

## Some Mechanical Properties of Sugarcane at Different Sizes and Loadings Relevant to Design and Construction of Sugarcane Juice Extractor.

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### ABSTRACT

This study evaluated the mechanical properties of two varieties of sugarcane; *Saccharumofficinarum* and *Saccharumbarberi*. Some mechanical properties (rupture force, rupture energy, bio-yield force, bio-yield energy and deformation at horizontal and vertical loading direction) were investigated using a Universal testing machine. Sugarcane is an economically important grass that is rich in calcium, chromium, cobalt and other health supportive substances. The stress undergone by the teeth while chewing sugarcane to obtain the juice content in addition to the inherent postharvest losses has necessitated the study of its mechanical properties to enhance effective mechanization of its processing and handling. At sugarcane sizes (diameter) from 33-40, rupture force, rupture energy, bio-yield force, bio-yield energy and deformation are 2677 N, 11.15 N.m, 2828 N, 8.92 N.m and 7.32 mm respectively at vertical loading direction, and at horizontal loading direction rupture force, rupture energy, bio-yield force, bio-yield energy and deformation are 3157 N, 17.83 N.m, 3115 N, 11.43 N.m and 8.41 mm respectively for *Saccharumofficinarum*. At sugarcane sizes (diameter) from 30-37, rupture force, rupture energy, bio-yield force, bio-yield energy and deformation are 2890 N, 29.68 N.m, 2991 N, 5.98 N.m and 10.35 mm respectively at vertical loading direction, and at horizontal loading direction rupture force, rupture energy, bio-yield force, bio-yield energy and deformation are 3510 N, 35.95 N.m, 4574 N, 15.49 N.m and 12.78 mm respectively for *Saccharumbarberi*. The results will be useful in designing sugarcane harvester and sugarcane juice extractor.

**Keywords:** mechanical properties, sugarcane stalk diameter, sugarcane, juice extractor,

Date of Submission: 06-07-2017

Date of acceptance: 26-07-2017

### I. INTRODUCTION

Sugarcane (*Saccharum spp*) is a tall grass with a stout jointed and fibrous stalk that looks similar to bamboo [1]. It belongs to perennial herbs of a genus of the grass family *Saccharium* and tribe *Andropogoneae* [2]. It is extensively cultivated in tropical and subtropical regions of the world for the sugar contained within its stems. Sugarcane is known as *Ireke* in Yoruba, *Okpete* in Igbo and *Reke* in Hausa languages, in Nigeria. It is rich in calcium, chromium, cobalt, copper, magnesium, manganese, phosphorous, potassium and zinc [2]. It also contains iron and vitamins A, C, B<sub>1</sub>, B<sub>2</sub>, B<sub>3</sub>, B<sub>5</sub>, and B<sub>6</sub>, plus a high concentration of phytonutrients (including chlorophyll), antioxidants, proteins, soluble fiber and numerous other health supportive compounds [2]. Matured sugarcane stalk is found to be composed of 11-16% fiber, 12-16% soluble sugars, 2-3% non-sugars, and 63-73% water [1]. The current estimated sugarcane production of the nation as at 2008 was put at over 1.4m tones [3]. The varieties of sugarcane available in Nigeria and the world in general as of

today as not been estimated but [4] and [5] categorized the types of sugarcane in Nigeria into Industrial (*Saccharumofficinarum*) and Local Chewing Sugarcane (*Saccharumbarberi*). In sub-Saharan African Countries, the suckle in sugarcane has been enjoyed by using teeth to bite off the rind and chewing off the internal tissues, then the juice is sucked in the mouth and the bagasse is spat out. This consumption method is considered to be grossly; unhealthy and uncivil aside the stress the teeth have to undergo [6]. Hence mechanization of sugarcane processing is not only necessary to meet the need for fresh sugarcane juice but also for reducing the post-harvest loss in sugarcane. Hence, an engine powered sugarcane juice extractor is essential for small and medium scale farmers. Keeping the above factors in mind, some properties of sugarcane pertaining to the crushing of sugarcane and extraction of juice is conducted for the design of an engine powered sugarcane extractor. The design of the major units such as the crushing unit, engine motor selection, the separation unit is dependents on the properties. A lot

