

But, $\omega = \frac{2\pi N}{60}$

Where;

$N =$ roller speed, rpm

### 2.2.6 Determination of pulley diameter

To reduce the speed of the belt, the speed ratio is given Equation (6) by [13]:

$$\frac{N_1}{N_2} = \frac{d_2}{d_1} \tag{6}$$

Where;

$N_1$ = Speed of driving pulley, rpm
$d_1$ = Diameter of the driving pulley, mm
$N_2$= Speed of driven pulley, rpm
$d_2$= Diameter of driven pulley, mm

### 2.2.7 Determination of angle of contact/lap

The angle of contact/lap is determined as in Equation (7):

$$\theta = (180 - 2\alpha)\frac{\pi}{180} \tag{7}$$

But, $\alpha = sin^{-1}\left(\frac{D_2 - D_1}{2C}\right)$

Where;

$\theta$= angle of the lap for driving pulley, rad
C= centre distance between the driving and the driven pulleys ($D_1$ and $D_2$)

### 2.2.8 Determination of belt tension

The belt tension is estimated using Equation (8) and (9) as given by Bhandari [14]:

$$P = (T_1 - T_2)V \tag{8}$$

$$2.3Log\left(\frac{T_1}{T_2}\right) = \mu\theta \operatorname{cosec}\beta \tag{9}$$

Where;

$P =$ power to drive the crushing roller, kW
$T_1 =$ Tension on the tight side of the belt, N
$T_2 =$ Tension on the loose side of the belt, N
$V$= belt speed, m/s
$\theta =$ Angle of lap, rad.
$\beta = {}^1/_2$ grooved angle, (˚)

### 2.2.9 Determination of shaft diameter

The maximum allowable stress using the ASME code (1948) can be obtained as the lower value of 18% ultimate tensile stress ($S_t$) and 30% yield stress ($S_y$). However, it was further stated that the allowable shear stress is reduced by 25% when there is a key way in the shaft [13]. Therefore; the lower value of the allowable stress is selected. To obtain the shaft diameter, Equation (10) as given by [13]:

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \tag{10}$$

Where;

$M_b =$ bending moment, $Nmm$
$M_t =$ tortional moment, $Nmm$
$K_b =$ combine shock and fatique factor applied to bending moment $= 1.5$
$K_t =$ combine shock and fatique factor applied to torsional moment $= 1.0$
$S_s =$ allowable shear stress for shaft with keyway
$d =$ shaft diameter, mm

### 2.2.10 Determination of shaft torsional rigidity

The torsional rigidity of the shaft is given in Equation (11) as given by [15]:

$$\theta_t = \frac{584 M_t L}{G d^4} \tag{11}$$

Where;

$\theta_t$ =The angle of twist, (°)
$M_t$ = Torsional moment, Nmm
$G$ = Torsional modulus of elasticity, GN/$mm^2$
$d$ = Shaft diameter, mm
$L$ = Length of the shaft, mm

### 2.2.11 Determination of gear speed

The gear trains consist of two gears to transmit motion. The relationship is given in Equation (12) by [13]:

$$\frac{D_G}{D_P} = \frac{N_P}{N_G} \tag{12}$$

Where;

$D_G$ = the pitch diameter of the gear, mm
$D_P$ = the pitch diameter of the pinion, mm
$N_P$ = speed of the pinion, rpm
$N_G$ = speed of the gear, rpm

#### 2.2.12 Determination of gear ratio

The gear ratio is also known as the velocity ratio is given in Equation (13) by [13]:

$$G = \frac{T_G}{T_P} = \frac{D_G}{D_P} \quad (13)$$

Where;

$G$ = Gear ratio or velocity ratio
$T_G$ = Number of teeth on the gear,
$T_P$ = Number of teeth on the pinion gear,
$D_G$ = Pitch circle diameter of the gear, mm
$D_P$ = Pitch circle diameter of the pinion gear, mm

#### 2.2.13 Determination of gear interference

The number of teeth on the pinion gear ($T_P$) to avoid interference may be obtained from Equation (14) by [13]:

$$T_p = \frac{2A_W}{G\left[\sqrt{1+\frac{1}{G}\left(\frac{1}{G}+2\right)sin^2\emptyset}-1\right]} \quad (14)$$

Where;

$A_W$ = fraction by which the standard addendum for the wheel
$G$ = Gear ratio or velocity ratio
$\emptyset$ = pressure angle or angle of obliquity (standard angle is 20°)

Tables 1 and 2 detailed the technical characteristics and production cost of sugarcane juice extractor in details.

