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Production and Characterization of Kenyan Sisal

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ABSTRACT

Sisal is one of the fibers that have lately recorded a rapid increase in demand. This can be attributed to an increasing awareness of the need to use eco-friendly materials. An increase in demand invariably leads to improved commodity prices, therefore making sisal production a very profitable venture. Kenya is among the largest producers of sisal. However, 80% of the sisal grown in Kenya is exported as raw materials. This is a major concern and therefore, needs to be addressed urgently. According to vision 2030, Kenya lays emphasize on the value addition of Kenyan agricultural products. This implies that agricultural products like sisal should be processed and then exported as high valued products. The value addition of Kenyan sisal can be enhanced if research into the production of sisal is done. Fiber characterization will also equip scientists and investors with the much needed information about the nature and potential of the Kenyan sisal. The aim of this research work concentrated on the production and characterization of the Kenyan sisal. The results of this research work show that Kenyan sisal production and yield has been declining in the last four decades. This is the trend in the other sisal producing nations, except Brazil whose production has been rising and China whose yield has been rising. The characterization of the Kenyan sisal indicated that the Kenyan sisal has a higher percentage of lignin and hemicellulose. The tensile strength of the Kenyan sisal was comparable to the lower spectrum of sisal tensile strength for sisal from other regions (countries).

Key words: Sisal, bast, fibers, tensile strength, cellulose, lignin

INTRODUCTION

Sisal is a natural vegetable fiber which can be obtained from the leaves of Agave (*Agave sisalana*) plant and is considered as an economic fibers in several countries which include Kenya, Tanzania, China and Brazil. In Kenya sisal is the sixth most important cash crop coming after tea, coffee, sugar, pyrethrum and cotton. The sisal growing and processing industry in Kenya can be traced back to 1914, when the first sisal growing firm was established in Thika. The industry grew by leaps and bounds in the first 50 years characterized by a rapid increase in acreage and quantity of sisal exported. The increase in sisal production lead to the establishment of a spinning factory in Juja and a sisal research station in Thika. The invention of cheaper synthetic fibers in the 1940's, can be marked as a major drawback for the world sisal production, since, it lead to reduced sisal demand. In Kenya the industry enjoyed some government protection mainly in the 1960's and 1970's (Odhiambo *et al.*, 2004). The government subsidies were however, removed in the 1980's dealing a major blow to the once thriving Kenyan sisal industry. This phenomenon was not limited to Kenya. Other major sisal producing countries such as Tanzania experienced a similar decline in sisal production, characterized by a big decline in acreage and fiber yields. This was attributed to decreasing fiber prices and poor crop husbandry (Hartemink and Wienk, 1995; Shamtu, 2000). The introduction of new applications for sisal fibers coupled with the push for eco-friendly fibers has however reversed the aforementioned trend.

Traditionally Sisal fibers can be classified into a variety of grades which include; the lower, medium and higher fibers, which are used for paper, rope and carpet making, respectively. Sisal has however found new applications in a variety of industries which include; the medical field (Thatoi *et al.*, 2008), the automotive and Building industry (Salazar *et al.*, 2011; Filho *et al.*, 2009). Apart from the sisal fiber which constitutes 4% of the sisal leaf, the sisal industry generates a lot of biomass commonly referred to as sisal waste. The biomass obtained during sisal decortication has for a long time been a nuisance to the sisal factories. While the factories were struggling to cope with the sisal waste another event seemingly unrelated came to the rescue of the sisal factories. The high rate of depilation of natural resources has compelled man to optimize the use of resources. Terms like “eco-friendly” or “green” processes are now common words in many government and industrial circles. While Kotchoni and Gachomo (2008), paints a picture of bio-fuel as a promising concept, Ramachandra (2008) assumed that green fuel is here with us and he goes ahead to design a model which can be used to assess the need for biogas for a given region. Green energy is here to stay, since the fossil fuels are getting depilated at a high rate. In Tanzania sisal biomass, which was a nuisance 20 years ago is being used to generate electricity hence, improving the profitability of the sisal industry. It is hoped that other sisal producing countries like Kenya will soon implement such eco-friendly activities. Sisal biomass can also be used to manufacture bio-fertilizers, since crop residue have proven potential for the manufacture of fertilizers (Taiwo, 2011). The Kenyan government is carrying out research to use sisal waste for bio-energy generation, livestock feed as well as organic fertilizer. This enhanced interest and investment in research and development will improve production and hopefully the profitability of the sisal industry.

