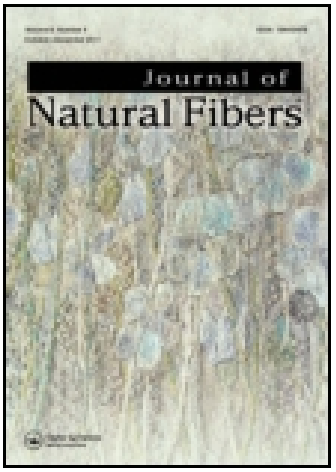

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Morphological, Thermal, and Mechanical Characterization of *Sansevieria trifasciata* Fibers

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Sansevieria trifasciata is a common perennial plant which freely grows and widely found in homes, parks, and woodlands. In this research, we studied the morphology using Scanning Electron Microscope and Fourier Transform Infrared (FTIR); thermal properties using Thermogravimetric (TGA) and Differential Scanning Calorimetric (DSC) analyses; mechanical behavior through tensile tests of Sansevieria trifasciata fiber (STF) obtained from Butaleja in Eastern Uganda. Findings show that the fiber has an irregular cross-sectional shape with lumens in the center, the fiber diameter was between 80 and 120 μm. TGA tests showed that the fiber is stable below 200°C with maximum cellulose decomposition temperature of 315°C. DSC showed that the fiber's crystallization temperature was 310.5°C and lignin decomposition temperature of 372.7°C. The surface functional groups were majorly of cellulose, hemicelluloses, and lignin in direct correlation with research elsewhere on natural fibers.

Keywords: *Sansevieria trifasciata*, natural fiber, TGA, DSC, FTIR

虎尾兰纤维的形态，热学和力学特性摘要虎尾兰是常见的多年生植物，其自由生长和广泛存在在家园，公园，和林地。在这项研究中，我们用扫描电子显微镜和傅里叶变换红外（FTIR）研究了形态；通过热重（TGA）和差示扫描量热法（DSC）分析热性能；在乌干达东部布塔莱贾获通过虎尾兰纤维拉伸试验（STF）验试力学性能。结果表明，该纤维具有在中心腔的不规则横截面的形状，纤维直径为80和120 μM. TGA测试表明，纤维稳定在200 ° C以下,最大纤维素分解温度315° C. DSC显示，纤维的结晶温度为310.5° C和最大木质素分解温度372.7° C. 表面官能团是主要纤维素，半纤维素，木质素与其它天然纤维研究直接相关。

关键词：虎尾兰，天然纤维，TGA，DSC，FTIR，虎尾兰

INTRODUCTION

The 21st century ushered in a gradual increase in utilization of different types of fibers for textile, automotive, aerospace, and other various structural applications (Koronis et al. 2011; Summerscales

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et al. 2010; La Mantia and Morreale 2011). The exceptional performance of synthetic fibers such as carbon and glass fiber as applied in automotive and aerospace is faced with challenges due to the fact that the main source for the production of carbon fiber and other synthetic fibers is petroleum. The dwindling petroleum sources coupled with fluctuating prices of crude oil, disposal concerns, and pollution by synthetics has led to look at alternatives in order to mitigate factors which directly contribute toward green house gas emissions (Koronis et al. 2011). The increasing costs of oil vis-à-vis the diminishing oil reserves world over and environmental concerns has led to the reigniting of the natural fiber spark and a global awakening towards use of sustainable and renewable technologies. De Almeida (2012) showed that products of biobased feedstock are expected to increase up to 25% by 2015.

Due to increase in industrialization in the developed countries, cultivation of industrial natural fibers such as flax, kenaf, hemp, and ramie for the purpose of production of fiber for structural composites is on the increase. This increase in use of natural fibers as reinforcements in composites especially by European car makers stems from the fact that the European commission under legislation 2000/53/EG tasked auto makers to make sure by 2015 most of the automotive components are recyclable.