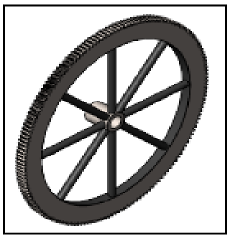

**Fig. 2. Speed reduction gear**

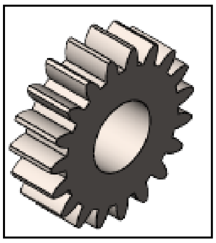

**Fig. 3. Crushing roller gear**

Figs. 2 and 3 show speed reduction gear and crushing roller gear, respectively.

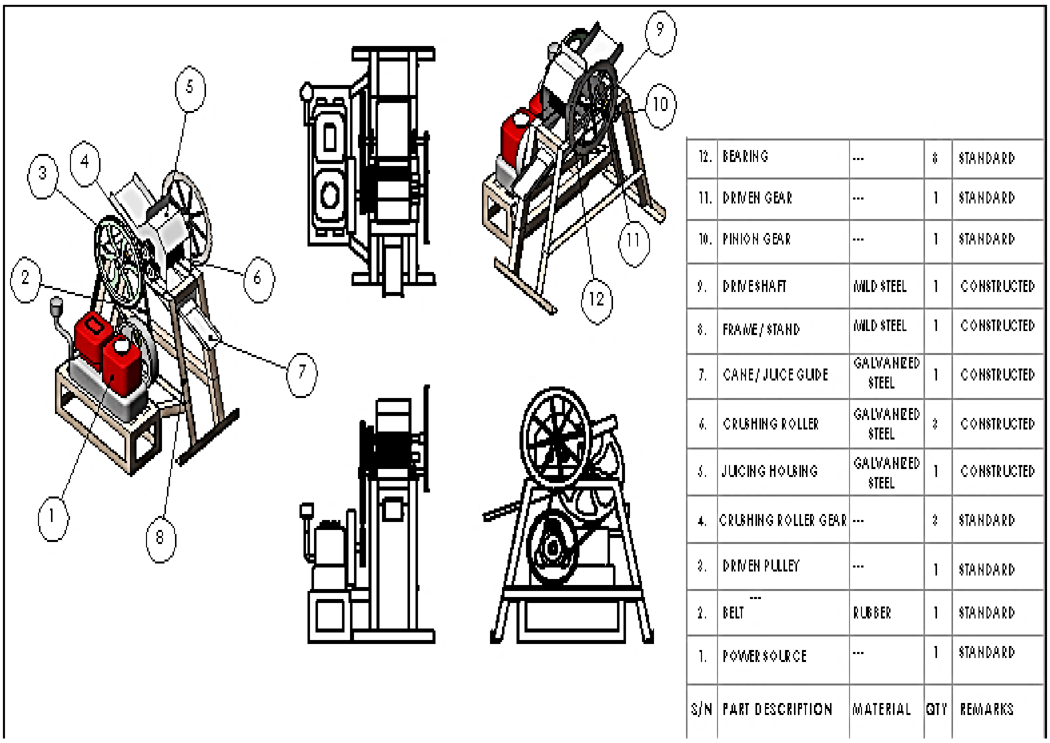


**Fig. 4. Assembly drawing of the sugarcane juice extractor**

**Table 1. Technical characteristics of the machine**

| Component | Dimension | Measurement |
|---|---|---|
| Frame | Length | 948 mm |
| | Width | 480 mm |
| | Height | 914 mm |
| Roller | Length | 315 mm |
| | Diameter | 90 mm |
| Pulley | Driving | 100 mm |
| | Driven | 400 mm |
| | Diameter | 25 mm |
| Gear | Driving | 64 mm |
| | Driven | 418 mm |
| | Diameter | 25 mm |
| Shaft | Length | 400 mm |
| | Diameter | 25 mm |
| Bearing | Diameter | 25.5 mm |
| Operating speed | | 72 rpm |
| Maximum cane diameter | | 32 mm |
| Power (watt) | Diesel engine | 5hp |

