**Nigerian Journal of Engineering Science Research (NIJESR).**
**Vol. 5, Issue 2, pp. 51-60, June, 2022**

**ISSN: 2636-7114**
*Journal Homepage: https://www.iuokada.edu.ng/journals/nijesr/*

# Performance Evaluation of a Modified Sugarcane Juice Extractor

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**Manuscript History**
*Received: 02/06/2022*
*Revised: 28/06/2022*
*Accepted: 29/06/2022*
*Published: 30/06/2022*

**Abstract:** *The production of sugarcane in commercial quantities suffered a serious setback in Nigeria, the observed weakest links in the value chain analysis are the end users who are the small scale entrepreneurs, expected to adopt the use of new technology for the purpose of their businesses. There is an existing sugarcane juice extractor designed and fabricated in the Department of Agricultural Engineering, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso. Some relevant components parts of the machine needed to be reduced in dimensions without losing their functionalities. This study has modified and evaluate the performance of the sugarcane juice extractor. The throughput of* 24.46 *kg/h and extraction efficiency of 81.55 % were achieved at corresponding optimum conditions of 80 rpm machine speed, 0.75 kg/min feed rate and three passes (Table 2). The ANOVA analysis (F- values) also indicated the order of significance of the input variables, giving machine speed as the variable, that affected the extraction efficiency, feed rate and number of passes.*

**Keywords:** *Modification, Performance Evaluation, Sugarcane and Machine Extractor*

## INTRODUCTION

Sugarcane is an important crop which belongs to the family of grass, genus *Saccharum*. Sugarcane is found to have at least six species of the genus, which implies that cultivated sugarcane is a multi - species hybrid, which are referred to as *Saccharum spp*. Sugarcane which originated from Southeast Asia, is currently cultivated in both tropical and subtropical countries throughout the world (Chinnaraja, 2017). According to Nmadu *et al.* (2013), two types of sugarcane are grown in Nigeria – industrial (*Saccharum officinarum*) and local (*Saccharrum barberi*) sugarcane. The industrial sugarcane is the soft type which is purple in colour, while the local sugarcane is the hard type which is yellowish - green in colour. Both types can be chewed or processed into sugar. The importance of sugarcane in human diet cannot be over emphasized, since it is one of the sources of obtaining sugar (Adewole *et al*., 2015). Juice extracted from sugarcane has been used for curing different types of human ailments in different parts of the world. Sugarcane extracts were established in a wide range of biological effects such as immune-stimulation, anti-thrombosis activity, anti-inflammatory activity, vaccine adjuvant and so on (Chinnaraja, 2017).

Olaoye (2009), Soetan, (2018) have reported variance in extraction efficiency, which is influenced by the processing parameters. The availability of the fabricated modified sugarcane juice extractor with low cost of production, will make it avoidable for small- scale entrepreneurs to purchase for doing their business. Also, this will enhance provision of employment opportunities for some citizens, and improve the country's gross domestic product (GDP). The aim of this study is to evaluate the performance of a modified sugarcane juice extractor. The objectives are to determine the effects of the selected processing parameters on the performance evaluation indices, such as extraction efficiency and throughput capacity. To use the ANOVA analysis (F- values) to indicate the order of significance of the input variables, giving machine speed as the as the variable that affected the extraction efficiency, followed by feed rate and number of passes.

## MATERIALS AND METHODS

### 2.1 Materials

The materials used were classified into raw materials and machine fabrication materials. Freshly harvested sugarcane (*Saccharum Officinarium*) was the major raw material used for this study. The machine fabrication materials are: stainless steel rollers, stainless steel sheet metal, angle bars, bearings, stainless steel rod, galvanized metal sheet, fine and large stainless screens, welding electrodes, bolts and nuts, sheaves, v- belts.