Various researches have been made on conventional natural fibers such as flax, kenaf, hemp, jute, sisal, ramie, and banana. However, there are other natural fibers such as Sansevieria species, Barkcloth, Nettle species, pineapple to mention but a few that have not been studied in details and yet have potential for reducing green house gas emissions and therefore mitigation of climate change. The potential of little known bark cloth fabric has been realized and the findings show good thermophysiological and comfort properties. Therefore, little known plants could provide green solutions especially in countries, where they are located for sustainable development of local communities and achieving a greener environment. (Rwawiire and Tomkova 2014).

Sansevieria trifasciata (Figure 1) commonly known as "snake plant" or "mother-in-laws tongue" is a species in the family of Asparagaceae. *Sansevieria trifasciata* freely grows all over the world and in Africa there are many various species of Sansevieria. Numerous researches on various sansevieria species to mention but a few have investigated their use in management of hypertension (Ayalogu et al. 2011); anti-inflammatory treatment (Chinasa et al. 2011); thrombolytic activity (Sikder et al. 2011); protection against carbon tetrachloride induced liver injury (Ikewuchi et al. 2011), and anti-oxidant activities (Roy et al. 2012).

Sansevieria cylindrica and Sansevieria roxburghiana Schult have been investigated for the production of fiber and composites (Sreenivasan et al. 2011). According to NASA, *Sansevieria trifasciata* is one of the plants which were studied for improving indoor air quality. The findings showed that *Sansevieria trifasciata* passively absorbed toxins such as benzene, xylene, and formaldehyde.

The performance of natural fibers in composites and textiles is highly dependent on the mechanical, thermal, and morphology of the fiber. Before thinking of applying a particular fiber for the end products of textiles and composites, studies in the characterization are important, it is from there that material engineers start to design meaningful products. For natural fibers, the microstructure, chemical constituents, and thermal behavior are important parameters which affect the performance (Summerscales et al. 2010); therefore in this research, we present the morphological, thermal, and mechanical characterization of *Sansevieria trifasciata* fiber.

MATERIALS AND METHODS

Extraction of Fibers

The fibers were extracted using stagnant water retting method (Kanimozhi 2011). *Sansevieria trifasciata* leaves were soaked in stagnant water for five days. This enhances the decomposition

of plant matter leaving behind the fibers. Using hand scrutching method (Figure 2), fairly clean fibers were obtained which were washed in running water and dried under the Sun.

Characterization Methods

Morphology of Fiber

The fiber samples were analyzed using a Vega-Tescan TS5130 Scanning Electron Microscope with 20 kV of accelerating voltage.

FIGURE 1 *Sansevieria trifasciata* plant.

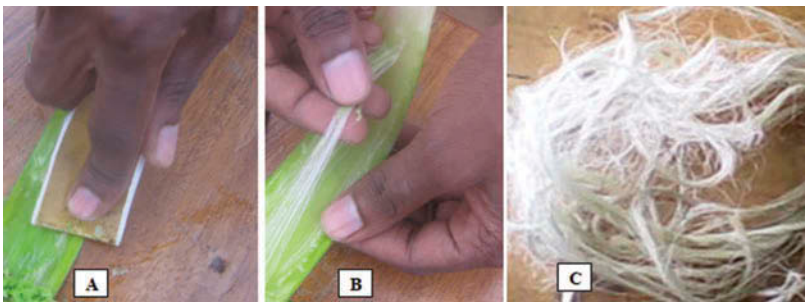

FIGURE 2 Manual extraction of STF: (A) hand scrutching; (B) lifting of STF; (C) extracted STF.

Chemical Composition

Fiber Moisture Content

Fiber moisture content was determined using the "Aqua Boy Moisture Tester." The Aqua-Boy Moisture Meter uses the principle based on the electrical conductivity of the material which always bears a fixed relation to the moisture.

Determination of Density

The density of fibers was measured by Archimedes method with isopropyl alcohol using ASTM D3800 and an electronic balance (Sartorius A210P model) was used to weigh specimens of fibers.

Fiber Length

Fiber length was measured using a calibrated metal scale by straightening the fibers over the flat table and the result is expressed in centimeters. Care was taken so that the fibers did not elongate.