**Table 2. Cost analysis of the sugarcane juice extractor**

| S/N | Materials | Specifications | Quantity | Unit cost (₦) | Total cost (₦) |
|---|---|---|---|---|---|
| 1 | Mild steel angle iron | 50 × 50 mm | 4 | 1500 | 6000 |
| 2 | Cast iron | Ø25 | 3 | 1500 | 4500 |
| 3 | Galvanized sheet metal | 2 mm | 1 | 5000 | 5000 |
| 4 | Cast iron ball bearing | 6205 bearings (Ø 20) | 8 | 1000 | 8000 |
| 5 | Thick pipe | 10" (6ft length | 1 | 9000 | 9000 |
| 6 | Electrode | | 1 pack | 1700 | 1700 |
| 7 | Cutting disc | | 2 | 500 | 1000 |
| 8 | Grinding disc | | 1 | 500 | 500 |
| 9 | Bolt and nut | M12 | 40 | 40 | 1600 |
| 10 | Sheet metal | 5 mm | 1 | 5000 | 5000 |
| 11 | Flat bar | 1 length | 1 | 1300 | 1300 |
| 12 | Gears | | 4 | 1500 | 6000 |
| 13 | Pinion | | 1 | 1000 | 1000 |
| 14 | Solid Mild steel | Ø70 | 3 | 5000 | 15000 |
| 15 | Cost of fabrication and assembly | | | 10,000 | 10,000 |
| 16 | Cost of transportation and miscellaneous | | | 6,000 | 6,000 |
| 17 | Labour cost | | | 20,000 | 20,000 |
| 18 | Total | | | | 90,000 |

## 3. RESULTS AND DISCUSSION

### 3.1 Principles of Operation of the Sugarcane Juice Extractor

The machine operates by 5 HP Diesel engine. The sugarcane was inserted into the rollers where crushing, squeezing and pressing of the sugarcane occur as the sugarcane passes through subsequent rollers. The juice extracted from sugarcane is then collected in the collector from the discharge outlet. The crushing unit was made up of three rollers arranged in triangular form. The clearance between the top and feed roller is 7.5 mm while, the clearance between top and discharge roller is 4.5 mm. The three rollers were nulled and then grooved horizontally to increase the surface roughness for easy gripping of sugarcane.

## 3.2 Performance Evaluation

The machine was tested to assess its performance based on extraction efficiency and Juice yield. One variety of sugarcane was used for the evaluation called *koma* (*Saccharum barberi*). It was obtained from Makarfi local government area of Kaduna state, Nigeria. Sorting was carried out to obtain sugarcane of relatively equal sizes of 3 cm (30 mm) and then cut into an equal length 30 cm (300 mm) which constitute three nodes (i.e. 10 cm) [6]. The machine was then set into operation by the power source and known weights of sugarcane were fed into the sugarcane crushing unit. The juice extracted from sugarcane is then collected in the collector from the discharge outlet. After the extraction, the mass of sugarcane fed into the machine was measured, the mass of juice extracted and mass of residual waste (bagasse) were also recorded.

### 3.2.1 Determination of output capacity

This is the rate of juice extraction in kg/h. It is the ratio of the weight of juice extracted to total time taken to extract the juice. It was determined using Equation (14).

$$C_O = \frac{W_e}{T} \quad (14)$$

Where;

$C_O$ = Output capacity, kg/h
$W_e$ = Weight of juice extracted, kg
T = Total time taken for extraction, h

*3.2.1.1 Effect of speed on output capacity*

The results of means output capacities as presented in Table 4 showed that the speed of 30 rpm recorded to have the highest mean output capacity of 148.2 kg/h while, the lowest mean of 103.96 kg/h was obtained at 50 and 60 rpm, respectively. This, however, agrees with the findings of [8] in which 30 rpm was recommended as crushing roller speed for juicing sugarcane.