### 2.2 Methods

A. Design Analysis of the Relevant Component Parts

*Design of Roller Size*

The size of the roller was gotten from the equations 1 and 2 as given by (Adewole *et al.,* 2015).

$$F = MSwr^2 \quad (1)$$

But,

$$w = \frac{2\pi NS}{60} \quad (2)$$

where;

M = maximum force of failure of the machine (0.5(F x S), N

S = factor of safety (S = 0.9)

w = angular velocity of the crushing rollers, rad/sec

r = radius of crushing, mm

F = rupture force at horizontal direction gotten from compressive strength test as 1826 N

$$w = \frac{2 \times 3.142 \times 250 \times 0.9}{60} \quad (3)$$

$w$ = 23.57 rad/sec

Hence,

$$r^2 = \frac{1826}{821.7 \times 23.57 \times 0.9 \times 100}$$

$r^2$ = 0.00105 m

$r = \sqrt{0.00105}$

r =0.0324

D = r × 2

D= 0.0648 m

*Peripheral Velocity of the Rollers*

The velocity of the rollers was gotten from equation 4 as given by Boih (2015)

$$v = \frac{\pi Dn}{60} \quad (4)$$

Where;

$V$ = velocity of the crushing roller (m/s)

$D$ = diameter of the crushing roller (m)

n = selected speed of the roller (rpm)

$$V = \frac{3.142 \times 0.0648 \times 250}{60}$$

V = 0.85 m/s

*Power Required for Crushing*

The power required by the extractor can be determined by using the formula given in equation (5) (Boih, 2015).

$$P = F \times V \quad (5)$$

Where:

P = power (Watts)

F = rupture force required to crush sugarcane (N)

V = velocity of the crushing rollers (m/s)

P = 1826 × 0.85

P = 1,552.1 W

Recall that 1 hp is 746 W, 1,552.1 is equivalent to 2 hp

*Design of Shaft*

The diameter of the shaft was determined from Equation 6 given by Khurmi and Gupta (2008).

$$T = \frac{\pi}{16} \times \tau \times d^3 \quad (6)$$

But, T which is the twisting moment for use in equation 6 to obtain the diameter, was gotten from equation 7 as given by Khurmi and Gupta (2008)

$$P = \frac{2\pi NT}{60} \quad (7)$$

Where:

d = is the diameter of the shaft (m)

T= is the twisting moment (or torque) acting upon the shaft

τ= is the maximum bending moment, which is 42 MPa

P = Crushing power (N)

N= selected speed of the roller (rpm)

$$T = \frac{P \times 60}{2\pi N} \quad (8)$$

$$T = \frac{1552.1 \times 60}{2 \times 3.14 \times 250}$$

T = 59 Nm or 59 × $10^3$ N/mm

$$59 \times 10^3 = \frac{3.14}{16} \times 42 \times d^3$$

$$d^3 = 7158.02$$

$d$ = 19.27 mm = 0.019m.

## Fabrication of the Modified Sugarcane Juice Extractor

Metal sheet was cut into different sizes and welded together to produce the machine cover. Angular iron was cut and welded to produce the engine base upon which the electric motor, reduction gear box and rollers fix with bearings will sit on. The rollers were made from stainless roller of 65mm diameter. It was bored at the center to allow shaft run through it and welded to the roller. The shaft of the gear box and that of the roller were coupled together using direct coupling. The juice collector was made from stainless sheet, with fine and large screens fixed on it. A plastic tap was fixed at the collecting end of the collecting tray for easy filling of the juice into the bottles. V-belt was fixed between the sheave of the electric motor and gear box, to allow power transmission from electric motor to the machine. Fig. 1 shows the pictorial view of the sugarcane juice extractor, while Fig. 2 shows the exploded view.

