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# Evaluation of fiber characteristics of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks for pulp and paper production

Funmilayo Abosedo Adesina<sup>\*</sup>, Babatunde Ajayi

Department of Forestry and Wood Technology, The Federal University of Technology Akure, P.M.B.704 Akure, Ondo State, Nigeria

<sup>\*</sup>Correspondence: Funmilayo Abosedo Adesina (funmisina13@gmail.com)

**Abstract:** Fiber characteristics of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks were investigated. Fiber characteristics such as fiber length, fiber diameter, lumen width, and cell wall thickness were measured in the macerated banana pseudo-stalk by microscopy. Slenderness ratio, flexibility coefficient (%) and Runkel ratio were also determined from these microscopic measurements. Mean value of the properties evaluated for *Musa* sp. respectively were as follows: Fiber length- 2.96mm; Fiber diameter- 21.71 $\mu$ m; Lumen width- 13.55 $\mu$ m; Cell wall thickness- 3.86 $\mu$ m; Flexibility ratio- 66.35%; Runkel ratio- 0.66 and Relative fiber length- 159.12. Based on the findings of this study the *Musa* sp. pseudo stalk is suitable for pulp and paper production due to its high quality of fibers.

**Keywords:** Fiber; *Musa* Sp.; Runkel Ratio; Pulp; Pseudo-Stalk**How to cite this paper:**

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## 1. Introduction

Forest conservation and rotational use of forestry and agricultural residues had been major concerns of people generally in recent years [1]. Beginning from 19th century, wood has become one of the major basic raw materials for the production of pulp, paper and fiber-based products. Increasing demand for wood as construction material, furniture, firewood, charcoal, etc. has led to the problem of wood scarcity and deforestation in many countries. Hence, researchers have directed attention to the use of non-wood materials for pulp and paper production [2].

The term “non-wood”, was coined in order to distinguish these plant fibers from the main sources of wood fibers; hardwood and softwood. Non-wood or agro-based fibers are derived from selected cellulosic tissues of various mono or dicotyledonous plants [3]. The use of non-wood fibers for pulp and paper production is an environmentally sound strategy because it requires lesser amount of chemicals needed for pulping. High pulp yields could be achieved within a short digestion time which results in significant savings on energy required for the process. Pulping cellulosic tissues in residues of agricultural produce is a creative and prudent way of encouraging forest conservation through agro-forestry. Banana (*Musa spp.*) is the second largest fruit crop in world is grown in tropical and subtropical regions [4]. It is often cultivated as cover crops for young trees in nurseries and plantations in south-western and south-eastern states of Nigeria. The usage of their pseudo-stalks is been explored for pulp and paper production [5-9].

However, the paper making characteristic of any given pulp is a function of fiber characteristics of the lignocellulosic plant matter. It has been established that fiber morphology is very useful in selecting the right fiber material for pulp and paper making.

[10]. The specific chemical and physical characteristics of the plant materials are very important considerations for development of a viable pulping process, and these have significant technical, ethical, environmental and economic implications for the pulp and paper industry [3]. Hence, evaluation of the fiber and paper characteristics of pulp from banana pseudo-stem is very important in order to address the issues raised above and derive maximum benefits from this underutilized agricultural produce residue as a viable resource for pulp and paper production.

## 2. Materials and methods

### 2.1. Sampling and study area

Samples of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* were obtained from one-year old plants on research farm of the Federal University of Technology Akure, Ondo State, Nigeria. Akure is located on latitude 7°17' N and longitude 5°10' E in the tropical rain forest zone of south western Nigeria with mean annual temperature of 25°C (minimum 19°C and maximum 34°C) and at an elevation of 350 m above sea level with gently undulating platform.

