

**DETERMINATION OF FIBRE PROPERTIES OF *AGAVE AMERICANA*
LEAVES AS A TEXTILE FIBRE FROM MBARUK,
NAKURU DISTRICT**

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DECLARATION

This Thesis is my original work and has not been presented for a degree in any other university.

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DEDICATION

I dedicate this work to my dear husband Sammy, my loving son Kamau and darling daughters Martha and Frecia.

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First and foremost, my gratitude goes to my heavenly Father for his special Grace, Love and Strength that were necessary for the completion of my study. To Him be the Glory and Honour.

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I wish to register my heart-felt thanks to Ms. F. Kaibi for her support during my study. Finally, I wish to extend my whole hearted appreciation to my loving husband Sammy for his support and encouragement.

MAY THE ALMIGHTY GOD BLESS YOU ALL

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ABBREVIATIONS/ ACRONYMS

A	Agave	1
AGOA	African Growth Opportunity Act	2
CRE	Constant Rate of Extension (Tensile Testing Machines)	23
CRL	Constant Rate of Load (Tensile Testing Machines)	23
CRT	Constant Rate of Traverse (Tensile Testing Machines)	23
cN	Centi-Newtons	49

ABSTRACT

Agave americana is an exotic plant, which is widely cultivated in the world for aesthetic purposes. It belongs to the family *Agavaceae* and in most varieties the leaf has a white or yellow marginal or central stripe from the base to apex. The Kenyan *A. americana* fibre has not yet been investigated as a textile fibre. The study aimed to investigate the potential of the fibre extracted from the *Agave americana* plant, and its quality for use as a textile fibre. This is essential since the United State (US) government has opened its market to Kenyan textiles products and other goods through the African Growth Opportunity Act (AGOA). The Agoa Act requires that the beneficiary countries start growing other varieties of vegetable fibres to make fabrics instead of relying only on imported yarns and fabric and locally grown cotton. The soil conditions where the leaves were harvested was analysed and determined. The *Agave americana* fibres were extracted from the plant leaves and the physical and chemical properties determined. For the purposes of this study plant samples were purposively collected and subjected to retting process to obtain the fibres. The fibres were then randomly assigned for the experimental tests. The data analysis was both qualitative and quantitative. From the analysis the prevailing soil type is sandy clay loam and was also acidic. The fibres obtained were flexible, smooth and lustrous and had similar burning characteristics like other known cellulosic fibres. The fibres are significantly long with a mean length of 65.2cm and a mean diameter of 0.15mm. This implies that the fibre has good spinning quality. The fibre has a tenacity of 2.94g/d (35.96cN/tex) when dry and 2.3g/d (20.60 cN/Text) when wet. Generally natural fibres are hydrophilic in nature and this was evident with the *A. americana* fibre with a moisture regain of 9.98% and moisture content of 9.19%. Yarns were spun from the fibres, dyed and samples of textile articles were made. The fibre disintegrated when exposed to strong acid and alkalis, but was resistant to weak acids and alkalis. From the findings of this research the fibre was found to qualify as a potential source of textile fibres and this could provide a secondary source of raw materials for textile products. Similarly the allied activities of cultivating and processing the plant could be a potential source of employment opportunities and income generation for many Kenyans. In Kenya the plant is grown as an ornamental outdoor and indoor plant and as a fence.

CHAPTER 1

INTRODUCTION

1.1 Background Information

Agave americana plant is an exotic plant that is widely cultivated in the world and probably originated from Eastern Mexico. It was introduced into Europe about the middle of the 16th century and is now widely cultivated for its aesthetic appearance (Mitchel, 1962). It belongs to the *Agavaceae* family. Common names include Century plant or American Aloe. It is not, however, closely related to the genus *Aloe*. The name "century plant" refers to the long time the plant takes to flower, although the number of years before flowering occurs depends on the richness of the soil and the climate. However, the plant generally flowers in 10-15 years in warm climate and much longer in colder ones (Msahli, Sakli F., 2005).

According to Mitchel (1962) the century plant is widely cultivated both indoors and outdoors for its 1.5 to 1.8 meters spiny leaves. The plant is used principally in boarder planting and edging plant. The leaf has a white or yellow marginal or central stripe from the base to the apex. As the leaves unfold from the centre of the rosette the impression of the marginal spines is very conspicuous on the erect young leaves. Each rosette is monocarpic and grows slowly to flower only once. During flowering a tall stem or mast grows from the centre of the leaf rosette and bears a large number of shortly tubular flowers. After the development of the fruit the original plant dies, but suckers are frequently produced from the base of the stem, which become new plants.

Plate 1.1. A. Americana Plant



Cultivation of *Agave Americana* Plant

According to a report by Moris (2006) the plant grows well in acidic, neutral or basic alkaline soils that are well drained, either light (sandy) or medium (loamy). *A. americana* plant grows well in Lanet and Mbaruk areas in Nakuru district, Kenya where it's being planted for its aesthetic purposes. According to Miller (1968) natural fibres are produced in a range of qualities due to variable growing conditions which prevent uniformity. This is an indication that even fibres from same origin can differ in quality depending on the conditions that the plant has been subjected to in the process of growth. In Tunisia, Mexico and West Indies the *A americana* fibres are used for technical applications such as reinforced materials for automotive industry and geo-textiles and also to make ropes and twines for Agricultural and marine purpose.