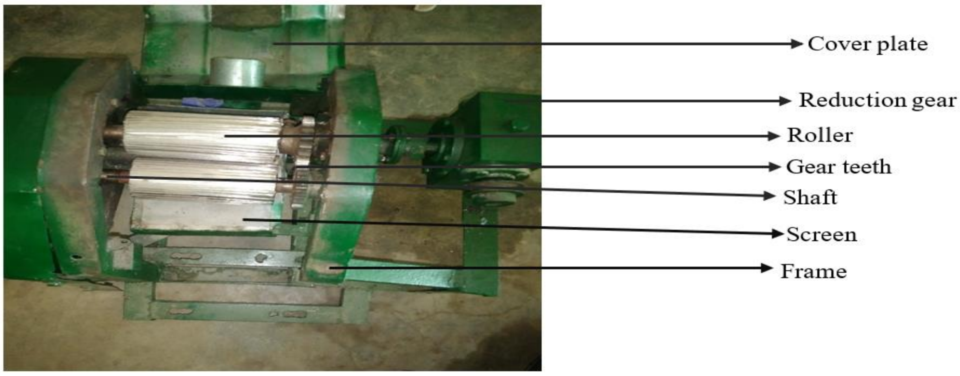


Fig. 1 Pictorial view of the sugarcane juice extractor showing component parts

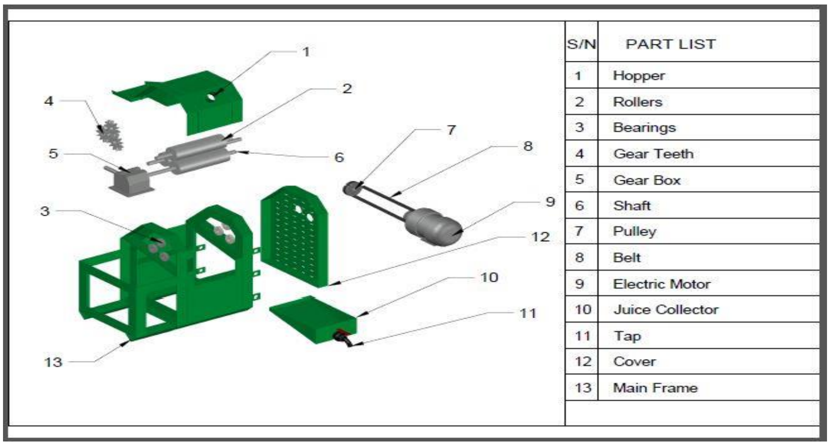


Fig. 2 Exploded view of the sugarcane juice extractor

## Procedure for Data Collection

Sugarcane stalks were fed into the machine by hand transversely between the rollers, and then the extracted juice was collected. For each specimen's extraction, the time required from the start of each crushing/ juice extraction process was recorded. Detailed tests were carried out to determine the throughput capacity of the machine and also the average time it takes to extract juice from the sugarcane were also recorded.

The bagasse remains and the juice extracted were collected to determine the extraction efficiency and extraction loss of the machine.

## Performance Evaluation Parameters

The various evaluation expressions that were used for estimating the performance of this machine are as follows:

### Extraction Efficiency

Extraction efficiency was determined using the mathematical expression in Equation (9) as given by Olaoye (2009).

$$J_E = \frac{W_{JE}}{C + W_{FS}} \times 100\% \quad (9)$$

where,
$J_E$ = extraction efficiency (%)
C = juice content present in a sugarcane stalk (75%)
$W_{FS}$ = weight of feed sample (kg)

### Throughput Capacity of the Machine

Throughput was determined using the mathematical expression in Equation (10) (Khurmi and Gupta, 2008).

$$J_E = \frac{W_{JE}}{T} \times 100\% \quad (10)$$

Where,
$C_J$ = throughput capacity of the machine (kg/h)
$W_{JE}$= Weight of the juice extracted (kg)
T = time used for extraction (hr)

$$C_J = \frac{0.685}{0.028}$$

$$C_j = 24.46 \text{ Kg/h.}$$

### Statistical Analysis

The interactions between the independent variables which are speed (rpm), feed rate (kg/min) and number of passes, and dependent variables which are the juice yield, machine efficiency and extraction loss, were analyzed by Regression Analysis, using coefficient of determination ($R^2$), p-value and Analysis of Variance (ANOVA). Design Expert 6.0.8 software was employed. A second-order polynomial (quadratic equation) was used to express the responses, $Y_{(n=1,2,3,4)}$ as a function of the independent variables as given in Equation 11.

$$Y = \beta_0 + \Sigma^n{}_{i=1}\, \beta_i \chi_i + \Sigma^n{}_{i=1}\, \beta_{ii} \chi^2{}_i + \Sigma^{n-1}\, \Sigma^n{}_{j=1+1} \beta_{ij} \chi_i \chi_j \quad (11)$$

Where:
$Y$ = response,
$\beta_0$ = constant coefficient,
$\beta_i$= linear coefficient,
$\beta_{ii}$ = the quadratic coefficient,
$\beta_{ij}$ = interaction coefficient,
$x_i$ *and* $x_j$ = coded values of the independent variables.