The increasing use of sisal in a variety of industries demands a thorough understanding of the properties of the fiber. According to De Andrade Silva and Filho (2007) the sisal plant leaf is a composite structure that is made up of three types of fibers: structural, arch and xylem fibers. Every sisal fiber contains numerous elongated individual fibers (fiber-cells). Each individual fiber-cell is made up of four main parts, namely the primary wall, the thick secondary wall, the tertiary wall and the lumen. Sisal leaves can be harvested from the age of 2 years. Harvesting can continue for 9 to 12 more years, producing over 200 leaves in its lifespan. This research concentrated on the study of the characteristics of the sisal fiber. Previous works indicated that the mechanical and chemical characteristics of sisal may vary depending on growing and processing conditions. The mechanical properties of the fiber have for example been shown to be dependent on the age of the fiber (Chand and Hashmi, 1993). A regression model designed by Mukherjee and Satyanarayana (1996) to study sisal fiber revealed that the structure and properties of sisal are affected by cellulose content, microfibrillar angle and other structural parameters which include cell dimensions and defects. Therefore, characterization of the Kenyan sisal will be important, since it will shed light on the quality of the sisal and hence encourage its appropriate application.

The use of sisal in a wide range of application has lead to an increase in sisal demand. This has been accompanied by an improvement of the prices of sisal, hence making sisal production a very profitable venture. The Kenyan government through the Kenya sisal board has embarked on a program to increase the acreage of sisal to meet the rising demand. There is however a major concern for economist in Kenyan due to the fact that over 80% of the sisal grown in Kenya is exported as raw fiber. According to the Kenyan Vision 2030, which lays emphasize on the value addition of Kenyan agricultural products, the value addition of Kenyan sisal should be considered. While the Kenyan vision 2030 may be considered as utopian like the Nigerian Vision 20:2020 which promises a lot and is likely to deliver little (Eneh, 2011), public university which includes Moi University are duty bound to demonstrate their commitment to the fulfillment of the vision. It was in this spirit that a research on the study of the Kenyan sisal was envisaged. The whole process of value addition of the Kenyan sisal will benefit a great deal if the Kenyan sisal is characterized. This will enable the Kenyan farmer to bargain for a competitive price for his sisal fiber. The characterization of the Kenyan sisal will also enable researchers to optimize its usage in various industrial applications. This study reported the production of sisal in Kenya in comparison with other major sisal producing nation (Brazil, Tanzania). China has also been considered due to the high sisal yields recorded in the last decade. The other part of the paper concentrates on the characterization of the Kenyan sisal fiber.

MATERIALS AND METHODS

Sisal production and yield: The production of sisal in Kenya, Tanzania, Brazil and China were studied from 1961 to 2009 from the commodity data website [http://data.mongabay.com/commodities/category/1-Production/1-Crops/789-Sisal], which records the production and export of products worldwide. Sisal fiber production and yield were considered.

Characterization of Kenyan sisal fiber: Sisal fiber samples were collected from Kenyan sisal factories and characterized. The fiber characteristics considered included the physical, mechanical and chemical properties of the fiber.

Chemical ingredients of Kenyan sisal: The chemical composition of the Kenyan sisal fiber was investigated using Chinese standards for the determination of the chemical ingredients of bast fibers (GB 5889-1986, P. R. of China).

Tensile properties: The mechanical properties were measured using a single fiber tensile machine, which had a speed of 5 mm min^{-1} and a gauge length of 10 cm.

Cross-sectional and longitudinal morphology: In order to evaluate the surface morphology of the fiber the sisal fibers were investigated using a Scanning Electron Microscopy (SEM), Hitachi TM1000. The excitation energy for the general procedure was 15 Kev. The fiber samples were sputtered with gold before examination to ensure good conductivity. The cross-sectional and longitudinal morphology were investigated.

Chemical groups in sisal: The chemical groups in sisal fiber were investigated using Fourier transform infrared spectrophotometry (FT-IR) Nicolet 8700. FT-IR spectra of each sample studied using a range of 4000 to 400 cm^{-1}. Spectra outputs were recorded in the absorbance mode as a function of wave number.