### 2.2. Determination of fiber dimensions

The samples were air-dried and cut to a length of 2 cm, macerated by boiling in water to expel air trapped in the biomass. The boiled matter was then immersed in a mixture of 30% H<sub>2</sub>O<sub>2</sub> and glacial acetic acid at ratio of 1:1 (v/v) maintained at 60°C for 48 hours in test-tubes. The fibers were mounted for measurements under a Leitz stereogram microscope under magnification of ×10 and objective lens eye piece was ×8. The fiber length (L), fiber diameter (D), lumen width (d) and cell wall thickness (CWT) of 5 replicates were determined. Subsequently, morphological indices such as; slenderness ratio, flexibility coefficient (%), and Runkel ratio were calculated from these microscope measurements using equations (1), (2) and (3).

$$\text{Slenderness ratio} = L \div D \frac{\text{fibre length}}{\text{fibre diameter}} \quad (1)$$

$$\text{Flexibility coefficient (\%)} = (d \div D) \times 100 \frac{\text{lumen width}}{\text{fibre diameter}} \times 100 \quad (2)$$

$$\text{Runkel ratio} = \frac{2w}{Lu} = \frac{2 \text{ cell wall thickness}}{\text{lumen width}} \quad (3)$$

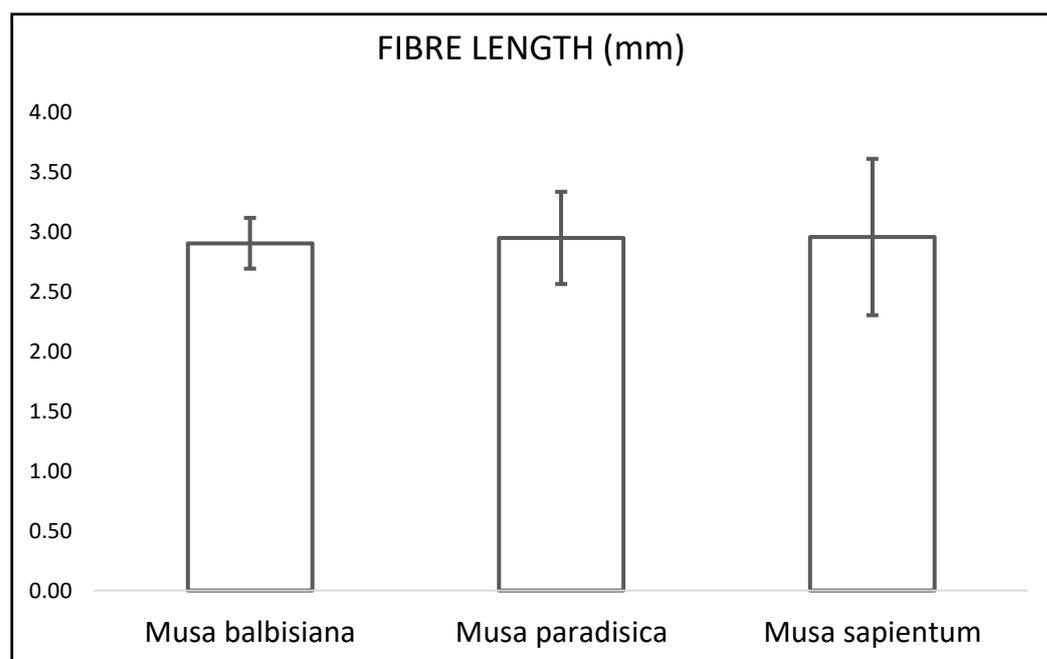
## 3. Results and Discussion

**Table 1. Fiber characteristics of *M. balbisiana*, *M. paradisiaca* and *M. sapientum* pseudo-stalks**

Fiber Characteristics	<i>Musa balbisiana</i>	<i>Musa paradisiaca</i>	<i>Musa sapientum</i>
Fiber length (mm)	2.91± 0.21	2.95±0.39	2.96 ±0.65
Fiber diameters (µm)	22.87 ±3.82	22.29 ±5.14	21.71 ±3.83
Lumen width (µm)	15.85 ±4.97	15.53 ±2.31	13.55 ±3.14
Cell wall thickness (µm)	3.51 ±1.05	3.01 ±2.08	3.86 ±0.56
Slenderness ratio	129.19 ±16.67	134.73 ±15.55	141.26 ±46.12
Runkel ratio	0.50 ±0.25	0.37 ±0.21	0.58 ±0.09
Flexibility ratio (%)	68.27 ±11.40	70.87 ±9.80	62.12 ±4.25