A statistical optimization was conducted by using Box Behnken Design, and the three independent variables was chosen for the experiment. A$3^3$ full factorial Box Behnken Design for the three variables, consisting of 8 factorial points, 6 axial points and 6 replicates at the center points were employed, indicating that altogether 18 experiments were carried out.

## RESULT AND DISCUSSION

### Effects of the Operating Parameter on the Extraction Efficiency

The result obtained from the experiment carried out on the evaluation of the performance of the modified sugarcane juice extractor is presented in (Table-1). This result shows that, the maximum extraction efficiency of 81.55% was obtained at operating machine speed of 80 rpm, feed rate of 0.75 kg/min and 3 passes, while the minimum extraction efficiency of 54.34% was obtained at operating machine speed of 120 rpm, feed rate of 0.75 kg/min and 1 pass. Olaoye (2011) reported to have worked on the development of a sugarcane juice extractor for small scale industries, and the efficiency of the developed sugarcane juice extractor ranged between 40 and 61 % at operating speeds of 0.25and 0.36 m/s. Adedoyin (2018) reported an efficiency range between 42.31 to 72.99 % at machine speed of 145 rpm and 250rpm. The high efficiency obtained in this study compared to previous research work, was related to the introduction of reduction gear to the design, to further enhance the torque and reduce the speed. The effect of the operating parameters on the extraction efficiency has been analyzed and presented in Table-2. The ANOVA analysis (F-values) also indicated the order of significance of the input variables, giving machine speed as the most important variable, that affected the extraction efficiency, followed by feed rate and number of passes. This order of the effect of the factors on the percentage expression efficiency, is in line with the findings of Olaoye (2009), Adewole *et al.* (2015) and Adedoyin (2018), which showed that machine speed had the highest effect on juice yield.

Table-1 Experimental matrix

| Std | Run | Machine speed (rpm) | Feed rate (kg/min) | Number of Passes | Extraction Efficiency (%) |
|---|---|---|---|---|---|
| 14 | 1 | 100 | 0.75 | 2 | 69.32 |
| 15 | 2 | 100 | 0.75 | 2 | 69.3 |
| 7 | 3 | 80 | 0.75 | 3 | 81.55 |
| 5 | 4 | 80 | 0.75 | 1 | 75.84 |
| 3 | 5 | 80 | 1.0 | 2 | 72.74 |
| 8 | 6 | 120 | 0.75 | 3 | 62.56 |
| 4 | 7 | 120 | 1.0 | 2 | 62.74 |
| 12 | 8 | 100 | 1.0 | 3 | 70.05 |
| 17 | 9 | 100 | 0.75 | 2 | 69.55 |
| 16 | 10 | 100 | 0.75 | 2 | 69.6 |
| 6 | 11 | 120 | 0.75 | 1 | 54.34 |
| 9 | 12 | 100 | 0.50 | 1 | 65.75 |
| 11 | 13 | 100 | 0.50 | 3 | 73.29 |
| 1 | 14 | 80 | 0.50 | 2 | 75.48 |
| 10 | 15 | 100 | 1.0 | 1 | 63.01 |
| 2 | 16 | 120 | 0.50 | 2 | 66.99 |
| 18 | 17 | 100 | 0.75 | 2 | 69.49 |
| 13 | 18 | 100 | 0.75 | 2 | 69.35 |

The regression model obtained, could be used to adequately predict the juice yield within the design space, as the $R^2$value obtained (0.9631) and the *adjusted* $R^2$value (0.9415) are closed to unity.