Crystallinity of sisal: The sisal fiber crystalline index was obtained from an X-ray Diffraction (XRD) patterns of the sisal fiber obtained from a D/MAX-2550PC X-ray detector diffraction system. The machine was set at voltage of 18 kW, current of 30 mA and scan rate of 2° min^{-1}.

RESULTS AND DISCUSSION

The trend of sisal production and yield: The production and yield of sisal in Kenya and other selected countries (Brazil, Tanzania and China) is given in Fig. 1 and 2. Corresponding values for three other countries (Brazil, Tanzania and China) have been included for comparison purposes. The figures indicated that the production of sisal in Kenya exhibited a declining trend in the last four decade. The production of sisal in Tanzania has shown a drastic decrease while Brazil has experienced an erratic production howbeit with marginal increase.

The Kenyan agricultural sector enjoyed government protection up to 1982, when agricultural subsidies were removed. During the years of government protection, sisal production was robust, with higher production level being realized in 1970. The major decline in production recorded in the late 1970's can be attributed to high level of corruption in government departments. When the government liberalized the agricultural sector, the small scale farmers were unable to grow sisal, due to low sisal prices and high cost of inputs. In 2008, for example eight large scale companies produced over 90% of the Kenyan sisal (Kiome, 2010). The production from small scale farmers was a merge 420 tons. The Kenyan government needs to look into ways and means of encouraging the small scale sisal farmers to boast sisal production. In Brazil, the bulk of the sisal is produced by the small scale farmers. It is a high time, Kenya tried to study the Brazilian sisal growing industry with an aim of encouraging small scale sisal farmers. Going by reported findings available in the public domain, the decline in sisal production in Tanzania was caused by poor husbandry, propagation of the wrong varieties and a decrease in the length of sisal leaves (Hartemink and Wienk, 1995). Similar factors could also be responsible for the decrease of sisal yield in Kenya, since the two are neighboring countries. The phenomena increase in sisal yield in China is hereby noted and should be considered a research subject by the Kenyan sisal industry.

The characterization of the sisal fiber

Cross-sectional and longitudinal morphology of sisal: The morphology of the Kenyan sisal fiber for the longitudinal and cross-section views obtained using the SEM are given in Fig. 3. These SEM images are similar to those obtained by Mukherjee and Satyanarayana (1984) for Indian sisal and Martins *et al.* (2004) for Brazilian sisal. The surface irregularities appearing on the surface of the fiber will lead to variations of sisal fiber properties. The cross-section view attest to the fact