Table 1 shows the fiber characteristics of pulp from banana pseudo-stalk. The table indicates that mean fiber length values of *M. balbisiana*, *M. paradisiaca* and *M. sapientum* pseudo-stalks are 2.91, 2.95 and 2.96 mm respectively. These values are comparable to 2.9 mm reported earlier [11]. Average fiber lengths measured in this study are slightly higher when compared with 2.87mm reported earlier for Nigeria grown *Musa sp* [9]. Figure 1 shows comparison of fiber lengths of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks. The results show that similar fiber lengths in the three species.

However, the mean fiber lengths are greater than that of *Gmelina arborea*, *Eucalyptus torellina* and *Nauclea diderrichii* with reported mean fiber lengths of 1.01mm, 1.14mm and 1.66mm, respectively [12]. These conform to [13] classification that fiber from *Musa sp.* belong to class of long fibers, making it suitable for production of high-quality pulp and paper. This is because, fiber length is proportional to the tearing resistance and tensile strength of a paper. Tensile strength determines folding endurance of the paper [12], and folding endurance is useful in measuring the deterioration of paper upon aging [5]. According to earlier report [5], paper resistance to tear increases with increase in relative fiber length. Thus, papers made from pulp of these pseudo-stalks are expected to have great strength, making them suitable for wrapping, circular pads used in carrying head loads and packing purpose [14].