1.2 Problem Statement and Justification

Kenya is currently forced to import most of its textile materials (Holm-Olsen, Agoa 2005) after the collapse of the textile industries. This is due to lack of enough fibres produced locally. However, there are proposals to reopen the industries. This will be

essential since the United States (US) government has opened its market to Kenyan textiles products and other goods from the region through the African Growth Opportunity Act (AGOA). The Act offered incentives to 38 sub-Saharan African countries to export textile products to the US market tariff and quota free, (AGOA Act, 20th December 2006). The Act also states that with effect from 2008 qualifying textile products should be made from locally produced yarns and fabrics or yarns and fabrics imported from the US. The AGOA regional advisor, called on sub-Saharan beneficiary countries to start growing other varieties of vegetable fibres to make fabrics, instead of relying only on imported yarns and fabrics and locally grown cotton (Holm Olsen, AGOA 2005) hence the need for research, development and utilization of other fibre sources.

Literature review indicates that, the pineapple, banana, *A. americana* and other plants are available in the tropical regions in abundance and their full potential as textile fibres has not been fully exploited and investigated (Chongwen, 2005). However, although the *A. americana* fibres are used for making ropes and twines for agriculture and for marine purposes in Mexico and Tunisia, It has not been examined to verify its usage as a quality textile fibre here in Kenya.

According to Kariuki, (1993), referring to Joseph, (1986), states that natural fibres produced under different environmental conditions such as soil type and weather can significantly affect the fibre properties. Method of extraction and stage of growth are other factors that affect properties of fibres. Due to the different climatic and soil conditions prevalent in Mbaruk and Lanet areas, Nakuru district, the chemical and physical properties of the *A. americana* fibres may be potentially different from those

observed from research carried out in other countries. Hence the need for research to investigate the potential of fibre extracted from locally grown *A. americana* plant leaves. If the plant is found to qualify as a source of quality textile fibres it can reduce reliance on imported fibres, yarns and fabrics, and create a regionally self sufficient textile industry adequate for supply of textile related products for the US market under AGOA.

1.3 Purpose of the Study

To investigate the potential of the fibre extracted from the Kenyan *A. americana* leaves for the production of fibres, yarns, fabrics and related textile articles.

1.4 Research Objectives

The objectives of the study were to:

1. Analyse and determine the soil condition of Lanet and Mbaruk area
2. Extract fibres from the *A. americana* plant.
3. Test and determine the physical and chemical properties of *A.americana* fibres.
4. Spin yarns from the fibres.
5. Construct articles using hand techniques from the developed yarns.
6. To compare *A. americana* fibre properties to the known standard of plant fibres.

1.5 Significance of the Study

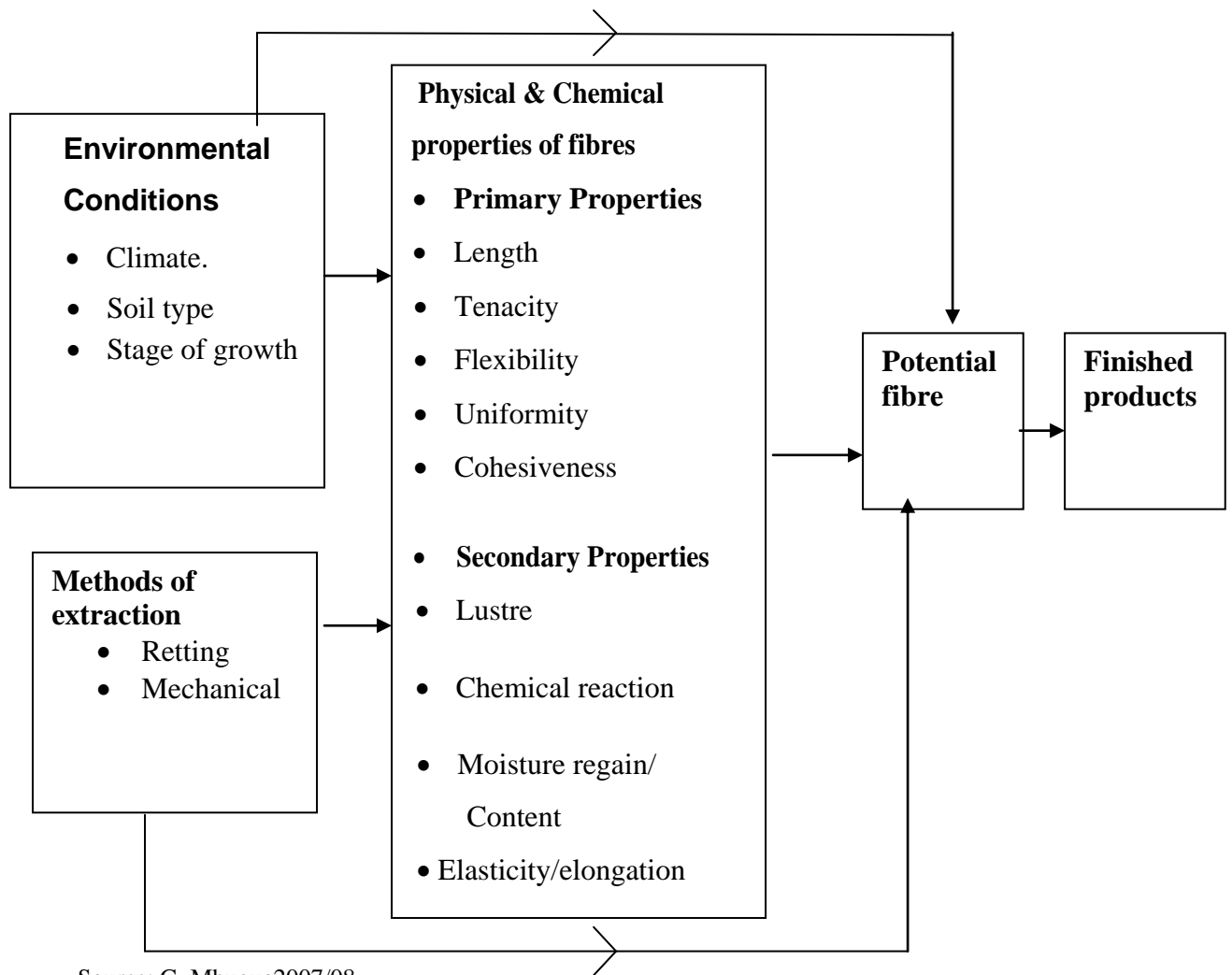
The *A. americana* plant and its allied activities of cultivation; fibre extraction, yarn making, fibre testing, and making value added products could be sources of employment opportunities and income generation for many Kenyans. *A. americana* plant will partially provide an alternative supply of fibres, suitable for textile clothing products. The varied use of *A. americana* fibre will assume in some areas an important economic role, such as the manufacture of textile products such handbags, mats, baskets etc. This will be made possible by having a well designed and managed project of cultivating the plant for fibres, which will supplement the importation of expensive raw textile fibres. In India the plant has medicinal value whereby the fresh juice of the plant is used as an external application for bruises and to cure toothache (Moris, 2006). Traditionally the plant fibre extracted by the Tunisians is used for rope and twine for agricultural and marine purposes (Msahili, et al, 2006).