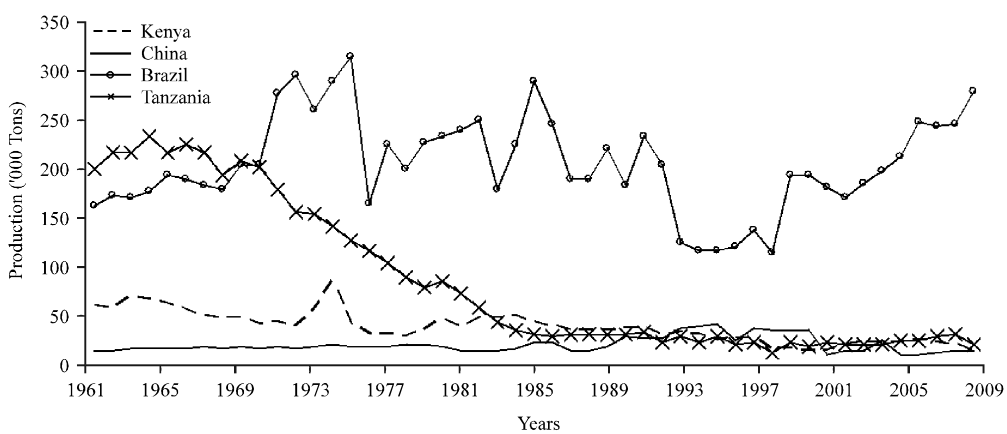

Fig. 1: Sisal production from 1961 to 2009

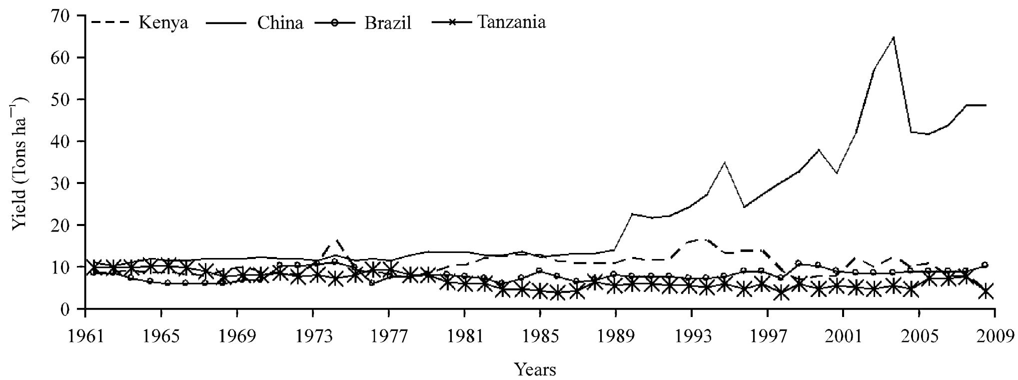

Fig. 2: Sisal yield from 1961 to 2009

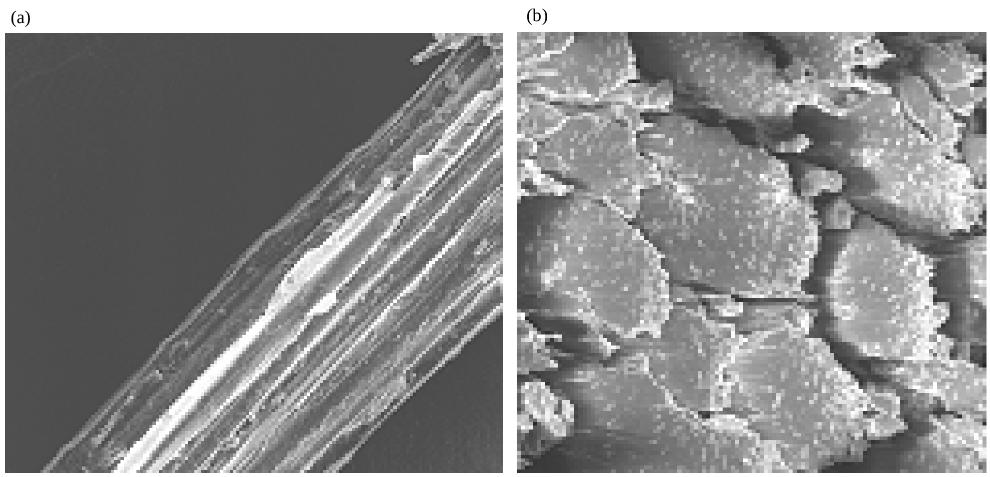

Fig. 3(a-b): The SEM of the Kenyan sisal fiber, (a) Longitudinal view and (b) Cross sectional view

that sisal fiber is made up of several fiber cells (Filho *et al.*, 2009). These fiber cells are held together by resin like material called lignin.

The chemical composition of Kenyan sisal: As stated earlier the chemical contents of sisal fiber were determined using Chinese standards for bast fibers. The composition of the Kenyan sisal fiber was 63-69% cellulose, 10-13% lignin, 18% hemicellulose, 0.8-1.6% pectin, 1.5% wax and 0.6-1% water soluble matter. As stated earlier the chemical contents of a bast fiber has been proven to affect the mechanical properties of the fiber (Mukherjee and Satyanarayana, 1984). Sisal fiber like other bast fibers is considered to be a natural composite material where cellulose is the main weight bearing component and cellulose and lignin are the matrix (the joining gum). Typically a fiber cell will consist of fibrillae in a matrix of lignin (De Andrade Silva and Filho, 2007). The fibrillae is also another composite consisting of cellulose in a matrix of hemicelluloses. As shown in Table 1 and 2 different researchers have reported varying values. The difference in the results could be attributed to the fact that sisal is a natural fiber and its properties are bound to be affected by the growing conditions. Referring to Table 2, which is a summary of the chemical contents of sisal as reported by several researchers, the cellulosic contents of the Kenyan sisal can be adjudged as average.