of researches have been reported on sugarcane such as physical properties of sugarcane [7], characteristics of sugarcane fibres[8].Quasi-static tests using a universal testing machine to determine shear, compressive resistance and bending resistance of forage crops[9]. Investigation of the mechanical properties of sugarcane stalks viz; bending resistance, cutting resistance, penetration resistance and crushing resistance for the development of a whole cane combine harvester [10]. Based on the review of previous work on sugarcane, the variation in sizes of sugarcane from one internodes to another has not been considered to see their effect on the mechanical properties of sugarcane, its becomes of interest to investigate if the variation in sizes will have effect on its mechanical properties. The specific objective of this study is to determine some mechanical properties of sugarcane namely rupture force, rupture energy, bio-yield force, bio-yield energy and deformation at rupture point over a range of some selected sugarcane size (diameter).

## II. MATERIALS AND METHODS

### 2.1 Sample Preparation

Two sugarcane varieties used for this study were sourced from OjaGboro in Ilorin, Kwara State, Nigeria. The two varieties are; *Saccharumofficinarum*(Industrial) and *Saccharumbarberi*(Local Chewing) sugarcane, which were peeled and unpeeled, and replicated three times, under vertical and horizontal loading direction. (Plate 1 and 2), this combined gives an experimental design of  $2 \times 2 \times 2 \times 3$ . They were cut into the same sizes of 10 cm (average size of a sugarcane node) with twelve (12) samples for each variety making a total of twenty four (24) samples for the analysis.



Plate 1: *Saccharumofficinarum* (Industrial Sugarcane)



Plate 2: *Saccharumbarberi* (Local Chewing Sugarcane)

### 2.2 Diameter of Sugarcane

The diameter of sugarcane varies from bottom to top and this variation depends upon the variety and the climatic condition which prevailed in the growth phase of the sugarcane [7]. Sugarcane diameter plays a significant role in the design of rollers used in sugarcane extractor and in the selection of the maximum and minimum clearance between the rollers. The diameters of the two varieties of sugarcane used in the compression test were carefully selected with the help of a vernier caliper with code number 532-120, 0-200 mm range and accuracy of  $\pm 0.01$  mm and taken as minimum, mean and maximum in the range as shown in Table 1 for horizontal and vertical loading as reported by [7][11].

Table 1: Some selected sugarcane diameter

Variety	min. dia.(mm)	mean dia. (mm)	max. dia.(mm)
<i>Saccharumofficinarum</i>	33	36	40
<i>Saccharumbarberi</i>	30	34	37

### 2.3 Mechanical properties

The compression tests were carried out using a Universal testing machine that is equipped with a 50 kg compression load cell and integrator with machine number 0500-10080. The measurement

accuracy was 0.001 N and 0.001 mm in deformation [12]. The rupture force, rupture energy, bio-yield force, bio-yield energy and deformation at rupture point were determined from the vertical and horizontal loading position; at a loading speed of 5

mm/min [13]. An individual sample of the sugarcane was placed on the lower plate (Plate.3a and b) and the top section attached to the chuck moved downward with a constant speed until fracture occurred as it is

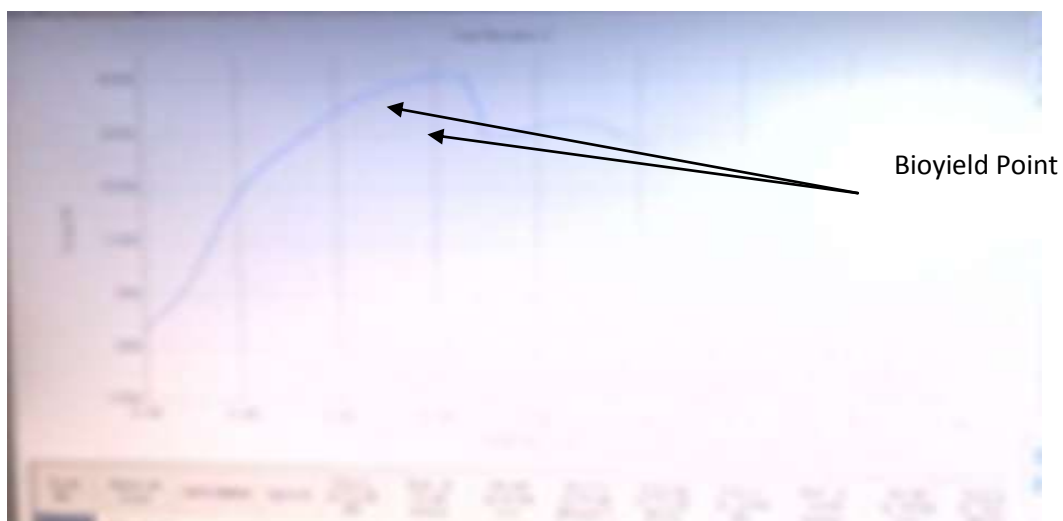
denoted in the force – deformation curve (Plate 4). The loading is stopped once the fracture was detected. Three replicates were made for each loading.



