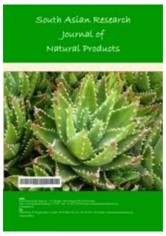

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Physical and Mechanical Properties of Four Banana Cultivars Popularly Grown in Southern Highlands of Tanzania

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Authors' contributions

This work was carried out in collaboration among all authors. All authors designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Natural fibres are considered to be ecofriendly and possess peculiar properties that preserve resources and thus rapidly emerges as novel low-cost materials in several discipline and engineering applications. Even though natural fibres demonstrate admirable potential for various applications, their physical and mechanical properties have been shown to differ with the plant source, species, location and other ecological factors. The present work investigates banana pseudostem physical and mechanical properties for potential fibre extraction from the four cultivars commonly cultivated in the Southern Highlands of Tanzania. Fibres from Matoke, Ndyali, Malindi and Uganda cultivars were manually extracted and experimentally analyzed. Breaking load, elongation, modulus and tenacity which are fundamental mechanical properties for engineering materials were investigated to determine banana pseudo-stem fibre performance. Findings

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revealed higher average values for: Tenacity in Matoke cultivar was 67.27 gf/tex, elongation in Malindi cultivar at 3.5% and modulus in Uganda cultivar of 32.23 GPa. The highest fibre recovery was recorded from Ndyali cultivar at 1.57%. Notwithstanding the priority ranking, the study concluded that all cultivars: Matoke, Malindi and Uganda cultivated in Southern Highlands of Tanzania achieved good tensile properties for potential engineering applications.

Keywords: Banana; pseudostem; physical and mechanical properties.

1. BACKGROUND

Human activities have been shown to have negative environmental impact. Applications of natural materials is considered to reduce this impact to sustainable levels through minimization of waste and pollution and therefore contributing towards achieving poverty reduction and protection of environment. Strengthened efforts owing to environmental concerns, natural resources conservation and mitigation towards agro-waste challenges have catalyzed development of natural materials with emphasis on renewability [1,2,3]. Natural fibres materials application is considered as the best alternative approach to mitigate agro-wastes management challenges which may cause environmental and ecological imbalances [4,5,6]. Natural fibres have numerous benefits compared to synthetic fibres. The benefits of natural fibres includes but not limited to their ability to decompose over time as a result of biological activity, lightweight and abundancy when related to synthetic ones [7]. Natural fibres being renewable, have demonstrated relatively high strength and stiffness and thus considered as suitable for most of engineering applications [8,9,10].

Banana is among plants with a potential for natural fibre extractions mostly from its pseudostem (trunk). Banana being a fast growing, high biomass yielding plant cultivated in more than 120 countries around the globe is among the primary sources of staple food in Tanzania [11,12,13]. Tanzania is among the leading bananas producing countries in the world. Most of banana cultivars grown in Tanzania are endemic to the East African highlands and are primarily distinguished by genome, phenotype and use [12]. The banana plant values lie in its fruit with enormous bio-mass residues yields from the pseudostem and fruit bunch (raquis) being rejected on the field as waste [14] [15,16]. The banana pseudostem is composed of water and other numerous polymers including cellulose, hemicellulose lignin and pectin [17], Pappu et al. [18], Martelli-Tosi et al. [19]. Banana fibres, specifically from pseudostem are recognized as potential engineering materials to enhance the physical and mechanical properties for many environmentally friendly industrial applications [20,21], Pappu et al. [18], Mostafa and Uddin [22], Zhen-Yu et al. [23]. Among different natural fibres, banana fibres from Tanzania are one of the unexplored high potential fibres with limited information in the literature. Natural fibers are naturally available in abundance and are currently beginning to find their way into engineering applications.

Fibers as is the case of other plants species are categorized based on physical and mechanical properties which vary greatly. Physical and mechanical properties may vary even from the same plant specie due to several factors during life cycle such as growing conditions, ripeness, during harvesting, extraction methods, and the transportation and storage [24-28]. In this article, physical and mechanical properties of banana pseudostems from the four cultivars commonly cultivated in the Southern Highlands of Tanzania are presented based on experimental investigations.

2. MATERIALS AND METHODS

2.1 Experimental Setup

2.1.1 Banana pseudostem samples conditions

For the present experimental investigation, banana pseudostem were collected during rainy season from the same location in Mbeya - Southern Highlands of Tanzania to ensure uniform conditions are satisfied [29]. As soon as plants such as banana experience water deficit, physiological, biochemical and molecular scale responses are triggered thus affecting its performance more than any other environmental factors characteristics [30,31].

2.1.2 Study samples selection

Banana pseudostem varieties of genomic group triploid banana cultivars *from* East African highland (AAA-EA) popularly cultivated in the Southern highlands of Tanzania were chosen for investigations of mechanical properties [32], Wairegi and van Asten, [33] Nsemwa et al. [34]. The analysis involved four varieties natively known as Matoke, Ndyali, Ndizi Uganda and Malindi. Three samples from each variety were selected randomly and fibre were extracted layer wise for testing and analysis of obtained data.

2.1.3 Testing conditions

Controlled conditions were applied to conduct all tests under room temperature. Fibres were extracted and sun dried before being stored in plastic bags to avoid changes in physical properties such as dimension, texture and shape which would have otherwise caused greater variation in test results [35]. The testing room was assumed to have small variation in humidity which would have not affected the experimental results. At a temperature of 28.3°C, the variation in humidity were 57.3% RH, 58.2% RH and 55.2% for first, second and third day of testing respectively.

2.1.4 Analysis of data

The analysis of mechanical properties of banana pseudostem involved four properties namely as modulus, elongation and tenacity and linear density to check variation among the varieties and across circular section of each study sample. One-way ANOVA statistical method at 95% confidence interval level was used in the data analysis. ANOVA has been selected considering its capability in comparing differences of means among more than 2 groups. ANOVA does comparison analysis by observing the variation in the data and where that variation is found.

2.2 Apparatuses

The following apparatuses were employed to achieve the study objectives:

i). Machete, tape measure, weighing scale, notebook, digital camera and a car were used to collect study samples and record some observations.
ii). Drying oven to determine general overview of water content in the banana pseudostem study samples.
iii). Scraping blunt blade and a squeezing roller were designed and manufactured locally for extracting fibres from banana pseudostem.
iv). A paper tab by help of Polyvinyl Chloride (PVC) clear cement were used to hold fibre specimen for easy mounting between clamps.
v). ZWICK/010 Tensile Testing Machine was employed to determine tensile properties of extracted banana fibre [36,37].
vi). Microsoft office Excel 2016 and Statistical Package for Social Science (SPSS 20) computer software were used to analyze obtained data.