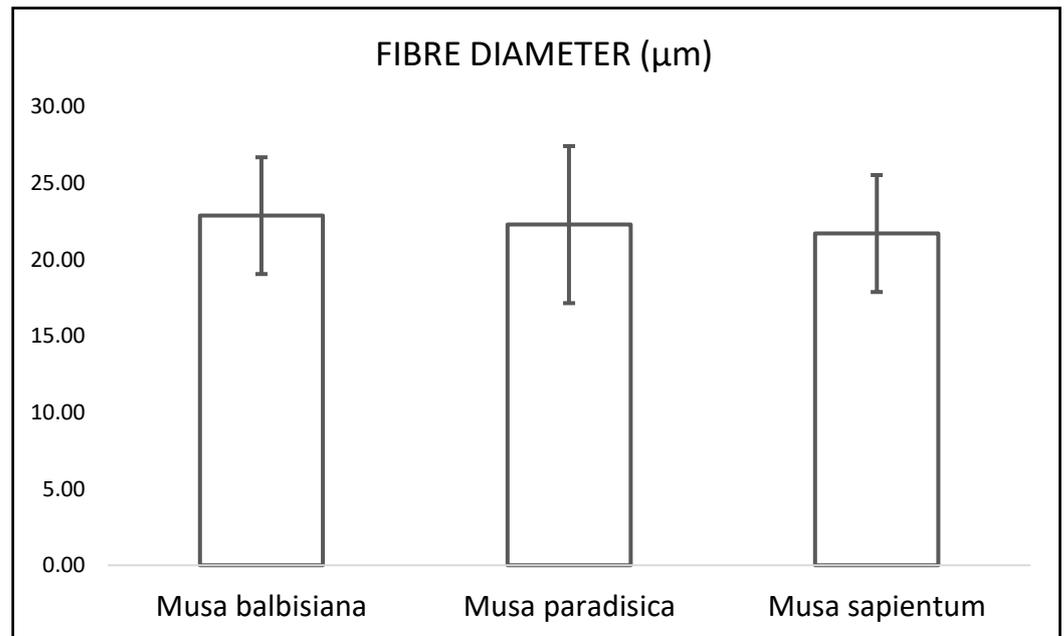


**Figure 1.** Comparison of fiber lengths of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks

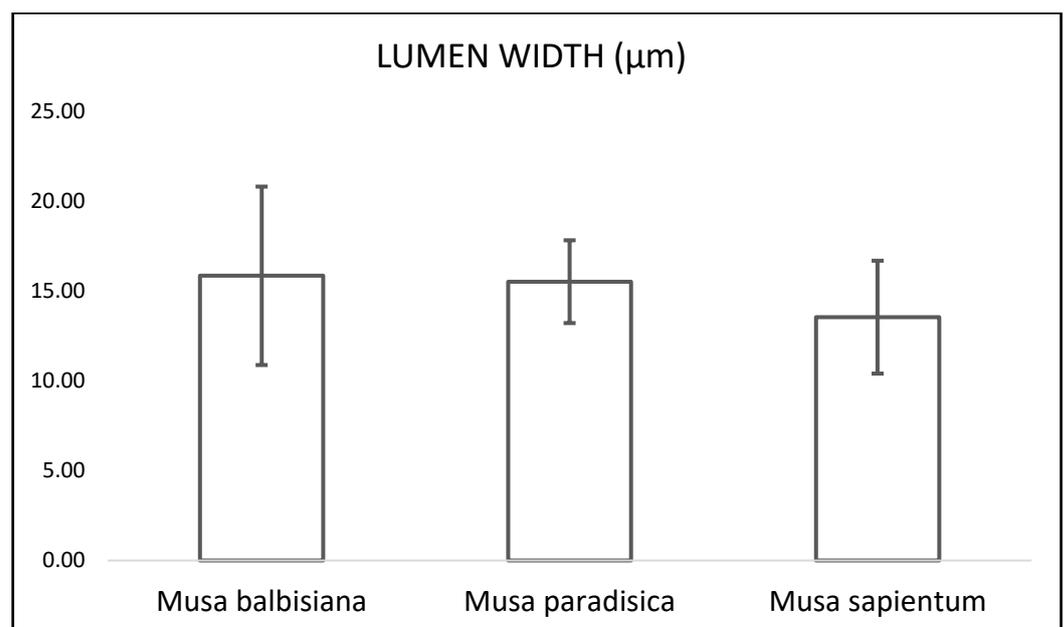
The mean values for fiber diameters are 22.87, 22.29 and 21.71  $\mu\text{m}$  for *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks, respectively (Table 1). These mean values are comparable to values previously reported [9, 11, 15]. The mean values observed in this study for *Musa* species are higher than the mean values reported for *Gmelina arborea*, *Eucalyptus torellina* and *Nauclea diderrichii* as showed by earlier study [12]. Figure 2 shows the comparison of fiber diameters of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks. The results indicate that *Musa paradisiaca* has the highest fiber diameter.

Thin fiber diameter tends to flatten into ribbon during pulping and paper making. It is a good source for fiber for greaseproof paper which is highly hydrated so that the paper is resistant to oil suitable for use in fridge, freezers and microwave oven [15]. From Table 1 above lumen width is 15.85, 15.53 and 13.55  $\mu\text{m}$  for *Musa balbisiana*, *Musa paradisiaca* and

*Musa sapientum* pseudo-stalks, respectively. These mean values agree with the result of previous studies [9, 16]. Figure 3 shows the comparison of lumen widths of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks. The result indicates that *Musa balbisiana* has the highest lumen width. Lumen width determines the Runkel ratio which makes it an important characteristic for evaluation of pulp for paper making. Fiber lumen enhances the beating of pulp and the penetration of the empty space of the fiber if the lumens are larger.