**Plate 3a:** Compressive test for peeled sugarcane sample



**Plate 3b:** Compressive test for unpeeled sugarcane sample



**Plate 4:** Force- deformation curve

## 2.4 Analysis of results

The data obtained were analysed using Analysis of Variance (ANOVA) and regression in Minitab 16.2.1 software (2010 Minitab Inc.) to

determine the effects of different sizes (diameter) on the mechanical properties of industrial and local chewing sugarcane varieties

### III. RESULTS AND DISCUSSION

Results of the compressive tests conducted on the two sugarcane varieties are presented in Table 2.

**Table 2.** Mechanical properties of sugarcane at vertical and horizontal loading directions analysed by Duncan multiple range test ( $p \leq 0.05$ )

Properties	Min.	Mean	Max.
<i>Saccharumofficinarum</i>			
<b>Vertical loading direction</b>			
Rupture force (N)	2677.00 ± 16.12 <sup>b</sup>	2891.33 ± 23.45 <sup>b</sup>	3157.00 ± 49.33 <sup>b</sup>
Rupture energy (N.m)	11.15 ± 0.04 <sup>a</sup>	14.16 ± 0.10 <sup>a</sup>	17.83 ± 0.56 <sup>a</sup>
Bio-yield force (N)	2828.00 ± 3.71 <sup>c</sup>	2992.00 ± 26.29 <sup>c</sup>	3115.00 ± 34.57 <sup>b</sup>
Bio-yield energy (N.m)	8.92 ± 0.20 <sup>a</sup>	10.49 ± 0.07 <sup>a</sup>	11.43 ± 0.14 <sup>a</sup>
Deformation (mm)	7.32 ± 0.10 <sup>a</sup>	7.71 ± 0.21 <sup>a</sup>	8.41 ± 0.06 <sup>a</sup>
<b>Horizontal loading direction</b>			
Rupture force (N)	1073.00 ± 22.27 <sup>b</sup>	1360.33 ± 104.00 <sup>b</sup>	1586.00 ± 55.57 <sup>b</sup>
Rupture energy (N.m)	3.09 ± 0.06 <sup>a</sup>	4.47 ± 0.14 <sup>a</sup>	6.90 ± 0.27 <sup>a</sup>
Bio-yield force (N)	1609.00 ± 7.62 <sup>c</sup>	1617.33 ± 68.05 <sup>c</sup>	1630.00 ± 60.65 <sup>b</sup>
Bio-yield energy (N.m)	1.73 ± 0.01 <sup>a</sup>	2.26 ± 0.07 <sup>a</sup>	2.56 ± 0.15 <sup>a</sup>
Deformation (mm)	3.28 ± 0.08 <sup>a</sup>	4.71 ± 0.37 <sup>a</sup>	6.45 ± 0.15 <sup>a</sup>
<i>Saccharumbarberi</i>			
<b>Vertical loading direction</b>			
Rupture force (N)	2890.00 ± 57.33 <sup>b</sup>	3235.00 ± 64.17 <sup>b</sup>	3510.00 ± 23.25 <sup>b</sup>
Rupture energy (N.m)	29.68 ± 1.18 <sup>a</sup>	33.64 ± 0.93 <sup>a</sup>	35.95 ± 0.68 <sup>a</sup>
Bio-yield force (N)	2991.00 ± 45.83 <sup>b</sup>	3974.33 ± 30.04 <sup>ab</sup>	4574.00 ± 38.92 <sup>c</sup>
Bio-yield energy (N.m)	5.98 ± 0.29 <sup>a</sup>	11.94 ± 0.32 <sup>a</sup>	15.49 ± 0.46 <sup>a</sup>
Deformation (mm)	10.35 ± 0.13 <sup>a</sup>	11.43 ± 0.16 <sup>a</sup>	12.78 ± 0.26 <sup>a</sup>
<b>Horizontal loading direction</b>			
Rupture force (N)	573.00 ± 9.01 <sup>b</sup>	855.33 ± 16.15 <sup>b</sup>	1316.00 ± 32.07 <sup>c</sup>
Rupture energy (N.m)	1.41 ± 0.09 <sup>a</sup>	2.74 ± 0.05 <sup>a</sup>	4.83 ± 0.06 <sup>a</sup>
Bio-yield force (N)	898.00 ± 5.81 <sup>c</sup>	1014.67 ± 4.61 <sup>c</sup>	1203.00 ± 31.01 <sup>b</sup>
Bio-yield energy (N.m)	0.89 ± 0.05 <sup>a</sup>	1.16 ± 0.04 <sup>a</sup>	1.29 ± 0.08 <sup>a</sup>
Deformation (mm)	3.19 ± 0.06 <sup>a</sup>	3.91 ± 0.05 <sup>a</sup>	4.96 ± 0.09 <sup>a</sup>