2.3 Materials

2.3.1 Study samples collection

A total of twelve banana pseudostem samples were collected, three from each variety (Matoke, Ndyali, Malindi and Uganda). The samples were collected from Kiwira village and transported to Uyole in Mbeya for fibre extraction and other basic preparations. During sample collection physical properties such as length, weight, diameters, number of layers and number of sheaths were recorded. The samples selection was done randomly from different fields within Kiwira village. The banana pseudostem was cut approximately 10 cm above the ground followed by the removal of all leaves and cleaning of black-brown dry outer sheaths. Thereafter, the banana pseudostem was for convenience of transport and fibre extraction cut to one meter in length, approximately 30 cm from the stem-end ready. The 30 cm from the stem-end were estimated to clear out a zone where the layout of sheath layers was not clearly identified.

2.3.2 Moisture content determination

A ring section at the center of each sample was cut and immediately stored in a separate plastic bag to protect it from any possible moisture content changes. The specimens were weighed to the accuracy of 0.1 gram and after that oven dried. Drying temperature in the oven was set at 103^{o}C for 24 hours as per ASAE S358.1 - moisture measurement-forages [38], Whalley et al., [39]. Weightings were carried out using an analytical balance immediately after specimen removal from the oven, with an accuracy of 0.01 gram in order to determine the dry weight for determination of moisture content using equation 1:

$$WC_{(wb)} = \frac{M_t - M_d}{M_t} \times 100 \quad (1)$$

Where,

$WC_{(wb)}$ = Water Content wet basis, percent.
M_d = Specimen dry weight
M_t = Specimen total weight

2.3.3 Fibre scraping

Fibre used in this study were extracted from the banana pseudostem using 'hand scraping' method as it is cheap, convenient and offers a good quality raw fibre [15,40] Hand scraping process was carried out in two stages in which few strips of banana sheaths were used for trial extraction to check the effect of water content and scraping tool, on fibre extraction. Some sheaths were extracted while in fresh state while some were left for one day under shed to drain water and become withered. Stage one extraction results led to actual extraction.

In stage two, the extractable pseudostem were weighed before there were made into separate sheaths. All extractable sheaths from each layer were weighed and placed for fibre extraction. The extraction process required a wooden bench and a sheath squeezing equipment. A hand driven squeezing roller was made locally to assist the scraping process. Each sheath was made into strips of about 7cm wide and passed through the roller for squeezing then brought on the wooden bench for scraping. A blunt flat steel bar was welded in T- shape and therefore used to scrap the sheath until it was free from vegetative matter.

2.3.4 Fibre recovery determination

Banana fibres from the extraction process were sun dried and stored in plastic bags to avoid moisture contamination and damage. Fibre extracted from each layer of the banana trunks were weighed and recorded to 0.01 g precision and the fibre recovery percent were calculated using equation 2.

$$\text{Fibre recovery (\%)} = \frac{\text{Weight of fibre}(g)}{\text{Weight of extractable sheath}(g)} \times 100 \qquad (2)$$

2.4 Experimental Procedure

2.4.1 Specimens preparation

The extracted banana fibres were stored in plastic bags and all precautions were taken to ensure the fibres are not under any load to avoid damage which could change physical properties. Specimens for tensile testing were prepared according to ASTM D 3822 standard preparation procedure [41,42]. Specimens preparations were done during the day time and left overnight to ensure curing of glue and acquire environment equilibrium before testing. Single fibre filament specimen was selected randomly and carefully separated from the bundle and glued onto a paper tab as depicted in the Fig. 1. The gauge length defines distance between the tabs. Several trials were done to identify proper glue or adhesive material which cure for short time and that ensures non slippage.

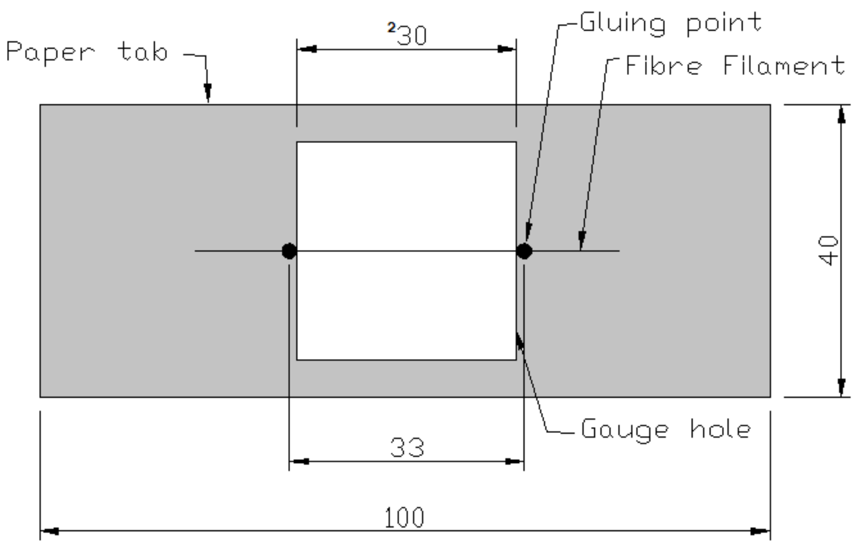

Fig. 1. Fibre specimen mounting in a paper tab
(*All units in mm*)

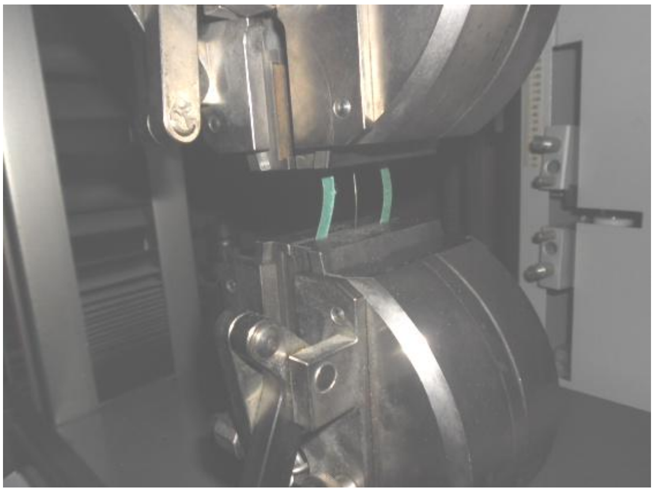

Fig. 2. Specimen mounted on ZWICK/010 tensile testing machine clamp

2.4.2 Tensile test

A total of three hundred and eighty pseudostem fibre samples were tested according to ASTM D 3822 standards using ZWICK/010 (Zwick GmbH & Co. KG, Germany) tensile testing machine. The machine had adequate response to record modulus of rigidity, maximum force at break, elongation at maximum force and stress-strain curve of fibre under test. Two points of stress were set on the machine to determine the modulus. The distance between the clamps was adjusted to achieve the gauge length of 30 mm and test speed was set to 30 mm/min. Each test specimen was mounted in the clamp jaws for test as depicted in Fig. 2. Precautions were taken to ensure fibre specimen was straight within the jaws and that it lies on the line of action between the force measuring sensors. After proper clamping, side bands of paper tab were cut to ensure only the fibre specimen was pulled. Then machine was set to pre-load the specimen at 2 cN/tex and pre-load speed of 120 mm/min without stretching the specimen. The tensile testing machine was then switched on. The machine was also set to return to its starting point and to zero the force after breaking the specimen. The same procedure was repeated until all specimens were tested.