1.6 Conceptual Framework

A conceptual framework of the relationship between fibre properties, fibre extraction and environmental conditions and the finished textile products.

The independent variables are the environmental conditions and method of fibre extraction, while the dependent variables are the fibre properties both the physical and chemical properties. The dependent variables influences the outcome of a potential fibre hence the finished product.

Figure 1.1: Relationship of environmental condition, methods of fibre extraction and finished product



Source: G. Mbugua2007/08

1.7. Limitations of the Study.

1. The study is limited because the fibre samples were harvested from one geographical area.
2. The method of fibre extraction was limited to the retting process only.

1.8 Assumptions

It is assumed that:

- i) The fibre has the potential for making fabrics for use as clothing, floor mats and for making accessories articles such as ladies handbags, for local use and for export.
- ii) The possibility of the fibre as a raw material for manufacture of gunny bags used for storage of grain.

1.9. Definition of Terms

1. Fibre:

The basic unit used in fabrication of textile yarns and fabrics.

2. Textile

A material formed of fibres, yarns, either by interlacing method of weaving, by the interloping of knitting, by braiding, felting, bonding or laminating.

3. Rosette

A cluster of leaves, or a solitary flower that begins to bloom.

4. Decortications

Mechanical processes of removing the flesh of any plant e.g. stem, roots or leaves to liberate fibres.

5. Microbial retting

A process that breaks the chemical bonds that holds the stem together and allows separation of the bast fibres from the woody core.

6. Moisture equilibrium

The condition reached in a controlled atmosphere by a sample or specimen when

there is no further significant loss or gain in weight.

7. Linear density

Mass per unit length of a yarn, it is expressed in tex.

8. Elongation at rupture

Elongation of a test specimen corresponding to the force at rupture.

9. Force at rupture

Force recorded at the point of rupture of a test specimen during a tensile test.

10. Pretension

Force applied to a test specimen at the beginning of a certain test.

11. Pita Fibre

Fibre obtained from *Agave Americana* plant and other related species, used for making cordage and paper.

12. Geo-Textiles

This refers to filter fabrics, they were first used in filtration application and were intended to be alternative to granular soil filters, in civil engineering and agricultural drainage.

13. Tex

Is a unit of fibre or yarn measurement equal to weight in grams of one kilometer of fibre or yarn.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Plant fibres have been used for making paper and clothing for a long time and the need for use of natural fibres has increased greatly. Among the natural fibres ninety per cent are of vegetable origin and among them 80 per cent is constituted by cotton and the remaining by long vegetable fibres like flax, hemp, sisal, ramie which are classified as minor fibres. According to Balesubramanian (2000), leaf fibres (fibres extracted from leaves) are an important unconventional source of fibres which could be analysed and evaluated for their use in textile and paper industries. *A. americana* fibre is a potential source of textile fibre which grows naturally in Kenya. Related literature has been discussed under the following subsections:

- a) Fibre classification.
- b) Fibre properties.
- c) Morphological and properties of *A. americana* Fibre.
- d) Extraction of *A. americana* fibres.
- e) Usage of *A. americana* fibres.
- f) Textile Testing Equipment