Table 1: Ingredients of sisal

Ingredients (% by weight)						
Cellulose	Lignin	Hemicellulose	Pectin	Waxes	Ash	Reference
73	11	11	2			Mwaikambo and Ansell (2002)
85-88	4-5					Joseph *et al*. (1999)
67-78	8-12	10-14.2	10	2		Mohanty *et al*. (2000)
59.2	7	24.6			1.92	Salazar *et al*. (2011)
70	12					Mukherjee *et al*. (1984)
45-56	7-9.0	21-24			0.6-1.1	Favaro *et al*. (2010)
66-78	10-14	10-14	10	2		Taj *et al*. (2007)
43-62	7-9				1-3	Rowell *et al*. (2000)

Table 2: Mechanical characteristics of sisal

Density (kg m^{-3})	Tensile strength (MPA)	Young modulus (GPA)	Tensile modulus (GPA)	Elongation (%)	Reference
	400-700		9-20	5-14	Joseph *et al*. (1999)
1450	468-640	9.5-22		3-7	Mohanty *et al*. (2000)
1400	450-700	7-13			Manikandan Nair *et al*. (1996)
1450	641		15		Bisanda and Ansel (1992)
1500	511-635	4-6			Taj *et al*. (2007)

Apart from the reports of Favaro *et al*. (2010), Rowell *et al*. (2000) and Salazar *et al*. (2011), the cellulose contents for the Kenyan sisal can be adjudged to be low. The lower percentage of cellulose, accompanied by higher percentage of hemicellulose may lead to some changes in the physical and mechanical characteristics of the fiber. Hemicellulose has lower degree of polymerization, is attacked by both acids and alkalis, while cellulose has very high resistance to alkali attacks, but is attacked by acids. Lignin binds the cellulose and hemicellulose together. Levels of 4-8% should be optimum. Higher percentages of lignin will have adverse effect on the mechanical strength.

Chemical groups in Kenyan sisal: The FT-IR spectroscopy was used to study the functional groups present in the sisal fiber. Fig. 4 gives the graph of the absorbency. The peaks at 3340.8 and 1035 cm^{-1} could be attributed to the O-H stretching and bending groups, respectively. There are a series of peaks in the 1720 to 1610 cm^{-1} range which could be attributed to the carbonyl stretching (C = O) for acetyl groups in hemicelluloses and for aldehydic groups present in lignin (Favaro *et al*., 2010; Abdul Khalil *et al.,* 2010) which is one of the ingredients found in bast fibers. The presence of an aldehyde could be confirmed by a peak that occurs at 2840 cm^{-1}. The vibration peak at 1244.4 cm^{-1} could be attributed to C-O stretching vibrations. Other minor peaks at 2922.9 and 1426.5 cm^{-1}, could be attributed to C-H_2 stretching and bending vibrations, respectively.

Crystallinity of sisal: The XRD diffraction curve for the Kenyan sisal fiber is given in Fig. 5. There are two main peaks; one sharp peak at 22.1° and a broad peak at around 15°. Other minor's peaks were noticed at 34.8 and 44.5°. The Crystallinity of the sisal fiber was 51.15%. These results are comparable to the values reported by Yi *et al*. (2010) for Chinese sisal, albeit on the lower side. As noted earlier the lower percentage of cellulose, coupled with a higher percentage of hemicellulose and lignin could have lead to lower crystallinity.