2.5 Fibre Linear Density

Each unstrained fibre filament specimen was cut to 105 mm and weighed on an analytical balance to a precision of 0.1 mg. Calculations of fibre linear density which is mass per unit length was done using equation 3.

$$\text{Linear density} = M_s \times \left(\frac{1000}{L}\right), \text{tex} \quad (3)$$

Where,

M_s = mass of fibre filament specimen
L = length of fibre filament specimen

Tex is a measurement of linear mass density of fibres (mass in grams per 1000 meters) [43].

2.6 Breaking Tenacity

Therefore, the breaking tenacity of the individual unstrained fibre specimen was calculated using the equation 4 and expressed in gf/tex.

$$\text{Breaking tenacity} = \frac{M}{T} \quad (4)$$

Where

M = breaking force, in grams-force, and
T = linear density, in tex

Tenacity is a measure of strength of a fibre or yarn. It is defined as the breaking (maximum) force of the fibre divided by the linear density [7].

2.7 Characterization of Banana Pseudostem Samples

Based on fundamental tensile properties, the banana pseudostem varieties were characterized for their potentiality on fibre extraction and end use limitations.

3. RESULTS AND DISCUSSION

3.1 General Physical Properties

Pseudostems from banana typically cultivated in the Southern Highlands of Tanzania exhibited slight variation on the number of layers as depicted in Table 1. Study samples collected showed that Ndyali and Malindi had equal number of layers whereas Matoke had the least number. The number of sheaths varied among the cultivars of with a greater number observed was in Ndyali as compared to Matoke, Uganda and Malindi. From the four banana pseudostems cultivars, Matoke was observed to have the lowest number of sheaths followed by Uganda. Observation of physical properties concluded that the number of sheaths vary from one cultivar to the other due to central core size.

3.2 Moisture Content Results

The highest average water content (MC) as depicted in Table 1, was determined as 87.46% from Matoke followed by Malindi and Uganda with the least being from Ndyali at 81.33%. The study findings showed that the MC for all the cultivars to be less than 90%. This study findings agrees with similar results which shows an average values of 75% [44] and as reported in Okelana [45], Li et al. [46] and Souza et al. [47]. The MC variations from both studies are presumed to be primarily due to age of the plant and season the samples were harvested.

3.3 Fibre Extraction Results

The trial fibres extraction exercise revealed the effect of scraping tool and water content in the sheaths. A sharp edge of metal bars that was used in finding the effectiveness of scraping seemed to damage fibres. Through several trials, blunt metal edges gave good results of the scraping process and damage to fibre was very minimal. Similarly, it was noted that scraping tool can affect the fibre yield. The water content from the study samples also showed to have effect on extraction process. There was an ease extraction with the freshly sheaths compared to withered sheaths as depicted in Fig. 3. The fibre color varied with water content as the freshly sheaths gave whiter fibre than withered sheaths.

Data obtained from weighing the extractable sheaths are depicted in Table 2. Upon removing dry brown and all damaged sheaths, a minimum of four and maximum of eight layers were obtained among the varieties for fibre extraction. High average extractable weight was recorded from Uganda variety. Manual scraping process was tedious and time consuming although it gave fibre in its raw form.

3.4 Fibre Recovery Results

Results of fibre yield and recovery percent by manual scraping method showed the highest recovery of the extractable weight as 1.57 % obtained from Ndyali cultivar, followed by Matoke at 1.12% and the lowest was recorded from

Table 1. Banana pseudostems physical properties

Variety	Sample	Weight (kg)	Diameter (mm)			Length (m)	No. of layers	No. sheaths	MC (% Wb)
			Bottom	Mid	Top				
Matoke	M1	55.00	200	160	100.00	4.70	8.00	14	82.8
	M2	56.00	190	155	110.00	4.00	7.00	15	95.1
	M3	37.00	140	115	80.00	3.90	5.00	10	84.5
	Average	49.33	176.67	143.33	96.67	4.20	7	13	87.5
Ndyali	N1	55	230.00	180.00	100.00	3.90	10.00	22	82.6
	N2	37	190.00	130.00	90.00	3.70	8.00	16	89.3
	N3	40	190.00	140.00	100.00	4.20	9.00	17	72.1
	Average	44	203.33	150.00	96.67	3.93	9.00	18	81.3
Malindi	Ma 1	62.00	250.00	200.00	140.00	3.20	8.00	18	83.0
	Ma 2	70.00	270.00	200.00	140.00	3.30	8.00	17	88.2
	Ma 3	68.00	240.00	180.00	120.00	3.80	8.00	16	89.8
	Average	66.67	253.33	193.33	133.33	3.43	9.00	17	87.0
Uganda	U1	85.00	250.00	200.00	130.00	4.70	8.00	16	83.9
	U2	60.00	240.00	150.00	120.00	4.35	9.00	15	79.5
	U3	55.00	200.00	140.00	110.00	4.50	8.00	13	83.7
	Average	66.67	230.00	163.33	120.00	4.52	8.00	15	82.3

Fig. 3. Fibre from fresh sheaths (left) and withered sheaths (right)

Table 2. Weights of extractable sheaths (kg)

Layers	**Banana varieties**											
	Matoke			**Ndyali**			**Malindi**			**Uganda**		
	M1	**M2**	**M3**	**N1**	**N2**	**N3**	**Ma1**	**Ma2**	**Ma3**	**U1**	**U2**	**U3**
1	5.1	2	2	2.5	2	2.5	4	2.25	2.5	3	4	2.25
2	2	2.5	1.75	2	2	2	2.5	2	2.5	2.5	4	2.25
3	1.8	1.5	1.75	2	1.5	2	2.25	2	2.5	2	3	2
4	1.8	2	2	1.5	1.4	1.6	2.25	2	2.25	2.25	3	2
5	1.7	2	0	1.25	1	1.2	2.25	2	2.25	2	2	2
6	0.6	2	0	1.25	1	1	2	1.2	2	2.25	0	0
7	0.5	0	0	1.25	1	1	0.75	1	1.5	0.7	0	0
8	0	0	0	1.25	0	0	0	0	0	0	0	0
	13.5	12	7.5	13	9.9	11.3	16	12.45	15.5	14.7	16	10.5
Core weight	5	4.5	2.5	4	3	2.9	4	4	4.5	5.5	6	5
Total (Kg/m))	32	28.5	17.5	30	22.8	25.5	36	28.9	35.5	34.9	38	26
Aver. gross wt. (Kg/m)	26			26.1			33.47			32.97		
Average extractable weight (kg)	11			11.4			14.65			13.73		

Uganda at 1%. The range of these results falls within 0.80 to 2.71%.as reported in Preethi and Balakrishna Murthy [48]. These results show that there is significant difference in fibre yield and recovery between the studied varieties. From this study, factors like number of sheaths, size of central core, moisture content of sheaths were observed to affect fibre yield. Some of these factors are presumed to vary due the nature of variety and others due to soil fertility and plants care. Generally, the quantity and quality of fibre depended on the number, width and location of each sheath in the banana pseudostem. The fibre yield results of this study a potential for future commercial production of banana pseudostems fibres.