Fiber Fineness

The fiber specimens were tested for fiber fineness according to ASTM D1577. Ten fiber samples each with cut length of 30 cm were selected and their corresponding values according to the test method were taken and the average computed.

Fiber Linear Density

Linear density was measured using the gravimetric method (Samanta et al. 2007) whereby 10 fibers each of 30 cm cut length were weighed separately for the purpose of calculation of linear density.

Fiber Tensile Testing

Testing of mechanical properties of sansevieria fibers was done using a Eureka strength tester according to ASTM D 3822.

Fourier Transform Infrared Spectroscopy (FTIR)

Nicolet iN10 MX Scanning FTIR Microscope was used to provide the spectrum of the sample. The FT-IR spectrum of each sample was obtained in the range of 4000–700 cm^{-1}.

Thermogravimetric Analysis (TGA)

Thermogravimetric analysis was carried out using a Mettler Toledo TGA/SDTA851^{e} under a dynamic nitrogen atmosphere heating from room temperature (25°C) to 500°C at a heating rate of 10°C/min. Weight changes of the fiber sample weighing approximately 7–8 mg were measured.

Differential Scanning Calorimeter Analysis (DSC)

The Perkin Elmer Pyrris 6 Differential Scanning Calorimeter was used. Samples weighing approximately 10 mg using Waga Torsyjna-WT scale were placed in aluminum pans and sealed. The specimens were heated in an inert nitrogen atmosphere from room temperature (25°C) to 450°C at a heating rate of 10°C/min.

RESULTS AND DISCUSSIONS

Fiber Morphology

Figures 3 and 4 show the scanning electron micrographs of STF. The average diameter of fiber was found to lie between 80 and 120 μm in the range of values recorded elsewhere for leaf fibers of sisal and pineapple. The surface of the fiber is characterized by parallel ridges connected with intermediate nodes along the fiber length similar to those of the microstructure of sisal (Basu et al. 2012) and pineapple (Sena Neto et al. 2013). The nodes and ridges are therefore responsible for higher breaking strength, higher initial modulus and lesser extensibility. The rough surface of the fiber provides a wider surface area for composite matrix thus improving fiber to matrix adhesion and overall performance as composite fiber reinforcement. The rough surface is also due to the waxes and other plant impurities which can be removed through various chemical treatments. The morphology also shows that the fiber has a hollow lumen; this characteristic can be utilized for acoustic and thermal insulation applications.

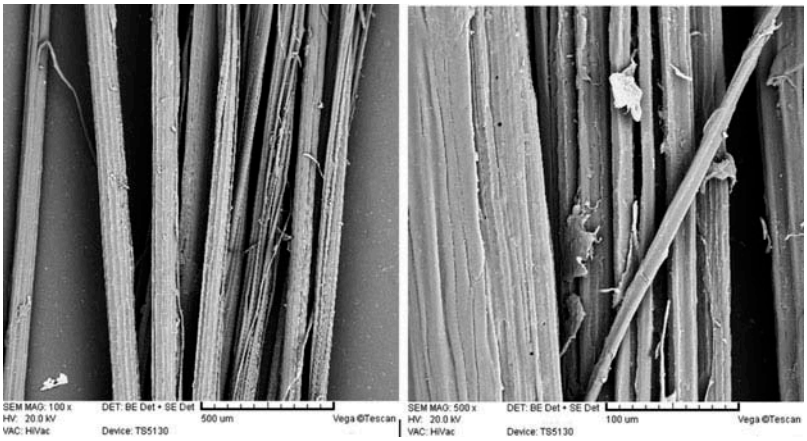

FIGURE 3 SEM images of STF at 100× and 500× magnification.