### Model Equation for Extraction Efficiency

This indicates that, the model can be used to navigate within the design space. The regression model Equation 12 developed for extraction efficiency with single factors, quadratic factor and interactive factors revealed that, C, AC and $A^2$ are directly proportional to the expression efficiency, while A, B, AB, BC, $B^2$ and $C^2$ with negatively coefficient indicates, an inverse proportionality with the extraction efficiency.

$$\text{Extraction efficiency} = 69.44-7.37A-1.62B+3.56C-0.38AB+0.63AC-0.13BC+0.30A^2-0.25B^2-1.16C^2 \quad (12)$$

### Mode of Interaction between the Operating Parameters

The modes of interaction between the operating parameters are expressed in Fig. 3, Fig. 4 and Fig. 5. The Fig. shows the 3D response surface plot of the effect of feed rate and machine speed, on the extraction efficiency of the sugarcane juice extractor. The figures revealed that, the efficiency increases sharply, as machine speed decreases from 120 rpm to 80 rpm, the effect of feed rate on the efficiency was observed to be a slight one with increase in feed rate from 0.5 to 1.0 kg/min. While there was also slight increase in extraction efficiency with increase in the number of passes from 1to 3. The ANOVA analysis shows that, the interactions between the operating parameters were not significant on the extraction efficiency.

Table-2 Extraction Efficiency ANOVA for Response Surface Quadratic Model

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| Model | 566.226 | 9 | 62.914 | 8.28327 | 0.0033 | Significant |
| A-Machine speed | 434.8301 | 1 | 434.8301 | 57.24981 | < 0.0001 | |
| B-Feed rate | 21.02761 | 1 | 21.02761 | 2.7685 | 0.1347 | |
| C-number of passes | 101.6025 | 1 | 101.6025 | 13.37701 | 0.0064 | |
| AB | 0.570025 | 1 | 0.570025 | 0.07505 | 0.7911 | |
| AC | 1.575025 | 1 | 1.575025 | 0.207368 | 0.6609 | |
| BC | 0.0625 | 1 | 0.0625 | 0.008229 | 0.9300 | |
| A^2 | 0.392727 | 1 | 0.392727 | 0.051707 | 0.8258 | |
| B^2 | 0.2673 | 1 | 0.2673 | 0.035193 | 0.8559 | |
| C^2 | 5.897045 | 1 | 5.897045 | 0.776406 | 0.4039 | |
| Residual | 60.76248 | 8 | 7.595309 | | | |
| Lack of Fit | 60.68033 | 3 | 20.22678 | 1231.088 | < 0.0001 | Significant |
| Pure Error | 0.08215 | 5 | 0.01643 | | | |
| Cor Total | 626.9885 | 17 | | | | |

Std. Dev. 2.76, R-Squared 0.9631, Mean 28.94, Adj R-Squared 0.9415, C.V. % 4.00, Pred R-Squared 0.9487,PRESS 971.00,Adeq Precision10.648