3.5 Tensile Test Results

Tensile testing results and calculated properties of banana fibre from three hundred and eighty samples of fibre chosen randomly from banana fibre collection at respective extractable layers of each variety are presented in Table 3. These results demonstrate that fibre from Uganda cultivar were coarse and stiffer than all cultivars investigated. The results reveal higher extensibility in Malindi cultivar followed by Matoke and Uganda cultivars. In this study, the range of tensile strength results are within those reported in Mwaikambo [49] and that of Kulkarni et al. [50] which were 529-914 MPa, 27-32 GPa and 1-3%; 711-930.734 MPa, 27-32 GPa, and 2.47-3.58%, in breaking stress, Young's Modulus and breaking strain respectively. Furthermore, results in Table 3 depicts that fibres with higher stiffness exhibit medium breaking elongation and therefore banana fibres are stiff and ductile which might be the effect of cellulose content [51].

Interrelated strength properties of banana pseudostems cultivated in the Southern

Highlands of Tanzania are depicted in Table 4. The properties show that the stiffness of fibres in all banana cultivars decrease from outer to inner part of the banana trunk, while elongation at break increases as indicated in Figs. 4 and 5. This reveals that, inner fibres from all cultivars exhibit lower force at break as compared to fibres from outer sheaths. Uganda cultivar fibres exhibit higher fibre modulus and elongation which contribute to potential stiffness and flexibility properties for composites. The variation of these tensile properties along the layers may render a room for making a composite of varied properties. However, Malindi and Ndyali cultivars seem to be better for handicraft activities such as table mats, wall hangings among others as they have showed good elongation and fibre fineness.

Statistical analysis using ANOVA-one way at $p \le 0.05$ or 95% significance level, as shown in Table 5 the overall results show that there was a significance difference for all banana cultivars in linear density, E-modulus, elongation, strength, load and breaking tenacity. Moreover, one-way ANOVA analysis between layers revealed that, the properties were different in each layer except for tenacity as explained. There was a significant difference between the layers (3,56) = 3.265, p = 0.028; $F(6,98) = 8.108$, $p = 0.001$; $F(5,84) = 7.686$, $p = 0.001$; and $F(4,70) = 2.944$, $p = 0.026$ in elongation for Matoke, Ndyali, Malindi and Uganda cultivars respectively. Furthermore, there was great difference in modulus $F(6,98) = 3.830$, $p = 0.002$; $F(5,84) = 6.638$, $p = 0.001$ and $F(4,70) = 6.939$, $p = 0.001$; for Ndyali, Malindi and Uganda cultivars respectively, except that there was no significance differences $F(3,56) = 2.029$, $p = 0.120$ for matoke cultivar.

3.6 Fibre Linear Density

Banana pseudostems fibres linear density was calculated for each cultivar and results were obtained as shown in Tables 6 and 7. The results depict a higher linear density for Uganda cultivar against almost similar values for Malindi, Matoke and Ndyali cultivars. This reveals that fibres from Uganda cultivars are heavier than all tested samples. Likewise, the results show that linear density vary significantly between layers for all cultivars with the inner having higher tex than the outer ones.

3.7 Breaking Tenacity

Fibre tenacity results for banana pseudostems are depicted in Table 8 and Table 9. Tenacity was revealed to be higher in Matoke cultivar at 67.23 gf/tex followed by Uganda (62.04 gf/tex), Ndyali (58.85 gf/tex) and Malindi (55.70 (gf/tex) cultivars. The results also show there was no

Table 3. Tensile properties of banana pseudostems fibres

Mechanical properties		Banana cultivars			
		Matoke	**Ndyali**	**Malindi**	**Uganda**
Young's Modulus (N/mm^2)	Minimum	18996.24	17852.44	22744.75	25537.65
	Maximum	38639.83	31060.48	33455.78	38062.61
	Average	28781.25	26122.57	28556.92	32235.08
	Std. Dev.	5745.16	3324.77	3211.61	4087.30
	C.Var.	0.20	0.13	0.11	0.13
Breaking elongation (%)	Minimum	2.5	2.7	2.7	2.8
	Maximum	4.0	3.5	4.3	3.8
	Average	3.2	3.1	3.5	3.2
	Std. Dev.	0.41	0.23	0.40	0.30
	C.Var.	0.13	0.07	0.11	0.09
Breaking stress (N/mm^2)	Minimum	679.97	493.91	823.64	818.16
	Maximum	1347.72	1043.62	1139.25	818.16
	Average	886.74	805.09	979.03	1010.97
	Std. Dev.	169.51	148.26	111.20	102.37
	C.Var.	0.19	0.18	0.11	0.10
Breaking load (N)	Minimum	8.53	7.86	9.66	8.85
	Maximum	12.10	12.46	12.76	14.03
	Average	10.67	9.63	11.25	12.33
	Std. Dev.	1.02	1.14	0.88	1.31
	C.Var	0.09	0.12	0.08	0.11