a, b, c: Means superscript with different letters in the same row differ significantly

#### 3.1 Rupture Force:

The rupture force of the Industrial and local chewing sugarcane varieties at the two loading directions are presented in Fig. 1. The rupture force of *Saccharumofficinarum* increases linearly from 2677 to 3157 N for vertical and non-linearly from 1073 to 1586 N for horizontal as the sugarcane size or diameter increases from 33 to 40 mm and so also the rupture force of the *Saccharumbarberi* increases linearly from 2890 to 3510 N for vertical and quadratically from 573 to 1316 N for horizontal as the sugarcane size or diameter increases from 30 to 37 mm. The force required to fracture the industrial sugarcane at vertical direction was significantly higher than for horizontal position ( $p \leq 0.05$ ) at all experimental diameters for both sugarcane varieties. Similar results were reported by [14] on mechanical properties of kenaf stems at varying moisture content, [15] on mechanical properties of cassava stalks and [16] on physical and mechanical characteristics for some agricultural residue such as cotton stalk, maize stalks and sugarcane bagasse which are reported for different directions. The relationship between the

sample rupture forces with different diameters at vertical and horizontal loading directions for *Saccharumofficinarum* and *Saccharumbarberi* was significantly correlated ( $p \leq 0.05$ ) and can be expressed using equations 1 to 4.

*Saccharumofficinarum*

$$R_f = 421 + 68.5D_i R^2 = 0.999 (\text{Vert. direction}) (1)$$

$$R_f = -1290 + 72.4D_i R^2 = 0.977 (\text{Hor. direction}) (2)$$

*Saccharumbarberi*

$$R_f = 234 + 88.4D_i R^2 = 0.999 (\text{Vert. direct.}) (3)$$

$$R_f = -2594 + 104D_i R^2 = 0.952 (\text{Hor. direction}) (4)$$

Where;

$R_f$  is the rupture force (N) and

$D_i$  is the diameter of sugarcane (mm).

Crushing and juice extraction is a subject of rupture force and the diameter of the sugarcane. Therefore, for the design of a sugar cane juice extractor, the values of the rupture force will be needed for the selection of the pulley or sprocket so as to determine the required speed that will supply the force needed to extract the juice from the sugarcane.