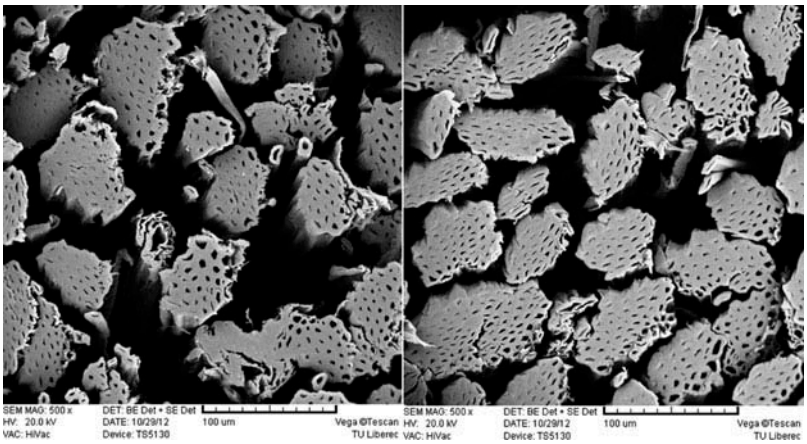

FIGURE 4 SEM cross-sectional view of STF.

TABLE 1
Physical properties

Sample number	*Mass (g)*	*Liner density (g cm^{-1})*	*Cross-sectional Area (m^2)*	*Density (kg m^{-3})*
1	0.0046	1.533×10^{-4}	1.131×10^{-8}	1355.73
2	0.0049	1.633×10^{-4}	1.131×10^{-8}	1444.15
3	0.0052	1.733×10^{-4}	1.131×10^{-8}	1532.57
4	0.0048	1.600×10^{-4}	1.131×10^{-8}	1414.68
5	0.0049	1.633×10^{-4}	1.131×10^{-8}	1444.15
6	0.0047	1.567×10^{-4}	1.131×10^{-8}	1385.20
7	0.0045	1.500×10^{-4}	1.131×10^{-8}	1326.26
8	0.0050	1.667×10^{-4}	1.131×10^{-8}	1473.62
9	0.0049	1.633×10^{-4}	1.131×10^{-8}	1444.15
10	0.0048	1.600×10^{-4}	1.131×10^{-8}	1414.68
Average	0.0048	1.600×10^{-4}	1.131×10^{-8}	1414.68

Chemical Composition

Fiber Fineness, Length and Density

The measured density of STF is 1414.7 kg/m^3 (Table 1), which is comparable to values, reported by Dittenber and GangaRao (2012) of other leaf natural fibers of sisal 1330–1500 kg/m^3 and pineapple leaf fiber 800–1600 kg/m^3, but less than the density of glass fiber (2500 kg/m^3). This implies that the low specific weight of STF just like other natural fibers increases its usability in the fabrication of natural fiber composites.

Moisture regain of the fiber was 10.5% a value comparable to the moisture content of other industrial fibers such as hemp, kenaf, sisal, jute and flax. The moisture content is a critical factor in composite fabrication and performance of natural fibers as reinforcing agents. Despite the fact that natural fibers are hydrophilic in nature, low moisture content is desirable in case the fiber is to be used in composite reinforcement. The fiber fineness was calculated to be 0.00016 g/cm less than the theoretical value of fiber glass which is 2.4 g/cm.

Average fiber length was determined as 109.3 cm through measurements of seven different samples with Coefficient of Variation 4%.

MECHANICAL PROPERTIES

The mechanical properties of natural fibers are largely affected by the type of plant species, crop cultivation, location, fiber location in the plant, climate, decortications method, transport conditions, and age of fiber (Dittenber and GangaRao 2012).

The average tensile strength and Young's modulus were 348.6 MPa and 15.3 GPa, respectively (Table 2). The coefficient of variation for tensile strength and modulus was 7.1% and 11.6%, respectively. Since fiber strength translates into fabric strength, the strength of the fabric-composite material would increase relatively. Elongation at break was 2.3% a value which is comparable to other researches elsewhere on leaf fibers (Ho et al. 2012).