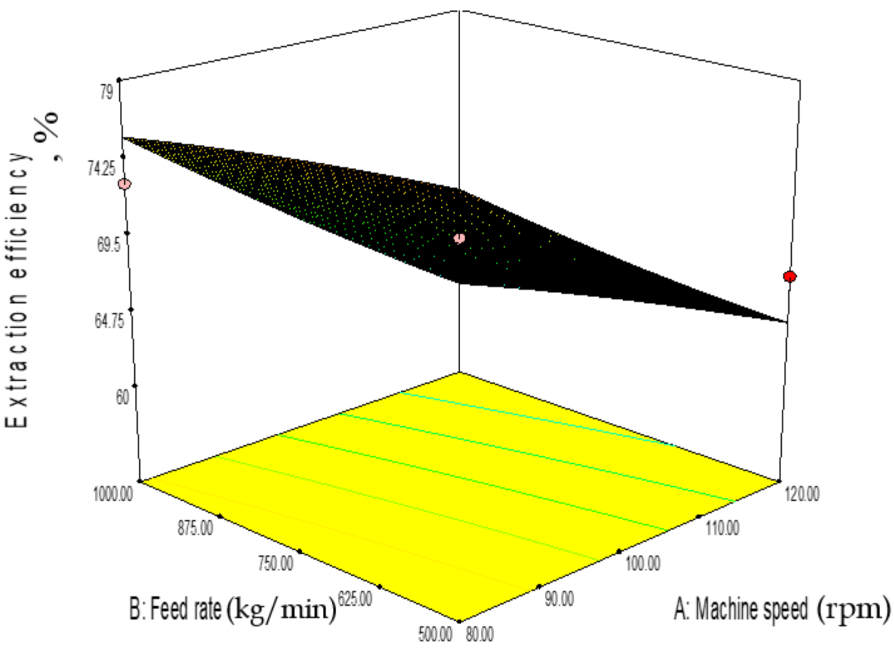


Fig. 3 The response surface plot showing the effects of feed rate and machine speed on the extraction efficiency of the sugarcane juice extractor

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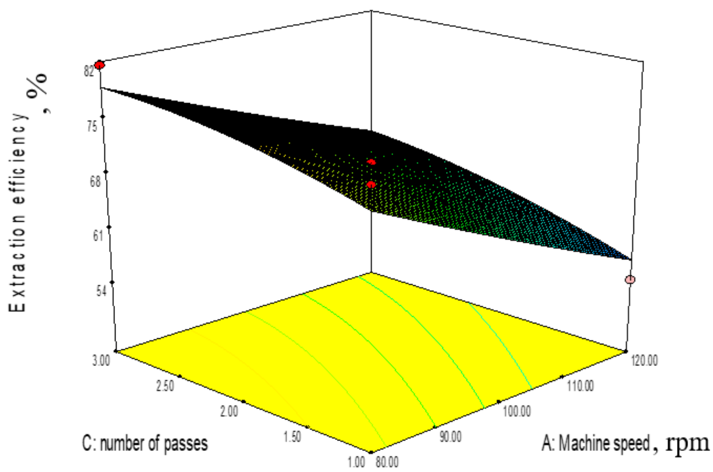


Fig. 4 The response surface plot showing effects of the number of passes and machine speed on the extraction efficiency of the sugarcane juice extractor

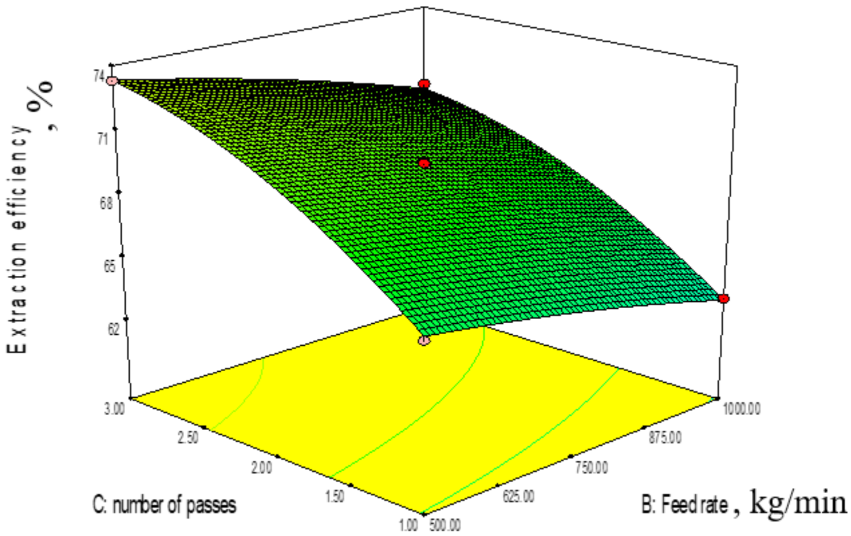


Fig. 5 The response surface plot showing effects of the number of passes and feed rate on the extraction efficiency of the sugarcane juice extractor

## CONCLUSION

The throughput capacity of 24.46 kg/h and extraction efficiency of 81.55 % were achieved at corresponding optimum conditions of 80 rpm machine speed, 0.75 kg/min feed rate and three passes (Table 2). The ANOVA analysis (F- values) also indicated the order of significance of the input variables, giving machine speed as the important variable, that affected the extraction efficiency, followed by feed rate and number of passes.

## CONFLICT OF INTEREST

The authors declare no competing interest.

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