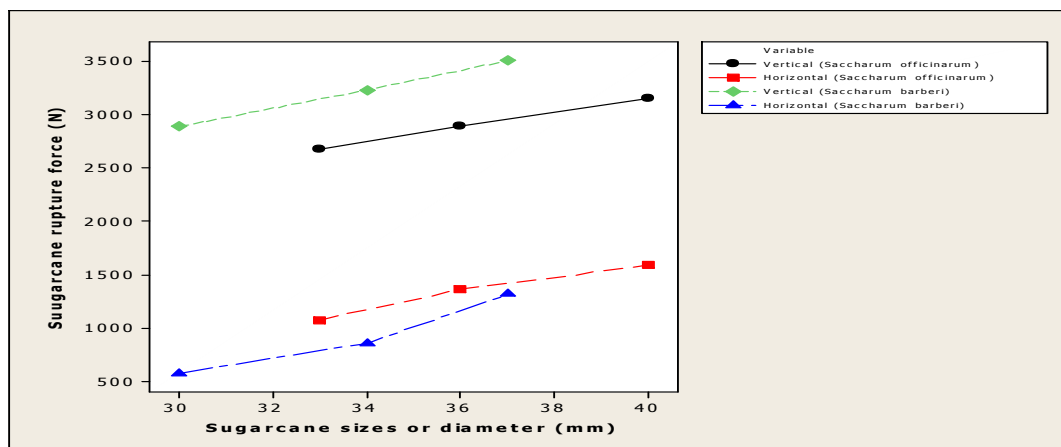


Figure 1: Effect of different sugarcane diameter on rupture force of *Saccharum officinarum* and *Saccharum barberi*

### 3.2 Rupture Energy

The rupture energy of the Industrial and local chewing cane is shown in Fig. 2. Rupture energy was greater for *Saccharum barberi* than *Saccharum officinarum* at vertical loading but lower for *Saccharum barberi* than *Saccharum officinarum* at horizontal loading. The rupture energy increases for *Saccharum officinarum* from 11.15 to 17.83 N.m and *Saccharum barberi* from 29.68 to 35.95 N.m at vertical loading, so also increases at horizontal loading for *Saccharum officinarum* from 3.09 to 6.90 N.m and *Saccharum barberi* from 1.41 to 4.80 N.m. There is a clear difference in the rupture energy for both varieties as it is known that *Saccharum barberi* is harder and have smaller diameter than *Saccharum officinarum*. The results are similar to those reported by [17] on mechanical characteristics for cotton and pigeon pie as agricultural residue and [14] on mechanical properties of kenaf stems at

varying moisture content but are not reported for different direction which is important to machine design. In vertical and horizontal direction of loading, rupture energy shows a strong significant ( $P \leq 0.05$ ) correlation to a size of sugarcane (diameter)

The relationship between rupture energy and size of sugarcane (diameter) at vertical and horizontal loading directions for *Saccharum officinarum* and *Saccharum barberi* are shown using the regression equations 5 to 8.

*Saccharum officinarum*

$$R_e = -20.2 + 0.95D_i R^2 = 0.999 \text{ (vert. direct.) (5)}$$

$$R_e = -15.1 + 0.548D_i R^2 = 0.994 \text{ (Hor. direct.) (6)}$$

*Saccharum barberi*

$$R_e = 2.76 + 0.901D_i R^2 = 0.995 \text{ (Vert. direct.) (7)}$$

$$R_e = -13.0 + 0.47D_i R^2 = 0.958 \text{ (Horiz. direct.) (8)}$$

Where;

$R_e$  is the rupture energy (N.m)