Surface Functional Groups

Functional groups assignments and their respective bonding interactions of STF can be deduced using FTIR Spectroscopy as shown in Figure 5. Natural fibrous specific bands and their corresponding bonding interactions have been studied by different researchers. (AlMaadeed et al. 2013;

TABLE 2
Mechanical properties

No tests	*Tensile stress (Mpa)*	*Tensile strain*	*Young's Modulus (Gpa)*
1	353.669	0.025	14.147
2	389.036	0.028	13.894
3	344.827	0.022	15.674
4	318.302	0.024	13.263
5	371.352	0.020	18.568
6	327.144	0.018	15.618
7	335.986	0.021	15.999
Aver	348.623	0.023	15.158

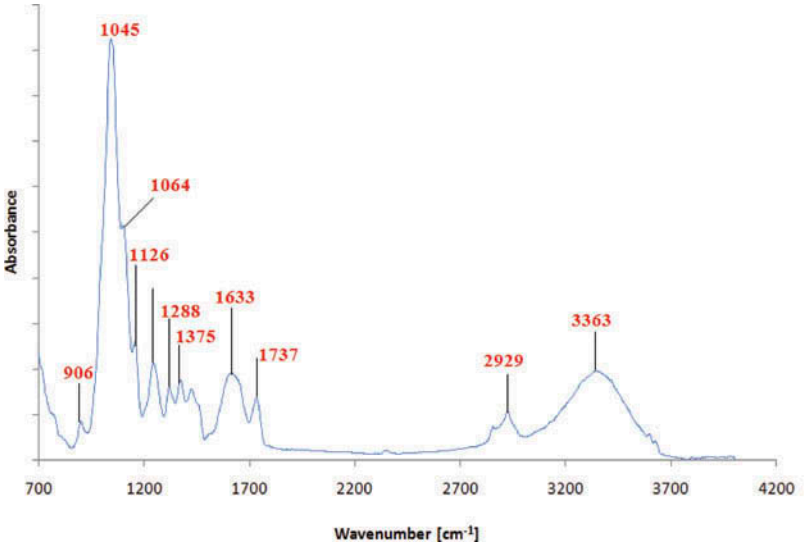

FIGURE 5 FTIR of STF.

Alhuthali et al. 2012; Alemdar and Sain 2008; Biagiotti et al. 2004; Elanthikkal et al. 2010; Liu et al. 2004; Mwaikambo and Ansell 2002; Seki et al. 2013; Sreenivasan et al. 2011).

A broad absorption band at 3363 cm^{-1} is due to O–H stretching vibrations of cellulose and hemicelluloses. The band at 2929 cm^{-1} corresponds to CH_2 and CH_3 stretching vibrations. The band at 1737 cm^{-1} is due to carbonyl groups (C = O) stretching and vibration of acetyl groups of hemicelluloses (Seki et al. 2013; Sreenivasan et al. 2011). After this peak, the sudden leveling off shows that the hemicelluloses are removed from the fiber. Aromatic vibration of benzene ring in lignin may be at 1633 cm^{-1}. The absorption band at 1375 cm^{-1} was owing to CH_2 bending in lignin whereas the peak at 1249 cm^{-1} was due to O–H in-plane bending (Seki et al. 2013). The peak at 1288 cm^{-1} was assigned to CH symmetric bending. A small peak at 1126 cm^{-1} may correspond to C–O stretching of acetyl group of lignin. The band at 1064 cm^{-1} may be due to C–O–C asymmetrical stretching in cellulose, whereas hemicelluloses can be noticed at 1064 cm^{-1}. The broad peak at 1045 cm^{-1} is due to -C–O–C- pyranose ring skeletal vibration. The band at 906 represents glycosidic -C_1–H deformation, with a ring vibration contribution and -O–H bending. These features are characteristic of β-glycosidic linkages between the anhydroglucose units in cellulose.