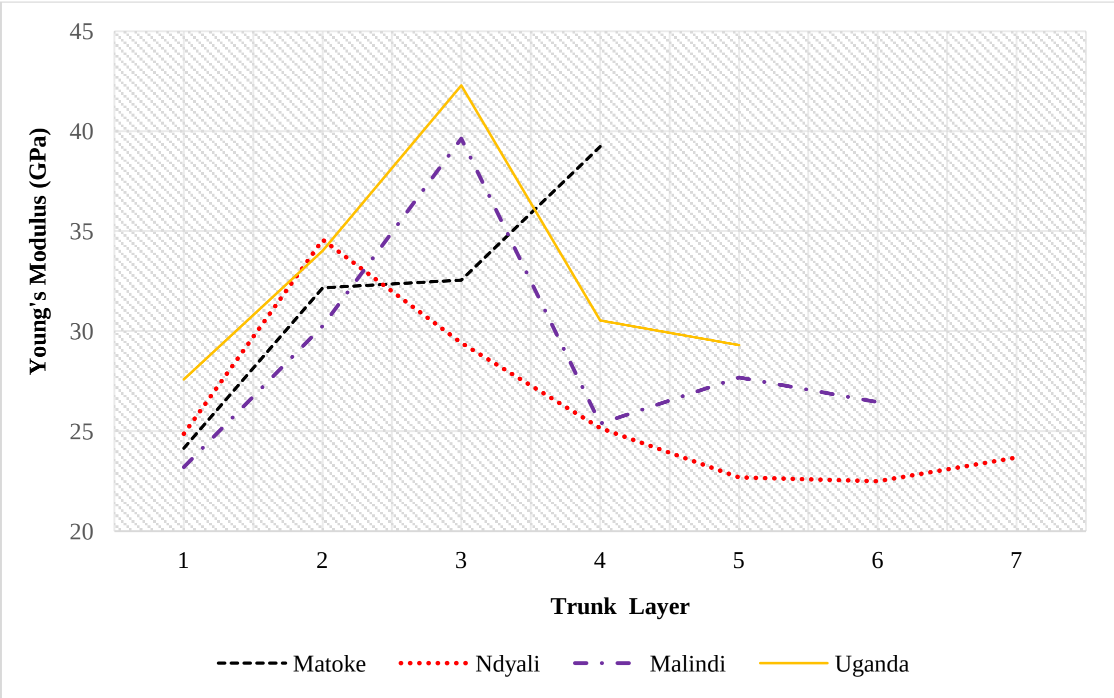

Fig. 4. Young's modulus comparisons among layers

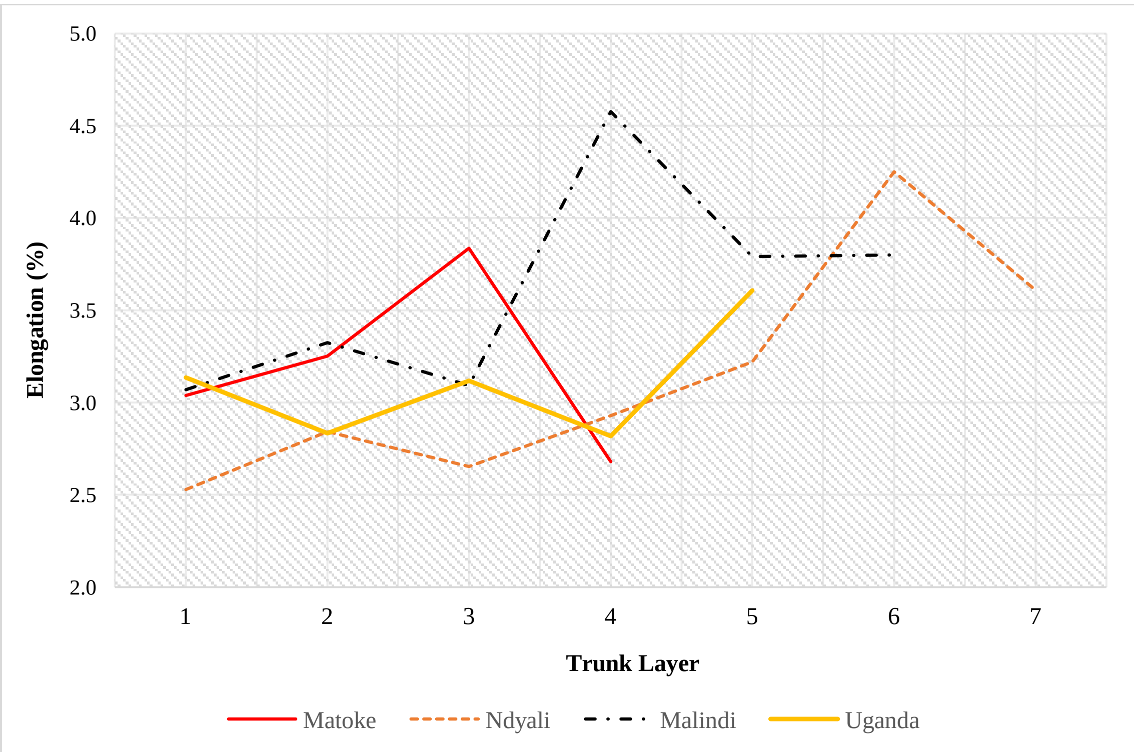

Fig. 5. Elongation comparisons among layers

significant differences of tenacity among layers, $F(3,56) = 1.348$, $p = 0.268$; $F(6,98) = 1.870$, $p = 0.94$; $F(5,84) = 0.014$, $p = 1.000$ and $F(4,70) = 0.620$, $p = 0.650$ in Matoke, Ndyali, Malindi and Uganda cultivars respectively. However, the trend of tenacity (strength) was seen decreasing as moved from outer layers towards inside layers.

Table 4. Young's modulus values across layers (n/mm^2)

Variety		L1	L2	L3	L4	L5	L6	L7
Matoke	Min	10502.8	15199.3	22627.0	12325.6	19535.6	12683.9	14131.8
	Max.	37106.0	59215.6	51197.3	61848.2	42965.6	35061.1	34633.6
	Aver.	24147.1	32160.9	32548.3	32556.0	30813.7	25523.0	27136.9
Ndyali	Min	10879.5	26518.8	11706.2	12627.1	6664.9	9104.8	10669.7
	Max.	46764.2	47988.9	50154.9	37764.3	44774.4	42699.9	33235.0
	Aver.	24859.8	34572.4	29410.4	25150.9	22692.3	22490.9	23681.3
Malindi	Min	13859.0	19325.5	15167.1	4653.8	14573.0	13511.4	16012.1
	Max.	37910.0	44576.9	64027.8	38559.8	44277.0	37854.5	31624.5
	Aver.	23201.3	30270.2	39630.4	25374.6	27680.6	26446.6	26196.4
Uganda	Min	14352.6	25071.7	27278.5	11821.9	21802.8	18363.2	15884.4
	Max.	44511.7	49238.6	56713.1	53532.2	45740.1	34584.0	38051.1
	Aver.	27589.2	34028.7	42284.7	30541.1	29296.6	26547.8	26121.8