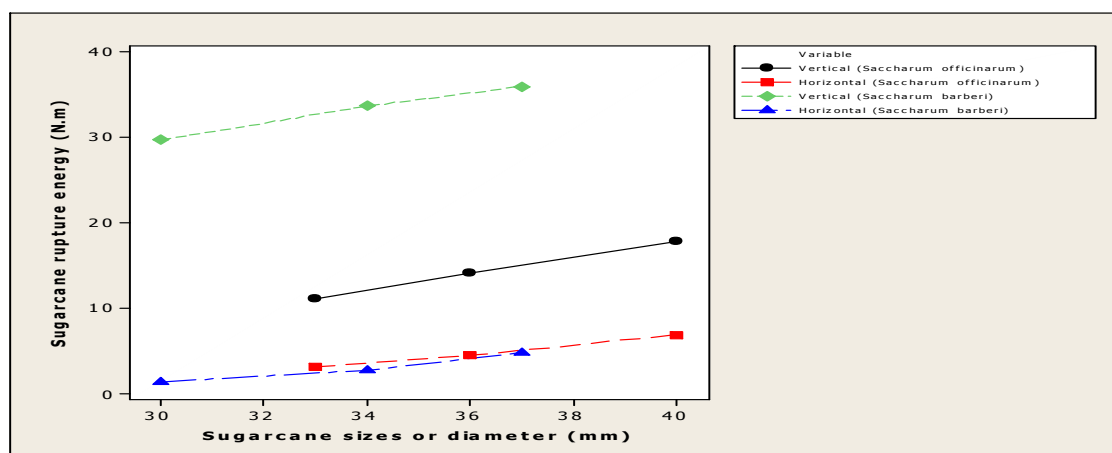


Figure 2: Effect of different sugarcane diameter on rupture energy of *Saccharum officinarum* and *Saccharum barberi*

### 3.3 Bio-yield force and energy

The bio-yield force and energy of the *Saccharum officinarum* and *Saccharum barberi* are shown in Figs. 3 and 4, respectively. The bio-yield

force for *Saccharum officinarum* at vertical and horizontal loading increases from 2828 to 3115 N and 1609 to 1630 N, respectively at the sugarcane size of 33 to 40 mm while the

*Saccharumofficinarum* bio-yield force at both vertical and horizontal direction increases from 2991 to 4574 N and 898 to 1203 N, respectively at the sugarcane size of 30 to 37 mm. Similar findings were reported by [18] for bio-yield force of pods of *proposes Africana* and [19] on mechanical properties of Carob pod (*Ceratoniasiliqua L.*). Bio-yield force is greater than rupture force in all loading directions, and it is observed from the result that the bio-yield force for *Saccharumofficinarum* is higher at horizontal direction than the *Saccharumbarberi*, this may be due to the fact that *Saccharumbarberi* generally are smaller in diameter and harder than *Saccharumofficinarum*. At vertical and horizontal loading direction, the bio-yield energy for industrial and local chewing sugarcane increases linearly from 8.92 to 11.43 N.m, 1.72 to 2.56 N.m, 5.98 to 15.49 N.m and non-linearly from 0.89 to 1.29 N.m respectively. The relation between bio-yield force, bio-yield energy and the size of sugarcane

(diameter) for *Saccharumofficinarum* and *Saccharumbarberi* under vertical and horizontal loading was significantly correlated ( $p \leq 0.05$ ) and can be expressed using equations 9 to 16.

*Saccharumofficinarum*

$$B_f = 1509 + 40.4D_i R^2 = 0.973(\text{Vert. direct.}) \quad (9)$$

$$B_e = -2.51 + 0.352D_i R^2 = 0.950(\text{Vert. direct.}) \quad (10)$$

$$B_f = 1509 + 3.01D_i R^2 = 0.999(\text{Hor. direct.}) \quad (11)$$

$$B_e = -2.09 + 0.118D_i R^2 = 0.941(\text{Hor. direct.}) \quad (12)$$

*Saccharumbarberi*

$$B_f = -3803 + 227D_i R^2 = 0.997(\text{Vert. direct.}) \quad (13)$$

$$B_f = -402 + 42.8D_i R^2 = 0.954(\text{Vert. direct.}) \quad (14)$$

$$B_e = -34.8 + 1.37D_i R^2 = 0.996(\text{Hor. direct.}) \quad (15)$$

$$B_e = -0.829 + 0.057D_i R^2 = 0.986(\text{Hor. direct.}) \quad (16)$$

Where;

$B_f$  is the bio-yield force (N),

$B_e$  is the bio-yield energy (N.m),

$D_i$  is the diameter of sugarcane (mm).