### 3.2.2 Determination of extraction efficiency

This is referred to as the juice extraction efficiency in per cent. It is the ratio of the mass of juice extracted to the mass juice present as given in Equation (15).

$$E_{ef} = \frac{W_e}{W_p} \times 100\% \quad (15)$$

Where;

$E_{ef}$ = Extraction Efficiency, %
$W_e$ = mass of juice extracted, kg
$W_P$ = mass of juice present (kg)

*3.2.2.1 Effect of speed on extraction efficiency*

The results of the effect of speed on extraction efficiency were assessed and presented in Table 3. The results showed that the speed of 30 rpm recorded 67.44% as the highest mean extraction efficiency while 60 rpm recorded 37.98% as the least mean extraction efficiency. This finding is in line with [8] who recommended 30 rpm as best crushing speed. The best efficiency of 67.44% obtained was higher than that of [6] and [16].

**Table 4. Effect of speed on output capacity**

| Speed (rpm) | Mean output capacity (kg/h) |
|---|---|
| S2 (30) | 148.20 |
| S3 (40) | 129.86 |
| S1 (20) | 122.66 |
| S4 (50) | 103.96 |
| S5 (60) | 103.96 |
| SE± | 4.496 |

**Table 3. Effect of speed on extraction efficiency**

| Speed (rpm) | Mean extraction efficiency (%) |
|---|---|
| S2 (30) | 67.44 |
| S1 (20) | 55.67 |
| S3 (40) | 54.93 |
| S4 (50) | 40.21 |
| S5 (60) | 37.98 |
| SE± | 1.810 |

## 4. CONCLUSION

The development and performance evaluation of a small-scale sugarcane juice extractor was achieved at the Department of Agricultural and bio-resources engineering workshop of the Ahmadu Bello University. The sugarcane juice extractor was tested recorded an output capacity of 148.20 kg/h and extraction efficiency of 67.44% for *koma* variety, respectively at a speed of 30 rpm.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES


1. Heiser CB. Seed to civilization: The story of food. Second Ed. W. H. Freeman and Co., San Francisco. 1981;254.
2. World Bank Group. Pollution prevention and abatement handbook. World Bank: National Development and Reform Commission. P. R. China; 1998.
3. Food and Agricultural Organization Statistics (FAOSTAT). Food and Agriculture Organization of the United Nations; 2013. Available:http://faostat.fao.org/site/567/default.aspx#ancor
4. National Sugar Development Council (NSDC). Information Brochure towards self sufficiency in sugar, Abuja. 2003;1-26.
5. Kaduna State Agricultural Development Project (KADP). Agricultural Production Survey Evaluation Report. 2013;26:1-8.
6. Olaoye JO. Partial mechanization of sugarcane juice extraction process. Uniilorin Sugar Research Institute. End of Session Report. 2008;21.
7. Oriola KO, Jekayinfa SO, Ola FA, Adedoyin AS, Akande FB. Some mechanical properties of sugarcane at different sizes and loadings relevant to design and construction of sugarcane juice extractor. International Journal of Engineering Research and Application (IJERA). 2017;7(7):62-70.
8. Abamaster Incorporated. Countertop Sugarcane Juice Extractor; 2010. Available:www.abamaster.com/productSpecWeb.php?modelId=2000.
9. Egbe E, Olugboji O. Design, fabrication and testing of a double roll crusher. International Journal of Engineering Trends and Technology (IJETT). 2016;511-516.
10. Hannah J, Stephens RC, Arnold E. Mechanics of machines: Advanced theory and examples. 2nd Edition; 1984.
11. Doughtic VI. Design of machine element. 4th Edition, Mc Graw-Hill Book Company, New York. 1985;382.
12. Kehinde AA, Michael TA, Robinson A. Development of a sugarcane juice extractor for small scale industries. Journal of Multidisciplinary Engineering Science and Technology (JMEST). 2015;2(5):1169.
13. Khurmi RS, Gupta JK. A text book of Machine design. (14th Ed). New Delhi: Eurasia Publishing House (PVT) Ltd. 2005;Chapters 7 and 14.
14. Bhandari VB. Design of machine elements. Tata McGraw-Hill Publishing Company Limited. 22nd Edition; 1994.
15. Grittin MM, Prasad LV. Handbook of mechanical design. Tata McGraw-Hill Publishing Co. Ltd. New Delhi; 1986.
16. Makinde-Ojo, Ayoola Macjay. Improvement of the fabrication and testing of a sugarcane juice extractor for the cottage industries. University of Agriculture Abeokuta; 2010.


---



*Peer-review history:*
*The peer review history for this paper can be accessed here:*
*https://sdiarticle4.com/review-history/51056*