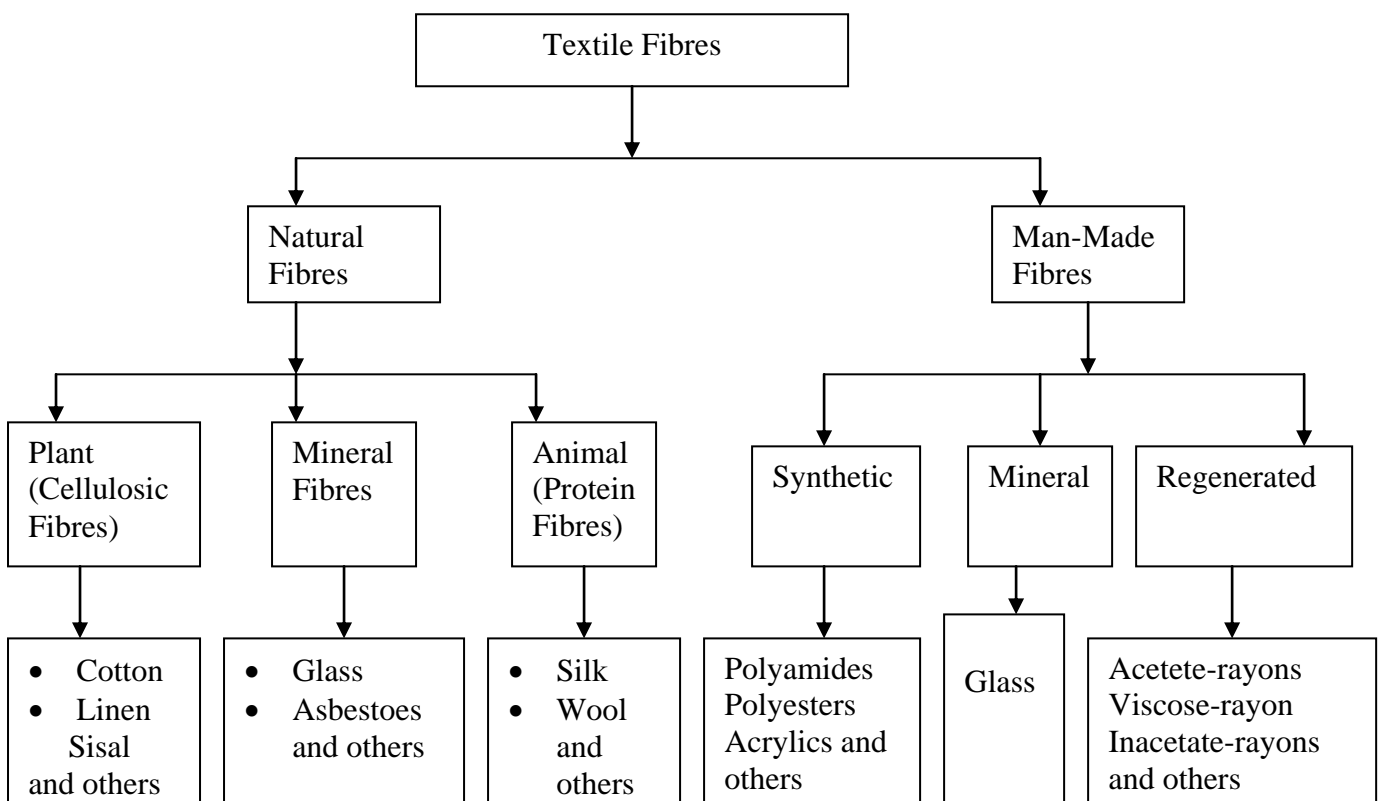
2.2. Fibre Classification

Potter and Corbman (1978) state that fibres are classified according to their sources. They are classified into two categories; the natural fibres and the man-made fibres. The natural fibres are grouped into natural vegetable fibre, the animal fibres and mineral fibres. The vegetables fibres are those that are taken from parts of plants such as cotton, linen, sisal, etcetera and the animal fibres are obtained from the coat of

animals such as wool from the fleece of sheep and from the secretion of silkworm example silk, among others.

Man made fibres are also grouped into synthetic and regenerated fibres. Regenerated fibres are those that are produced by chemical treatment of certain raw materials, among them being wood pulp and cotton linters. The raw materials for synthetic fibres, are entirely from chemical sources such as petroleum products. Some of the most important fibres in this group are the polyamides, polyester fibres and the acrylic fibres. Joseph (1986) states that the use of man-made fibres has increased over the past years. Technology advancement in production of the man-made fibres, cost reductions in the end-use sector, are some of the reasons.

Figure 2.1 classification of fibre



2.3 Fibre Properties

In order to qualify as a suitable substance for use as a textile fibre, a polymer must possess certain essential properties or characteristics (Kariuki, 1993; Nkatha, 1998) referring to Joseph (1986). The production of textiles requires fibres to have ability to withstand the processing of fibres, have the potential to be spun into thread, and make cloth from the thread. Cloth can be constructed in a variety of ways such as knotting, knitting and braiding, but most cloth is made by weaving.

These essential properties of fibres are categorized as primary and secondary properties. Primary properties are the essential properties or characteristic that a polymer must possess in order to qualify as a textile fibre while the secondary properties are those characteristics that are desirable in order to improve consumer satisfaction with the textile made from the fibre (Joseph, 1986).