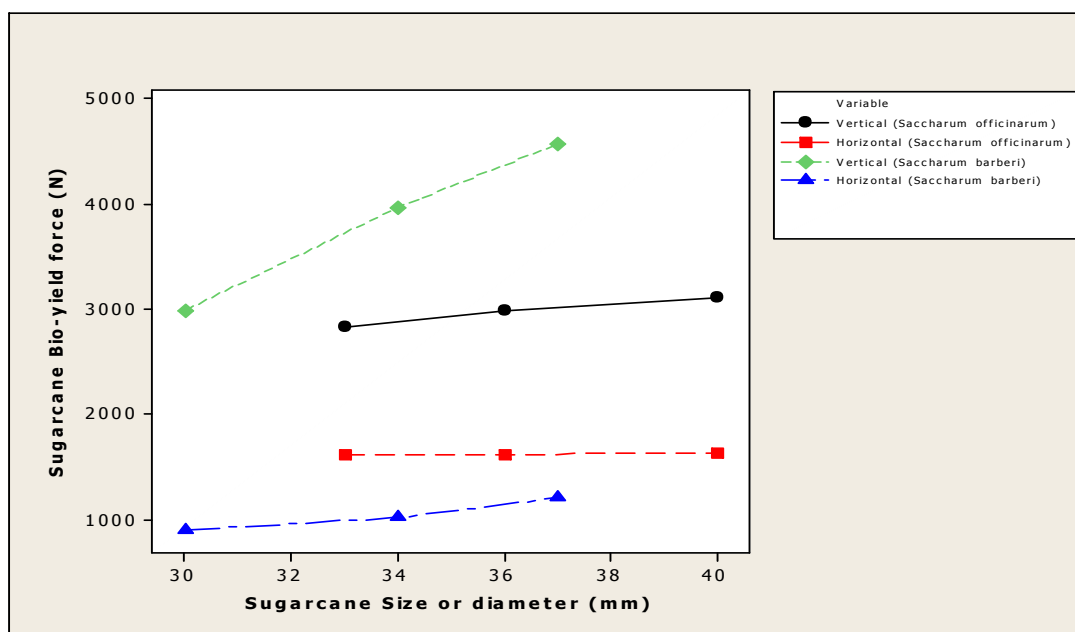


Figure 3: Effect of different sugarcane diameter on bio-yield force of *Saccharumofficinarum* and *Saccharumbarberi*

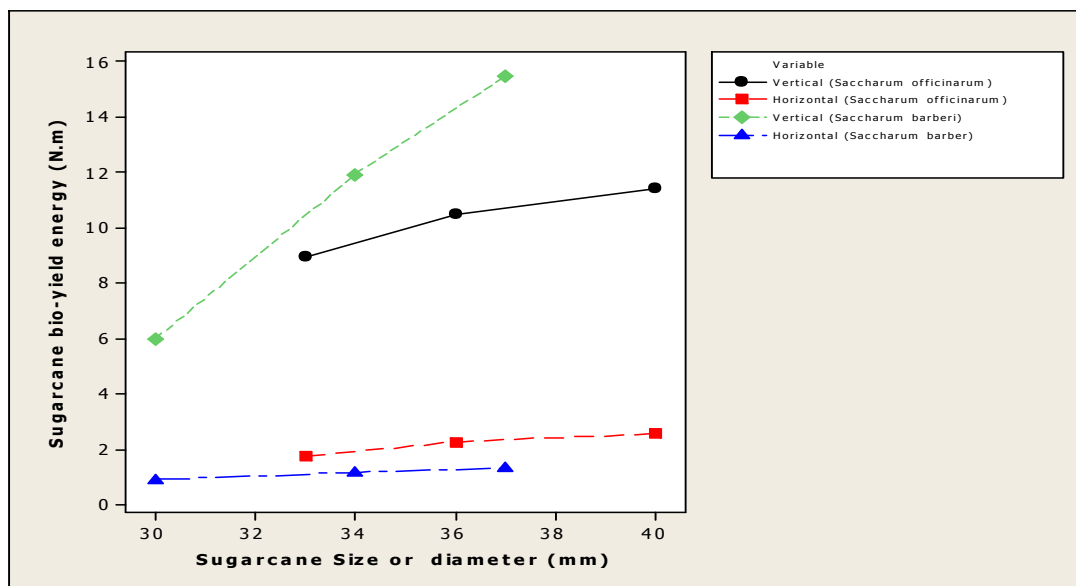


Figure 4: Effect of different sugarcane size or diameter on bio-yield energy of *Saccharum officinarum* and *Saccharum barberi*