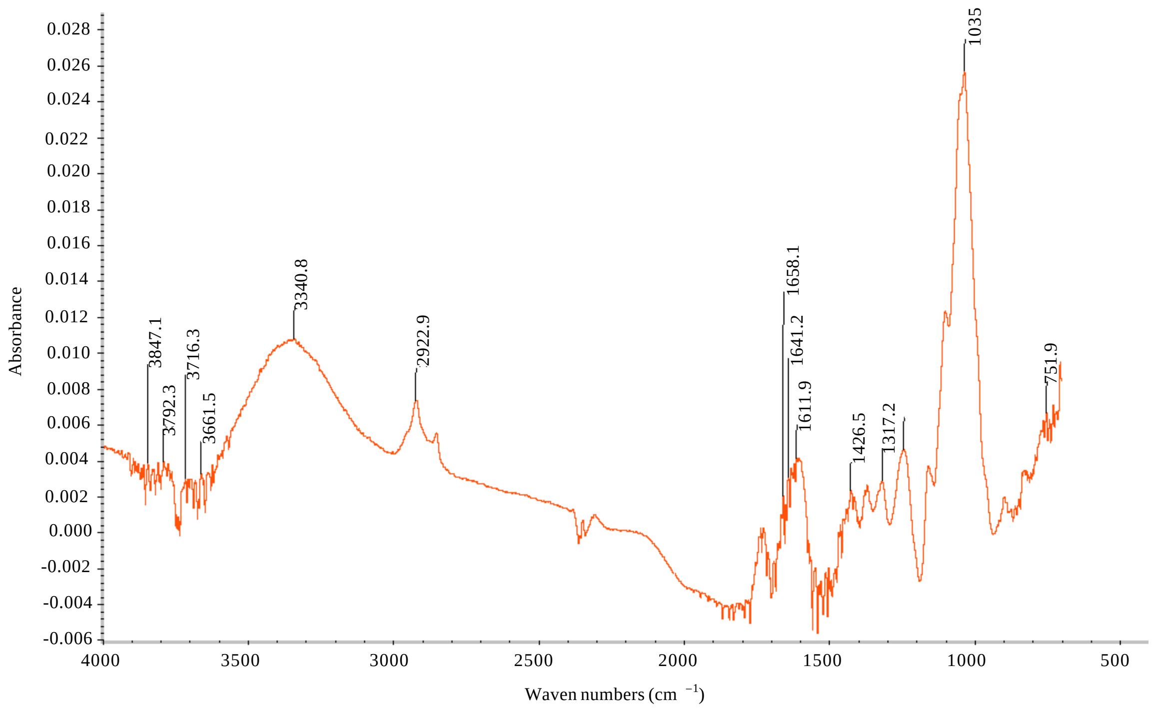

Fig. 4: The FT-IR for Kenyan sisal fiber

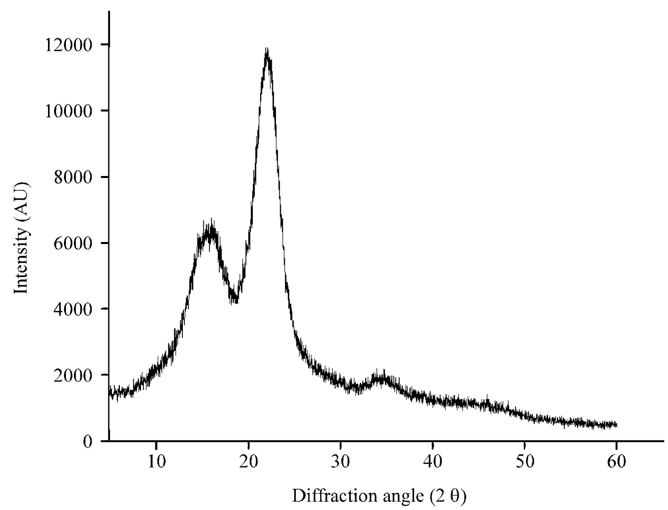

Fig. 5: X-ray diffraction for Kenyan sisal

Tensile properties: The tensile strength for the Kenyan sisal was 450 MPA (410 -570) while the elongation was 4.76% (3.9 to 5.17%). A summary of the mechanical properties of sisal given in Table 2, indicated that the tensile properties of the Kenyan sisal was comparative lower than those reported by other researchers. Considering reports from Joseph *et al.* (1999), Mohanty *et al.* (2000) and Taj *et al.* (2007), higher cellulose contents accompanied with lower lignin contents gives higher tensile strength. This could be attributed to the fact that cellulose is the main strength bearing element in the sisal fiber structure and lignin and hemicellulose are the matrix member of the component.

The lower tensile strength reported for the Kenyan sisal could therefore be attributed to the lower percentage of cellulose coupled with higher percentages of lignin.

CONCLUSION

A study of the production and characterization of the Kenyan sisal was undertaken. According to the data obtained, it can be concluded that Kenyan sisal production and yield has been declining in the last four decades. This is the trend in the other sisal producing nations, except Brazil whose production has been rising and China whose yield has been increasing. The Characterization of the Kenyan sisal indicated that the Kenyan sisal has a higher percentage of lignin and hemicellulose. The tensile strength of the Kenyan sisal was comparable to the lower spectrum of sisal tensile strength for sisal from other regions (countries).

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