Table 5. Properties comparison among banana cultivars using one-way ANOVA

Parameter being compared	Comparison in variety of banana fibres	P - Value	Overall p-value
Young's Modulus	Matoke Vs Ndyali	0.324	
	Matoke Vs Malindi	0.999	
	Matoke Vs Uganda	0.127	0.003
	Ndyali Vs Malindi	0.402	
	Ndyali Vs Uganda	0.001	
	Malindi Vs Uganda	0.093	
Breaking Elongation	Matoke Vs Ndyali	0.986	
	Matoke Vs Malindi	0.042	
	Matoke Vs Uganda	1.000	0.011
	Ndyali Vs Malindi	0.017	
	Ndyali Vs Uganda	0.988	
	Malindi Vs Uganda	0.040	
Breaking Stress	Matoke Vs Ndyali	0.360	
	Matoke Vs Malindi	0.255	
	Matoke Vs Uganda	0.069	0.001
	Ndyali Vs Malindi	0.005	
	Ndyali Vs Uganda	0.001	
	Malindi Vs Uganda	0.917	
Breaking Load	Matoke Vs Ndyali	0.056	
	Matoke Vs Malindi	0.476	
	Matoke Vs Uganda	0.004	0.001
	Ndyali Vs Malindi	0.001	
	Ndyali Vs Uganda	0.001	
	Malindi Vs Uganda	0.166	
Breaking Tenacity	Matoke Vs Ndyali	0.065	
	Matoke Vs Malindi	0.005	
	Matoke Vs Uganda	0.404	0.007
	Ndyali Vs Malindi	0.776	
	Ndyali Vs Uganda	0.769	
	Malindi Vs Uganda	0.231	
Linear Density	Matoke Vs Ndyali	1.000	
	Matoke Vs Malindi	0.001	
	Matoke Vs Uganda	0.001	
	Ndyali Vs Malindi	0.001	0.001
	Ndyali Vs Uganda	0.001	
	Malindi Vs Uganda	0.491	

Table 6. Linear density values among banana varieties

Property		Matoke	Ndyali	Malindi	Uganda
Linear Density K g/1000 m (tex)	Minimum	14.76	14.01	18.50	16.76
	Maximum	19.86	20.68	23.81	29.71
	Average	17.56	17.61	21.27	22.59
	Std. Dev	1.60	2.24	1.49	3.99
	C.Var.	0.09	0.13	0.07	0.18

Table 7. Linear density values across layers (tex)

Variety		L1	L2	L3	L4	L5	L6	L7
Matoke	Min	11.43	15.24	14.29	9.52	5.71	9.52	10.48
	Max.	18.10	33.33	28.57	29.52	39.05	27.62	30.48
	Aver.	14.92	21.02	21.59	19.62	16.86	11.14	11.81
Ndyali	Min	10.48	11.43	9.52	6.67	8.57	8.57	13.33
	Max.	24.76	27.62	27.62	26.67	25.71	28.57	23.81
	Aver.	18.20	17.14	16.06	16.63	15.56	20.19	19.49
Malindi	Min	8.57	13.33	18.10	20.95	17.14	14.29	12.38
	Max.	18.10	33.33	28.57	29.52	39.05	27.62	30.48
	Aver.	14.22	21.90	23.62	24.70	22.98	20.57	20.00
Uganda	Min	11.43	15.24	10.48	8.57	17.14	18.10	7.62
	Max.	30.48	29.52	58.10	26.67	30.48	24.76	10.48
	Aver.	19.37	21.65	32.57	18.73	24.38	21.33	9.14

Table 8. Tenacity values among banana cultivars

Property		Banana cultivars			
		Matoke	Ndyali	Malindi	Uganda
Breaking Tenacity (gf/tex)	Minimum	48.59	43.92	40.85	47.83
	Maximum	87.32	71.43	63.36	80.81
	Average	67.23	58.85	55.70	62.04
	Std. Dev.	10.92	7.65	7.4	9.71
	C.Var.	0.16	0.13	0.13	0.16

Table 9. Tenacity values across pseudostems layers (gf/tex)

Banana cultivar	Banana pseudostems fibres layers							
		L1	L2	L3	L4	L5	L6	L7
Matoke	Min	24.28	26.89	28.19	17.36	26.07	75.76	49.24
	Max.	119.80	92.18	95.83	73.53	196.76	127.48	104.09
	Aver.	64.94	64.01	61.40	50.69	77.89	98.55	84.05
Ndyali	Min	21.00	31.00	14.50	27.29	19.59	35.03	35.89
	Max.	73.56	110.24	124.84	98.32	91.51	79.87	65.05
	Aver.	46.02	67.23	63.43	63.15	58.92	56.64	56.55
Malindi	Min	24.35	32.72	24.91	39.07	32.51	27.20	23.59
	Max.	114.41	107.53	76.19	71.89	87.77	78.23	94.93
	Aver.	57.12	57.32	55.84	56.76	57.19	57.02	49.11
Uganda	Min	39.29	42.58	42.58	28.32	37.63	54.31	135.93
	Max.	105.35	.58	91.58	93.23	65.50	76.08	151.45
	Aver.	61.69	59.04	59.04	54.48	53.92	66.01	142.91

3.8 Tensile Properties Characterization of Banana Pseudostems

The characterization of banana cultivars grown in southern highlands of Tanzania showed difference in their tensile properties. The analysis of fibres from banana cultivars demonstrated a significant difference in terms of tenacity, Young's modulus and elongation among the four as depicted in Table 10. It has also been shown that the physical and mechanical properties of plants vary with plant varieties and geographical conditions as reported in Asim et al. [52] Rowell et al. [53], Glinski [54] and Omotoso and Ogunsile [55].

Table 10. Fundamental properties differences among banana cultivars

Fundamental property	Banana cultivars			
	Matoke	**Ndyali**	**Malindi**	**Uganda**
Tenacity (gf/tex) (% Change)	48.59 – 87.32 (79.71)	43.92 – 71.43 (63.77)	40.85 – 63.36 (55.10)	47.83 – 80.81 (68.95)
Young's Modulus (GPa) (% Change)	18.99– 38.64 (103.46)	17.85 – 31.06 (74)	22.74 – 33.45 (47.1)	25.54 – 38.06 (49.02)
Elongation (%) (% Change)	2.5 – 4.0 (60)	2.7 – 3.5 (80)	2.7 – 4.3 (160)	2.8 – 3.8 (135)

Table 11. Comparison of natural fibres and synthetic properties

Fibre type	Tensile strength (MPa)	Tensile modulus (GPa)	Elongation (%)	References
Banana	529 - 914	27 - 32	1 - 3.2	Indira et al. [56] & Mwaikambo [49]
Banana pseudostems	494 - 1348	17.85 - 38.64	2.5 – 4.3	Present work
Jute	200 - 773	2.5 – 55	1.5 – 3	Kozlowski et al. [57] & Mwaikambo [49]
Flax	345 - 1200	27.6 - 100	2 - 3.3	Kozlowski et al. [57] & Mwaikambo [49]
Kenaf	295 - 1191	22 - 60	1.6 – 3.5	Kozlowski et al. [57]
Coir	106 - 175	4 - 6	15 - 40	Al-Bahadly [58] & Mwaikambo [49]
Abaca	12	41	3.4	Mwaikambo [49]
Sisal	80 - 840	9 - 22	2 - 14	Mwaikambo [49]
Cotton	287 - 800	5.5 - 12.6	6 - 8	Mwaikambo [49]
E-Glass	2000 - 3500	70 - 73	2.5	Rejab et al. [59]
Carbon	4000	230 - 240	1.4 -1.8	Al-Bahadly [58]

Fibre tensile properties comparison between the findings of the present study with other natural fibres and synthetic fibres is depicted in Table 11. It is observed that, the tensile strength and the tensile Young's modulus of banana fibre as determined from this study were lower compared to those of synthetic fibres (E-Glass and Carbon). Nevertheless, elongation of banana fibres were determined to be higher than synthetic fibres. In relation to other natural fibres, banana fibre from this study showed higher elongation range except for coir fibre which differed greatly in all properties.