### 3.4. Deformation at rupture point:

The deformation at rupture point is presented in Fig 5 for both Industrial and Local chewing sugarcane at vertical and horizontal loading direction. The deformation for *Saccharum officinarum* increases from 7.32 to 8.41 mm in vertical loading direction and 3.28 to 6.45 mm in horizontal loading direction, while for *Saccharum barberi* increases from 10.35 to 12.78 mm in vertical loading direction and 3.19 to 4.96 mm in horizontal loading direction. It was observed that the deformation is higher for *Saccharum barberi* in vertical loading direction than for industrial sugarcane and vice versa in horizontal loading direction. Similar findings were reported by [20] on some mechanical properties of agbaraba-a

native Nigeria bamboo but were not reported for different direction.

The relationship between deformation and different sizes of sugarcane (diameter) at vertical and horizontal loading for *Saccharum officinarum* and *Saccharum barberi* was significantly correlated ( $p \leq 0.05$ ) and can be expressed respectively using the equation 17 to 20.

$$D_{rp} = 2.12 + 0.157D_i R^2 = 0.99 \text{ (Vert. direct.) (17)}$$

$$D_{rp} = -11.6 + 0.452D_i R^2 = 0.99 \text{ (Hor. direct.) (18)}$$

*Saccharum barberi*

$$D_{rp} = -0.03 + 0.343D_i R^2 = 0.97 \text{ (Vert. direct.) (19)}$$

$$D_{rp} = -4.36 + 0.249D_i R^2 = 0.965 \text{ (Hor. direct.) (20)}$$

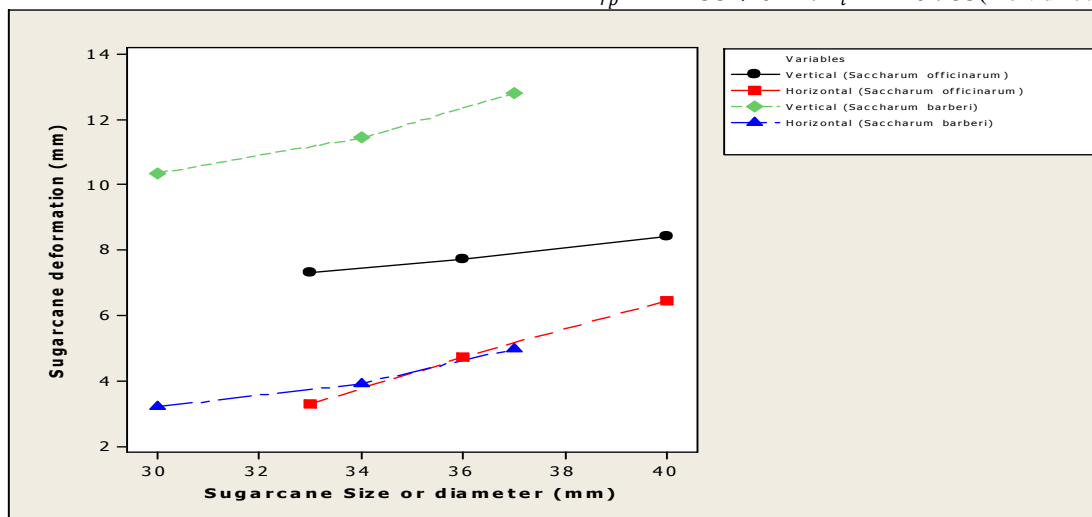


Figure 5: Effect of different sugarcane size or diameter on deformation of *Saccharum officinarum* and *Saccharum barberi*

## IV. CONCLUSION

Some of the mechanical properties required for the design and fabrication of sugarcane juice



extractor have been determined (the rupture force and energy, bio-yield force and energy, and deformation). The mechanical properties are function of the sugarcane size, an adjustable mechanism will be necessary in the construction of a sugarcane extractor to accommodate different sizes of sugarcane. Data obtained will be useful in the design of sugarcane crusher, juice extractor and other sugarcane processing machine.

### ACKNOWLEDGMENT

The researchers are grateful for the Tetfund University based research grant awarded for this project under the TETFUND INTERVENTION PROJECT REF: TETFUND/DESS /LAUTECH/OGBOMOSO/RP/VOL. VI

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