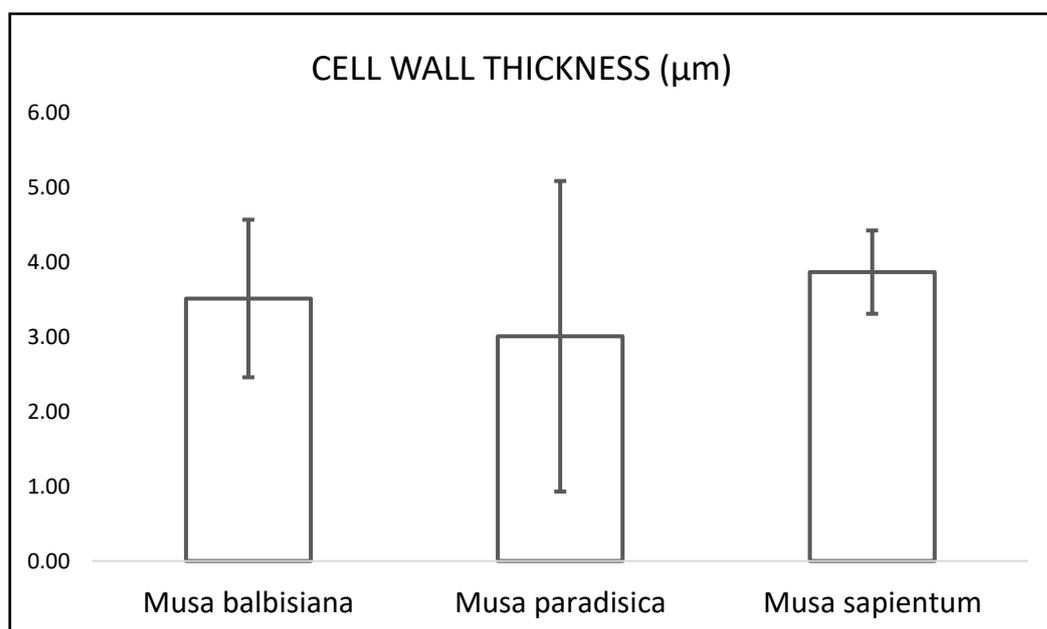


**Figure 2.** Comparison of fiber diameters of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks



**Figure 3.** Comparison of lumen widths of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks

Cell wall thickness from Table 1 above are 3.51  $\mu\text{m}$ , 3.01  $\mu\text{m}$  and 3.86  $\mu\text{m}$  for *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks, respectively. Earlier reports show that mean values of 8.50 $\mu\text{m}$  and 5.50 $\mu\text{m}$  have been recorded for cell wall thickness of *Musa* species [9, 11]. Figure 4 shows the comparison of cell wall thicknesses of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks. The result indicates that *Musa paradisiaca* has the highest cell wall thickness. Also, the cell wall thickness for *Gmelina arborea*, *Eucalyptus torellina* and *Nauclea diderrichii* was 3.00 $\mu\text{m}$ , 5.00 $\mu\text{m}$  and 6.00 $\mu\text{m}$  respectively as documented by previous studies [12]. Cell wall thickness is a good indicator in of determining the strength properties of a material to be considered for pulp production. Cell wall thickness modifies the fiber length in exhibition of paper strength as indicated by previous report [17]. The influence exerted by the cell wall thickness will affect the fiber to fiber bond which determines how bulky of dense the paper is. These thicknesses are important in cards, printing paper, condense paper and saturated paper [18].