2.3.1. Primary Properties

The primary characteristics are essential in the manufacturing industry (Joseph, 1986) and they include:

2.3.1.1 High Length to width ratio

This requires the fibrous material to possess adequate length for good spinnability. According to Tortora (1981), longer fibres can be spun at faster speed requiring less twist to produce commercial yarns. Longer fibres are both cheaper to produce into yarns and provide quality fabrics with less tendency to pill. This property dictates the characteristic of a yarn in terms of appearance, evenness and strength. Longer fibres produce yarn which is shiny in appearance and this enables fancy yarns to be

produced for special products (Joseph, 1986; Wingate, 1976).

According to Nkatha (1998), and Gordon (1984), longer fibres tend to increase yarn tenacity consequently increasing the durability of the fabric made from the fibre, and this gives best end use performance of the fabric made from the fibre. Shorter fibres create dull appearances yarn and yarn obtained is rough, fluffy and soft to the feel while longer fibres create a shinny appearance and yarn is smooth and free from fluff. Longer fibres produce fabric with smooth surface and this has less attraction to dirt.

2.3.1.2 Tenacity

This is the ability of the fibre to posses adequate strength. Fibre strength varies considerably among different fibres. This property enables the fibres to withstand mechanical friction during spinning processes. Hall (1975), argues that stronger fibres make durable fabric and that can be light in weight. According to Tortora (1992), the strength of the fabric depends on many other factors. The strength of the fabric is more compatible to the strength of the yarn rather than that of the fibre. For most fabrics a minimum fibre tenacity of about 2.5 gram per denier (g/d) is usually desirable. However, a number of relatively weak fibres with strength less than 2.5g/d are often used in making durable fabrics. This is because such fibres have other important properties that compensate for this low tenacity and produce yarns and fabric with characteristics that appeal to consumers. This fibre property governs the characteristics of the final fabric. Its important where product end use requires high degree of strength especially in work clothes and industrial fabric (Tortora, 1981; Joseph, 1981). However, the fibre must posses sufficient strength to produce adequate durability in the end use to which it is allocated. Some fibres lose their tenacity when wet e.g. pineapple and wool and this means that the fabric made from

them needs gentle handling when washing so as not to injure the fibres. Other fibres gain strength when wet for example cotton and linen.

2.3.1.3 Flexibility / Pliability

This is the ability of the fibre to bend easily without breaking. Fibre must be flexible in order to make yarns and fabrics that can be creased, draped and also have the ability to move with the body to allow freedom of movement (Booth, 1968; Joseph, 1986). This property is important in fabric durability and fabric performance. Fibres which are flexible will form fabrics that have the quality of drapability and ability to move with the body and give when walked or sat upon. This characteristic contributes to clothing comfort. Since flexible fibres do not break easily, this quality also facilitates the spinning process.

2.3.1.4 Cohesiveness/ Spinning Quality

This property enables the fibres to hold or stick together in yarn manufacturing processes. The cohesiveness of the fibres may be due to longitudinal contour or cross-section shape that enables them to fit together and entangle sufficiently to adhere to each other. The cohesiveness of a fibre manifests itself in such yarn characteristics as thickness, surface appearance, surface texture and fabric durability (Hellen, 1969).

2.3.1.5 Uniformity

To make high quality yarns, fibres should be similar in length, width and flexibility when spinning. Yarns that are composed of generally uniform fibres are preferred because they are regular, they appear smooth, and they accept dyestuffs more evenly.

To obtain good quality yarns it is important that the fibres be similar in length and width.

2.3.2. Secondary Properties

The secondary properties are those that are desirable as they may and frequently improve consumer satisfaction with the textile made from the fibres (Nkatha, 1998 and Joseph, 1986). Characteristics on this group include:

2.3.2.1 Physical Shape

The shape of a fibre includes average length, surface contours, surface irregularities and cross-section. These characteristics are the basis for the description of both macroscopic and microscopic appearance of the fibre. The surface contours affects cohesiveness, resilience and thickness of the fibre (Joseph, 1986). The property also contributes to the resistance to abrasion, pilling and comfort of the fabric.

2.3.2.2 Lustre

This refers to gloss, sheen or shine that a fibre possesses. It's the result of the amount of light reflected by a fibre, and it determines the fibres natural brightness or dullness. The availability of fibres with different levels of lustre provides opportunities to market textile products that satisfy demands by consumers for choices based on appearance and aesthetic factors.

Joseph (1986), argues that the degree of luster is obtained in several ways; the use of long fibres produces smooth surface that has a natural luster, and the use of chemicals in certain finishes is also used. The luster of a fibre has an important effect on its ultimate use. Fabrics expected to have high luster are made of highly lustrous fibre.

Availability of fibres with different levels of Lustre presents a base for appearance and aesthetic factors that consumers would look for in a fabric.

2.3.2.3 Colour

The natural colours of fibres vary from pure white to deep grey, tan and black. Natural fibres exhibit the greatest colour difference. In order to enhance and improve the fibres aesthetic value, further fibre processing and colour application e.g. bleaching, dyeing or printing is necessary. This would give the fabric some desirable property that would enhance consumer appeal on the fabric.