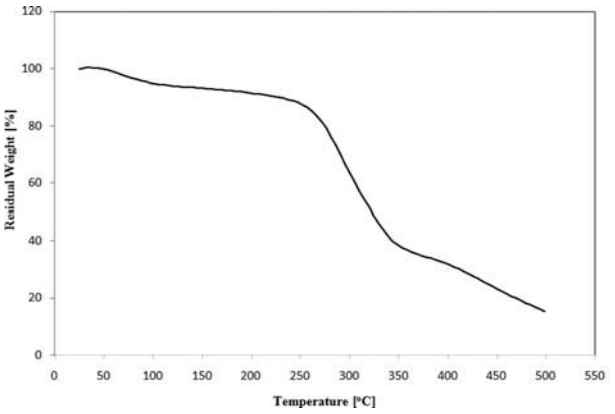

FIGURE 6 TGA curve of STF.

Thermal Properties

Figure 6 shows the thermogram of STF, the first stage from 25°C to 100°C is attributed to evaporation of water accounting for about 6% loss in weight. (Nguyen and Barrall 1981). The temperature range 100–220°C accounting to 4% loss in weight is attributed to desorption of water, intramolecular dehydration with formation of carboxyl and C–C bonds of cellulose. The third stage accounting to about 60% weight loss starts from about 220°C to 370°C with a maximum decomposition temperature corresponding to 315°C. The temperature range 220–315°C corresponds to the cleavage of glycosidic linkages of cellulose which leads to the formation of H_2O, CO_2, alkanes and other hydrocarbon derivatives (Seki et al. 2013). The last stage of decomposition starting from around 400°C corresponds to 20% loss in weight is due to char or other decomposition reactions.

STF thermograms have showed that the fiber is stable below 200°C; therefore, alternatives of composite fiber reinforcement can be explored provided the working and production temperature of composites is kept under this temperature.

Figure 7 shows the Differential Scanning Calorimetry and Derivative DSC curve of STF. The first peak at 70°C corresponds to heat of evaporation (115 J/g) of water from STF. A higher glass transition temperature implies that a fabric made out of STF is predicted to be wrinkle-free fabric.

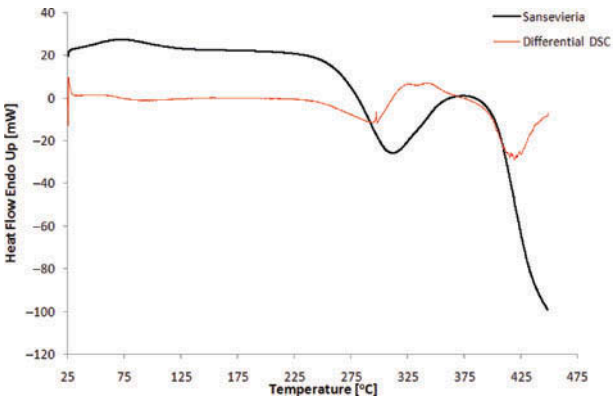

FIGURE 7 DSC and Differential DDC of STF.

The second peak is onset at 255.7°C which is due to decomposition of cellulose and hemicellulose which is in agreement with the weight loss as can be observed from the TGA thermogram in Figure 6. It is observed that the dip in the curve is STF crystallization temperature at 310.5°C with latent energy of crystallization $\Delta H_C = -41.5$ J/g. The last peak at temperature 372.7°C is attributed to decomposition of lignin with heat of fusion, $\Delta H_m = 903.4$ J/g.

CONCLUSION

Characterization of *Sansevieria trifasciata* fiber has been done. The morphological studies have showed that the fiber is made up of nodes/ ridges which give its strength against elongation. The fiber has a central lumen which is a good physical property in application of the fiber in sound and thermal insulation products. The transverse cross-sectional shape of the fiber is polygonal therefore meaning that for the purpose of calculating the diameter, a polygonal mode is ideal. The tensile strength of 348 MPa of the fiber is comparable to the strength of other allied fibers.

Thermal behavior of the fiber shows that it is stable below temperatures of 200°C, therefore in case of production of composites; the maximum working temperature of below 200°C should be set for production of sound and quality composites in case compression molding or injection molding is to be used. The absorption bands show the presence of cellulose, hemicelluloses, and lignin.

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