4. CONCLUSIONS

The study investigated suitability of banana pseudostems fibres from four cultivars popularly grown in the Southern Highlands of Tanzania. Fibres from Matoke, Ndyali, Malindi and Uganda cultivars were manually extracted and experimentally examined to determine physical and mechanical properties. The following conclusions were drawn:

- The manual method of fibre extraction showed a positive trend of fibre yield but it cannot be recommended for mass production because it is tedious and time consuming.
- The study findings showed that the moisture content for all the cultivars to be less than 90% which agrees to similar studies.
- The number of bananas pseudostems sheaths varied among the cultivars primarily due to central core size.
- Tensile test results demonstrated that fibre from Uganda cultivar were coarse and stiffer than all with higher breaking tenacity observed in Matoke cultivar. The results further revealed higher extensibility in Malindi cultivar followed by Matoke and Uganda cultivars.
- The percentage of fibre recovery is only about 1% therefore the large proportion is still considered as a waste and therefore recommends further study on the usefulness of the remaining.

- Fibre linear density results show significant variations between layers for all cultivars with the inner layers having higher tex than the outer ones.

The results from present work demonstrated that the banana cultivars grown in the Southern Highlands of Tanzania achieved good tensile properties for potential fibre extraction.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Jawaid M, Khalil HA. Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. Carbohydrate Polymers. 2011;86 (1):1-18.
2. Kannan P, Arunachalam P, Prabukumar G, Govindaraj M. Biochar an alternate option for crop residues and solid waste disposal and climate change mitigation. African Journal of Agricultural Research. 2013;8(21):2403-2412.
3. Amir N, Abidin KAZ, Shiri FBM. Effects of fibre configuration on mechanical properties of banana fibre/PP/MAPP natural fibre reinforced polymer composite. Procedia Engineering. 2017;184(573-580).
4. Thakur VK, Thakur MK. Processing and characterization of natural cellulose fibers/thermoset polymer composites. Carbohydrate Polymers. 2014;109(102-117).
5. Väisänen T, Haapala A, Lappalainen R, Tomppo L. Utilization of agricultural and forest industry waste and residues in natural fiber-polymer composites: A review. Waste Management. 2016;54(62-73).
6. Chattopadhyay S, Pan N, Roy A, Samanta K. Pretreatment of jute and banana fibre — its effect on blended yarn and fabric. Journal of Natural Fibers. 2020;17(1):75-83.
7. Saheb DN, Jog JP. Natural fiber polymer composites: A review. Advances in Polymer Technology: Journal of the Polymer Processing Institute. 1999;18(4): 351-363.
8. Kalia S, Dufresne A, Cherian BM, Kaith B, Avérous L, Njuguna J, Nassiopoulos E. Cellulose-based bio-and nanocomposites: A review. International Journal of Polymer Science; 2011.
9. Mahjoub R, Bin Mohamad Yatim J, Sam M, Rahman A. A review of structural performance of oil palm empty fruit bunch fiber in polymer composites. Advances in Materials Science and Engineering; 2013.
10. Munoz E, García-Manrique JA. Water absorption behaviour and its effect on the mechanical properties of flax fibre reinforced bioepoxy composites. International Journal of Polymer Science; 2015.
11. Goswami T, Kalita D, Rao P. Greaseproof paper from banana (*Musa paradisica* L.) pulp fibre; 2008.
12. Kalyebara R, Nkuba JM, Ramadhan MS, Byabachwezi EMK, Edmeades S. Overview of the banana economy in the Lake Victoria regions of Uganda and Tanzania. An economic assessment of banana genetic improvement and innovation in the Lake Victoria region of Uganda and Tanzania. 2007;155(25).
13. Pereira A, Maraschin M. Banana (*Musa* spp.) from peel to pulp: ethnopharmacology, source of bioactive compounds and its relevance for human health. Journal of Ethnopharmacology. 2015;160(149-163).
14. Tock JY, Lai CL, Lee KT, Tan KT, Bhatia S. Banana biomass as potential renewable energy resource: A Malaysian case study. Renewable and Sustainable Energy Reviews. 2010;14(2): 798-805.
15. Chauhan S, Sharma A. Enzyme treatment in improving the quality of pseudo stem fiber of banana plant to use this bioresource for making handmade paper. International Journal of Fiber and Textile Research. 2014;4(57-61).
16. Gogoi K, Phukan MM, Dutta N, Pradeep Singh S, Sedai P, Kumar Konwar B, Maji TK. Valorization and miscellaneous prospects of waste *Musa balbisiana* Colla pseudostem. Journal of Waste Management; 2014.
17. Jayaprabha J, Brahmakumar M, Manilal V. Banana pseudostem characterization and its fiber property evaluation on physical and bioextraction. Journal of Natural Fibers. 2011;8(3):149-160.
18. Pappu A, Patil V, Jain S, Mahindrakar A, Haque R, Thakur VK. Advances in industrial prospective of cellulosic macromolecules enriched banana biofibre resources: A review. International Journal