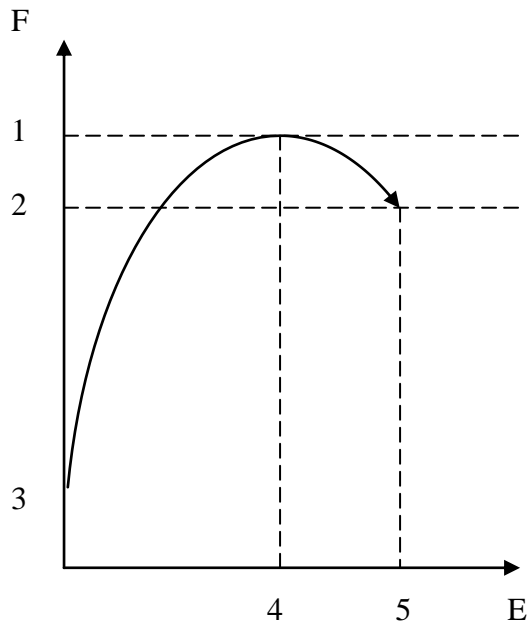
2.3.2.4 Moisture regain and Moisture absorption

Textile fibres, in general, have a certain amount of water as an integral part of their structure. According to Joseph (1996), fibres with good moisture regain accept dyes and finishes more readily than fibres with low regain. However fibres with low moisture regain will wash and dry quickly, while fibres with high moisture regain are relatively slow to dry. The relation of fibre strength to moisture regain has an important consideration in evaluating fibre behaviour. Some fibres are stronger when wet than dry, others weaker when wet and still others exhibit no change. Therefore, the care or maintenance of textile products is influenced by the strength regain relationship (Tortora, 1992, Hellen 1969). A fibre with low wet strength requires careful handling during laundering to prevent undue stress and damage on the wet fibre. Potter and Corbman (1978), state that moisture regain has an important bearing on health and comfort. A fibre that permits some moisture absorption is comfortable to wear especially during hot weather. For example linen and cotton absorb moisture more quickly and for this reason coupled with their strength and hygienic

characteristics, are excellent for towel and handkerchiefs. However, fibres with low moisture absorbency like nylon feel uncomfortable on warm and humid days. Absorbent fibres are good for the skin contact apparel and diapers (Hellen 1969).

2.3.2.5 Elasticity / Elongation

Elongation is the amount of stretch or extension that a fibre will accept. Elastic recovery designates the percent of return recovery towards the original length. The amount of elongation is an important factor in evaluating elastic recovery. Booth (1968), argues that the greater the elastic quality, the more the fibre will resist tearing. Elasticity permits the materials to drape well on the body. Since elastic fibres do not break as easily as inelastic ones, this quality facilitates the spinning process (Joseph, 1986). For example nylon is the highly elastic fibre with good elongation properties. This assures outstanding shape retention of nylon fabrics. Figure 2.2 shows elongation of a test specimen produced by maximum force. This also shows the maximum force recorded when a test specimen is taken to rupture during a tensile test under the specified conditions.

Figure 2.2 Example of Force-Elongation Curve

F = Force

E = Elongation

1 = Maximum Force

2 = Force at Rupture

3 = Pretension

4 = Elongation at maximum force

5 = Elongation at Rupture

2.3.2.6 Resilience

This is the ability of a fibre to return to shape following compression, bending or similar deformation. This property is important in determining the crease recovery of a fibre or fabric. Joseph (1986), states that when a fibre is resilient, it can be spun or twisted into springy yarns and the resultant fabric is also resilient. This quality causes the fabric to be wrinkle-resistant. Resiliency also contributes to abrasion resistance of a fabric. According to Hellen (1969) resilience and elasticity improve wearing qualities and their shape. Fabric with good resiliency does not crease and needs little

or no ironing and this is an important factor to the consumer.

2.3.2.7 Thermal behavior

This indicates the behavior of the fibres at various temperatures. Burning characteristics of a fibre are important in determining care and use. Nkatha (1998), states that burning of small quantities may be used as a means of differentiating one fibre group from another. For example some fibres scorch and flame, others melt and flame or shrink. Some fibres are self extinguishing, others are completely non-combustible. Fibres which are self extinguishing are good for children, sleepwear and protective clothing.

2.3.2.8 Resistance to chemical/environmental conditions and biological organisms

These properties include the way the fibres react to selected chemicals and environmental conditions i.e. sunlight and other climatic variables and to micro organisms such as bacteria, fungi and insects such as moths. Chongwen (2005), states that for improving some characteristics and spinnability of vegetable fibres chemical treatment can be used to modify the fibres. Tortora (1992), indicates that cellulosic fibres are damaged by strong mineral acids and harmed by dilute concentrations of these substances. The bonds connecting the sub-units are unstable to acid and the result is a loss of tensile strength and the susceptible fibres dissolve with time.

2.4 Morphological and physical properties of *A. americana* fibres.

Msahli and Sakli (2005) indicated that the *A.americana* fibres are white to yellowish in colour, and have a hard touch due to the existence of lignin on the surface. Also observed were the longitudinal streaks, which are characteristics of long vegetable fibres.

Msahli and Sakli (2005), also state that sticky and waxy substances hold the fibres together. The fibres show oval and irregular sections with large lumen when observed on cross- section view. According to Msahli and Sakli (2005) the *A. americana* fibres are coarse fibres. Compared to the fibres of the same family, the *A .americana* fibres are said to be light, with a density equal to 1.36 measured at 21°C using the gradient column technique. Compared to other plant textile fibres, the *A .americana* fibres are more hydrophilic than cotton, flax and other vegetable fibres (Msahli et.al .2006) with a regain equal to 17%. At this point they are comparable to jute and wool fibres. The *A. Americana* fibre has a high resistance to chemical agents such as acids and alkalis. Its very fragile when exposed to high temperature of up to 108° C (Msahli and Sakli, 2005).