**Figure 4.** Comparison of cell wall thicknesses of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks

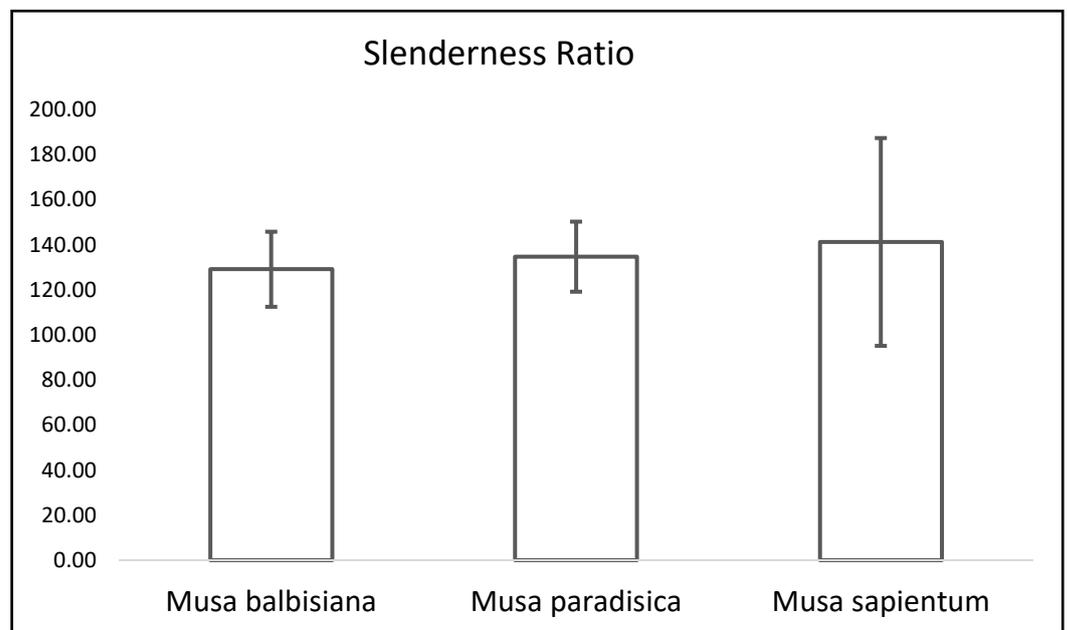
Slenderness ratio from Table 1 above are 129.19, 134.73 and 141.26 *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks, respectively. Earlier studies [13] observed 138.31, 101.98, 120.89 and 114.91 respectively for banana pseudo-stem waste using potassium base pulping process. A high value slenderness ratio provides greater paper formation and well-bonded papers [19]. The slenderness ratio gives indication especially about the tear index [20]. Figure 5 shows the comparison of slenderness ratios of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks. The result indicates that *Musa sapientum* has the highest slenderness ratio.

From Table 1 above, Runkel ratio are 0.50, 0.37 and 0.58 $\mu\text{m}$  *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks, respectively. The mean values from this study is within the range of desirable Runkel ratio, which makes a good source of quality raw material for pulp and paper making. The value is also similar to previous reports [9]. Figure 7 shows the comparison of Runkel ratios of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks. The result indicates that *Musa balbisiana* has the highest Runkel ratio. Runkel ratio is an essential primary parameter required for determining raw material which are suitable for pulp and paper making. According to standard the value

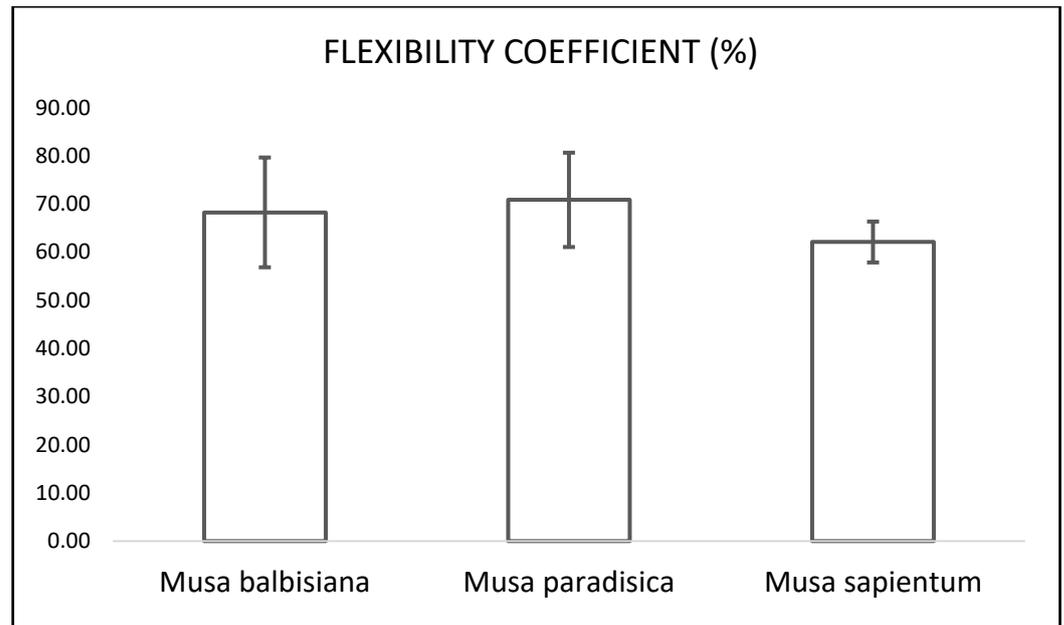
for Runkel ratio must not be more than one (1) to ensure that high quality pulp, in terms of strength, is obtained [21].