of Biological Macromolecules. 2015;79 (449-458).
19. Martelli-Tosi M, Torricillas MDS, Martins MA, Assis OBGD, Tapia-Blácido DR. Using commercial enzymes to produce cellulose nanofibers from soybean straw. Journal of Nanomaterials; 2016.
20. Chandramohan D, Marimuthu K. Characterization of natural fibers and their application in bone grafting substitutes. Acta of Bioengineering & Biomechanics. 2011a;13(1).
21. Chandramohan D, Marimuthu K. A review on natural fibers. International Journal of Research and Reviews in Applied Sciences. 2011b;8(2):194-206.
22. Mostafa M, Uddin N. Experimental analysis of Compressed Earth Block (CEB) with banana fibers resisting flexural and compression forces. Case Studies in Construction Materials. 2016;5 (53-63).
23. Zhen-Yu W, Jie W, Feng-Hong C, Yun-Hai M, Singh T, Fekete G. Influence of banana fiber on physicomechanical and tribological properties of phenolic based friction composites. Materials Research Express. 2019;6(7):075103.
24. Lampke T, Mishra S, Bismarck A. Plant fibers as reinforcement for green composites, Natural Fibers, Biopolymers and Biocomposites. CRC Press. 2005;52-128.
25. Maleque M, Belal F, Sapuan S. Mechanical properties study of pseudo-stem banana fiber reinforced epoxy composite. The Arabian Journal for Science and Engineering. 2007;32(2B): 359-364.
26. Dittenber DB, GangaRao HV. Critical review of recent publications on use of natural composites in infrastructure. Composites Part A: Applied Science and Manufacturing. 2012;43(8):1419-1429.
27. Jordan W, Chester P. Improving the properties of banana fiber reinforced polymeric composites by treating the fibers. Procedia Engineering. 2017;200 (283-289).
28. Palilo AAS, Majaja B, Kichonge B. Physical and mechanical properties of selected common beans (*Phaseolus vulgaris* L.) cultivated in Tanzania. Journal of Engineering; 2018.
29. Chavarria G, dos Santos HP. Plant water relations: Absorption, transport and control mechanisms, Advances in selected plant physiology aspects. InTechOpen; 2012.
30. Colom M, Vazzana C. Drought stress effects on three cultivars of *Eragrostis curvula*: Photosynthesis and water relations. Plant Growth Regulation. 2001; 34(2):195-202.
31. Shao HB, Chu LY, Jaleel CA, Zhao CX. Water-deficit stress-induced anatomical changes in higher plants. Comptes Rendus Biologies. 2008;331(3): 215-225.
32. Onyango M, Haymer D, Keeley S, Manshardt R (Ed.). Analysis of genetic diversity and relationships in east African'Apple Banana'(AAB genome) and 'Muraru'(AA genome) dessert bananas using microsatellite markers. In: IV International Symposium on Banana: International Conference on Banana and Plantain in Africa: Harnessing International. 2008;879:623-636.
33. Wairegi L, van Asten P. Norms for multivariate diagnosis of nutrient imbalance in the East African highland bananas (*Musa* spp. AAA). Journal of Plant Nutrition. 2011;34(10):1453-1472.
34. Nsemwa LTH, AA N, CD, K, D, K, TJ, M, M, M, JA, M. Evaluation of an integrated crop and pest management strategy to improve banana production and marketing analysis in Rungwe and Ileje Districts. Book of Results of the Southern Highlands Zone Agricultural Research and Development Fund. ARI-Uyole. 2013;81-99.
35. Iqbal M, Sohail M, Ahmed A, Ahmed K, Moiz A, Ahmed K. Textile environmental conditioning: Effect of relative humidity variation on the tensile properties of different fabrics. Journal of Analytical Sciences, Methods and Instrumentation. 2012;2(02):92.
36. Abo-Hamar SE, Federlin M, Hiller KA, Friedl KH, Schmalz G. Effect of temporary cements on the bond strength of ceramic luted to dentin. Dental Materials. 2005;21 (9):794-803.
37. Lube T, Rasche S, Nindhia TGT. A fracture toughness test using the ball-on-three-balls test. Journal of the American Ceramic Society. 2016;99(1):249-256.
38. Brusewitz G. Microwave drying for moisture determination with accuracy related to temperature. Transactions of the ASAE. 1984;27(4):1217-1221.
39. Whalley W, Clark L, Gowing D, Cope R, Lodge R, Leeds-Harrison P. Does soil strength play a role in wheat yield losses

caused by soil drying? Plant and Soil. 2006;280(1-2):279-290.

40. Indira K, Jyotishkumar P, Thomas S. Thermal stability and degradation of banana fibre/PF composites fabricated by RTM. Fibers and Polymers. 2012;13 (10):1319-1325.
41. ASTM_International. Standrd test method for tensile properties of single textile fibers¹. ASTM Internationalpp; 2007.
42. Naik DL, Fronk TH. Weibull distribution analysis of the tensile strength of the kenaf bast fiber. Fibers and Polymers. 2016;17 (10):1696-1701.
43. Celanese A. Complete textile glossary. Celanese Acetate LLC, Ne w York; 2001.
44. Pillay M, Tenkouano A. Banana breeding: Progress and challenges. CRC Presspp; 2011.
45. Okelana MA. Chemical properties and potential utilization of *Banana pseudostem*. ASSET: An International Journal (Series A)}. 2012;1(1):63-70.
46. Li K, Fu S, Zhan H, Zhan Y, Lucia L. Analysis of the chemical composition and morphological structure of banana pseudo-stem. BioResources. 2010;5(2):576-585.
47. Souza E, Liebl G, Marangoni C, Sellin N, Montagnoli M, Souza O. Bioethanol from fresh and dried banana plant pseudostem. Chemical Engineering Transactions. 2014; 38(271-276).
48. Preethi P, Balakrishna Murthy G. Physical and chemical properties of banana fibre extracted from commercial banana cultivars grown in Tamilnadu State. Agrotechnol S11. 2013;8(2):1-3.
49. Mwaikambo L. Review of the history, properties and application of plant fibres. African Journal of Science and Technology. 2006;7(2):121.
50. Kulkarni A, Satyanarayana K, Rohatgi P, Vijayan K. Mechanical properties of banana fibres (Musa sepientum). Journal of Materials Science. 1983;18(8):2290-2296.
51. Smole MS, Hribernik S, Kleinschek KS, Kreže T. Plant fibres for textile and technical applications, Advances in agrophysical research. IntechOpen; 2013.
52. Asim M, Abdan K, Jawaid M, Nasir M, Dashtizadeh Z, Ishak M, Hoque ME. A review on pineapple leaves fibre and its composites. International Journal of Polymer Science; 2015.
53. Rowell R, Han J, Rowell J, Frollini E, Leo A, Matteoso L. Characterization and factors effecting fibre properties. Natural Polymer and Agorofibres Composites. By E. frollini, AL Leo, and LHC Matteoso, San Carlos, Brazil. 2000;115(133).
54. Glinski J. Soil physical conditions and plant roots: 0. CRC presspp; 2018.
55. Omotoso M, Ogunsile B. Fibre and chemical properties of some Nigerian grown musa species for pulp production. Asian J. Mat. Sci. 2009;1(14-21).
56. Indira K, Parameswaranpillai J, Thomas S. Mechanical properties and failure topography of banana fiber PF macrocomposites fabricated by RTM and CM techniques. ISRN Polymer Science; 2013.
57. Kozlowski R, Baraniecki P, Barriga-Bedoya J. Bast fibres (Flax, hemp, jute, ramie, kenaf, abaca). Biodegradable and sustainable fibres. Woodhead Publishing, Cambridge, England. 2005;36-88.
58. Al-Bahadly EAO. The mechanical properties of natural fiber composites. Doctor of Philosophy, Faculty of Engineering, Swinburne University of Technology; 2013.
59. Rejab M, Theng C, Rahman M, Noor M, Rose A. An investigation into the effects of fibre volume fraction on GFRP plate. Matrix. 2008;1(20):80.

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