2.5 Extraction of *A.americana* fibre

The process of extraction of *A. americana* fibres has not been documented. However, Msahli, et. al (2006) suggest that a fibre extraction method similar to that used on sisal can be used. Rehns and Espg (1991) state that a process of decortications is used to extract the sisal fibres from the leaf tissues. The leaves are crushed and beaten by a rotating wheel set with blunt knives so that only the fibre remains. All other parts of the leaves are washed away before drying in the sun or by hot air. Rehns and Espg

(1991) further argue that, proper drying is important as the fibre quality depends largely on moisture content.

Artificial drying has been found to result in generally higher grade fibres than sun drying (Rehns and Espg, 1991). Dry fibres are then machine combed and sorted into grades. Msahli and Sakli (2005) indicated that *A. americana* fibres can be extracted from their leaves either mechanically by a combined action of crushing and beating using a machine called Raspador or by retting the leaves in water and cleaning either by hand or with a decorticator. According to Msahli and Sakli (2005) research done on the *A. americana* plant indicates that the microbial retting of the leaves in water would be the easiest and cheapest method of extraction of the fibres.

Retting is a microbial process, which breaks the chemical bonds that hold the fibre bundles together (Ehrensing, 1998). This partial rotting of the stem allows easy separation of individual fibre strands and the woody core.

Ehrensing (1998) also states that since retting is a biological process, it requires both available moisture and a temperature warm enough for microbial action to occur. The two traditional types of retting include water retting in which plant stems are immersed in water (river, pond or tanks) and field or dew retting in which the crop is spread in the field where rain and dew provide moisture for retting. Water retting produces fibres of greater uniformity and higher quality than can be produced by field retting, though it is very labour and capital intensive (Ehrensing, 1998).

2.6. Soil Composition

Soils are a mixture of different rocks, minerals and decaying plants and dead animals.

According to Wambeke (1992), soil can be very different from one location to another but generally consist of organic and inorganic materials, water and air. The inorganic materials are the rocks that have been broken down into smaller pieces. The size of the pieces varies and may appear as pebbles, gravel or as small particles of sand or clay. The organic materials are decaying living matter that could be plants or animals that have died and decayed until they become part of the soil. The amount of water in the soil is closely linked with, the climate and other characteristics of the region. Sand determines aeration and drainage characteristics while the tiniest sub-microscopic clay particles are chemically active, binding with water and plant nutrients. The ratio of clay to sand determines soil types. The composition of the soil affects the plants characteristic such as growth rate and to some extent the plants fibre properties (Kariuki, 1993 referring to Joseph, 1986).

2.7 Usage of *A. americana* plants

In Indian traditional medicine the fresh juice of the plant is regarded as a good external application for bruises. The largely fleshy leaves when cut into slices, may also be used as a poultice, while the gum exuding from the leaves and roots is used as a cure for toothache. The *A. americana* is used for the treatment of skin problems in folk veterinary medicine in Italy. It has also been used as an insecticide (Moris, 2004). The juice from many species of agaves can cause acute dermatitis. It will produce reddening and blistering lasting one to two weeks. During the development of the inflorescence there is a rush of a sap to the base of the young flower stalk. In the case of *A. americana* and other species this is used by the Mexican to make their national beverage, pulque (Wikipedia 2005). By distillation a spirit called mezcal is prepared; one of the most well known forms of mezcal is tequila.

Also according to Wikipedia (2005) the leaf of *A. americana* is the source of pita fibre used as a fibre plant in Mexico and the West Indies and southern Europe. The fibre can also be used in technical applications such as making reinforced materials and geotextiles. In Tunisia the *A. Americana* fibres are used to make ropes and twines for agricultural and marine purposes. Wikipedia (2005) states that the Native Americans of Mexico used the *Agave* to make fibre ropes. In India the plant is extensively used for hedges along railroads. Currently in Kenya the plant is mostly used as an outdoor plant for its aesthetic appearance.

2.8 Textile Testing Equipment

In order to carry out quality fibre testing, Merkel (1991) suggests that a textile laboratory should at least have the following textile testing equipment. A *sliding Psychrometer* or two *ordinary thermometers*. Whether or not one has a conditioned space that can be maintained at the standard atmosphere of $65 \pm 2\%$, one should be able to check the temperature and humidity in the laboratory under which tests are performed. To test the fibre length *two metric rulers* are sufficient to measure the length of the fibre samples.

An electronic balance with a capacity of several hundred grams and sensitivity helps to determine weights of samples, and weighing chemicals to be used in the tests.

Moisture regains in textile fibres or material is usually measured by first drying the material in an *oven*, which should be operated at a temperature slightly above the boiling point of water. The material is then cooled in *desiccators*. The desiccators are needed because one cannot weigh the fibre or material accurately when it is warmer

than the surrounding atmosphere. If the material or fibre cools in the open air, instead of in the desiccator, it will regain some moisture before it is weighed. The weight of the material immediately after removal from the desiccators is said to be oven dry weight (Merkel, 1991).