The flexibility ratio from Table 1, are 68.27%, 70.87% and 62.12% for *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks, respectively. As reported by earlier studies observed mean values of 55-70% for hardwood [12]. The degree of fiber to fiber bond in paper formation depends mainly on the flexibility and compressibility of individual fiber. Figure 6 shows the comparison of flexibility coefficients of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks. The result indicates that *Musa balbisiana* has the highest flexibility coefficients.

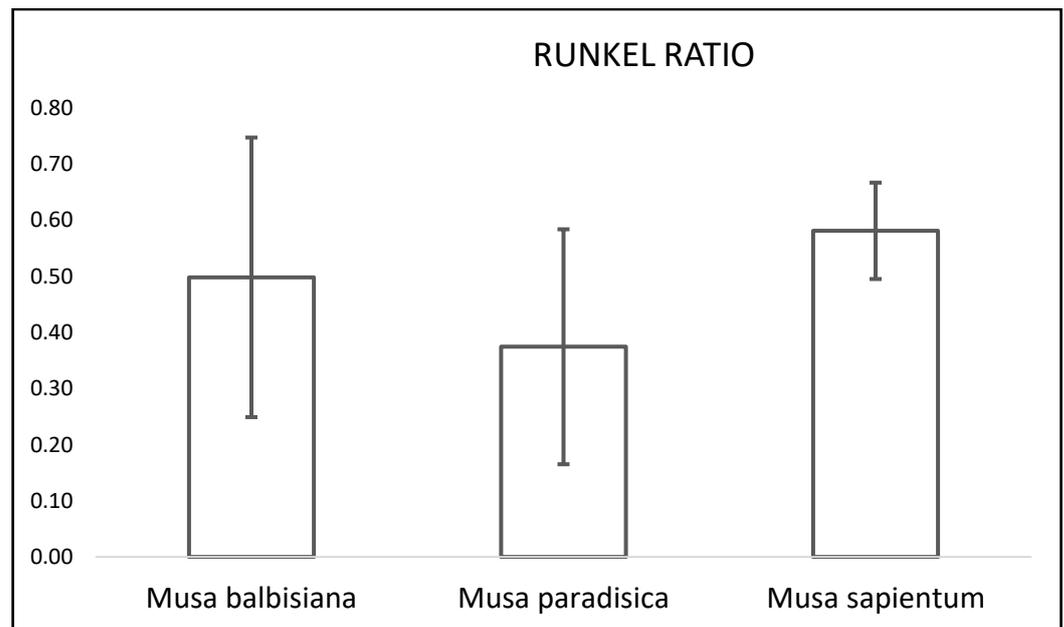
The strength properties of paper such as tensile strength folding endurance and bursting strength are majorly affected by the way in which individual fibers are bonded together in paper sheet. [22, 23]. The higher the value of fiber length to width ratio, the greater the fiber flexibility and the better the chance of forming well bonded paper [22]. The fiber is expected to collapse readily and flatten during beating operation. [23]. It is expected that the pulp made from *Musa sp.* pseudo-stalks will have greater inter-fiber bond and tensile strength typically required for printing papers.



**Figure 5.** Comparison of slenderness ratios of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks



**Figure 6.** Comparison of flexibility coefficients of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks



**Figure 7.** Comparison of Runkel ratios of *Musa balbisiana*, *Musa paradisiaca* and *Musa sapientum* pseudo-stalks

#### 4. Conclusion

Fiber characteristics are an essential factor for determination of any raw material for pulp and paper production. Based on the findings of this study the *Musa sp.* pseudo-stalks are suitable for pulp and paper production due to the high quality of fibers they possess. Its high fiber length will result to high tensile strength good for producing quality paper such as currency note, tea bag and circular pad. The fiber can also be mix with other pulpwood with short fiber length to also produce quality paper.

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