A textile fibre, yarn or fabric is under tension when the two ends are pulled in opposite directions or one end is pulled while the other end is held in a clamp. Tensile test on fibre, yarns or fabrics may be continued until the material breaks. Then the breaking load and the breaking elongation are measured, (Merkel, 1991). This is done by the use of a *tensile testing machine*, e.g. the CRE-Constant Rate of Extension, CRT - Constant Rate of Traverse and lastly the CRL-Constant Rate of Load that is normally used for testing wide elastic fabrics. At Kenya Bureau of Standards they have the CRE Tensile testing machine.

In burning test the researcher requires only a small flame and *tweezers* or a small clamp. A *candle* is usually used as a flame source; the clamp holds a tuft of fibres. Microscopic differences among the various textile fibres can be seen in both longitudinal and cross-section view under a *microscope* at a magnification of 100 times or more.

CHAPTER III

METHODOLOGY

3.1. Introduction

This chapter includes the following sub sections: research design, soil analysis, sampling of the plant, fibre extraction process, fibre testing, fibre testing procedures yarn spinning construction of articles and data analysis.

3.2 Research Design

The experimental research design was employed. The independent variable included the standard properties of fibres, while the dependent variables were physical and chemical properties of the fibres. The researcher intended to investigate the quality of fibre extracted from the *A. americana* plant. After fibre extraction and processing the sample was randomly assigned to the experimental tests. The procedure included observation and description of what was observed.

3.3 Soil Analysis

Soil samples were collected within a radius of 3 kilometers from the areas where the leaves were harvested. The soil samples collected were categorised into two; top soil and sub soil. Twelve top soil samples were collected within a radius of three kilometres and were dug out upto a depth of 20cm. The soil samples were then transferred into a bucket. The soil in the bucket was thoroughly mixed and a quarter a kilo of soil placed into a polythene bag and labelled top soil. At every point from where the top soil samples were collected sub-soil samples from 20-50cm depth were collected and placed into a second bucket and then mixed thoroughly. A quarter kilo

of the sub-soil was then placed into a polythene bag and labelled sub-soil. The soil samples were collected during the dry season. The soil samples were presented to the National Agricultural Research Laboratories at the Kenya Agricultural Research Institute (KARI) Nairobi. A routine soil analysis was conducted on the soil samples.

3.4 Sampling of the Plant

The *A. americana* plant was harvested from Nakuru District at Lanet and Mbaruk Locations. The locations were selected as they had similar environmental conditions and had an abundance of the *A. Americana* plant leaves. The leaves were purposively collected in order to obtain leaves almost of the same age; this was done by observing the colour, size and position of the leaf on the plant. Generally the plant leaves were of the same size. The position of the extracted leaves was on third level from the base towards the apex, (third leaf from the base of the plant) to avoid very old or very young leaves. The oldest leaves are at the base while the youngest are at the apex. A total of seventy five plant leaves from twenty five different plants were collected for the experiment (i.e. three leaves from each plant selected).

3.5 Fibre Extraction Process

According to Balesubramanian (2000), research done on the *Agave* plant indicated that the microbial retting of the leaves in water was found to be the easiest and cheapest method of extraction of the fibres. Microbial retting process breaks the chemical bonds that hold the stem together and allows separation of the bast fibres from the woody core. Moisture was a key requirement for microbial breakdown to occur. The chosen leaves were ripped off the plant by use of a sharp knife and then bundled together. The leaves were then subjected to the retting process, whereby the leaves were immersed in water in a tank at room temperature. The retting process

took about 26 days to rot away the cellulosic matter that holds the fibres together. The fibres obtained were then washed in plenty of water to remove the green slime residue and dried under a shade to avoid bleaching.

3.6 Fibre Testing

The fibre testing was carried out at the Testing Service Department (Textile) at the Kenya Bureau of Standards in Nairobi

3.7 Fibre Testing Procedure

Fibres samples each weighing 30gm were conditioned in a conditioning chamber to reach moisture equilibrium. The conditioned fibres were picked randomly and then assigned for the experimental treatments. The tests were carried out with the standard textile testing conditions of relative humidity $65 \pm 2\%$ and temperature at $20 \pm 2^\circ\text{C}$ to ensure accuracy and reliability of results.

The fibres were subjected to the following tests:

(a). Physical Test

i) Microscopic Examination:

Both the longitudinal and cross-sectional views of the fibres were examined.

Procedure: -

- a) For the longitudinal examination, a single strand of fibre was placed on a microscope slide and the fibre observed and features noted.
- b) For cross-section view, a single strand of the fibre was also observed on a microscopic slide, where a single strand of the fibre was suspended vertically by hand with the free end of the fibre touching the bottom of a cylindrical rubber

container. Melted paraffin wax was poured into a rubber container and the fibre was held in position until the wax solidified. The rubber container was pressed on the sides gently to release the cylindrical shaped wax with the fibre embedded in the middle. A sharp razor was used to slice the wax in cross-section to expose the cross-sectional view of the fibre. The section was observed under a microscope. Both the longitudinal and cross-section view are important for comparison with other fibres. The shape and surface contours are the most important determinants of the character of fibre luster cohesiveness and resiliency. Cross-section contributes to characteristics such as appearance, hand or feel and surface texture of fabric.

(ii) **Burning tests**

This was primarily to investigate the thermal reaction of the *A. americana* fibres. It showed the fibre behaviour at different temperatures. These provide valuable data regarding appropriate use and care of the fabrics.

Procedure: -

A sample of the fibre was held using a pair of tweezers and slowly moved towards a candle flame. The reaction of the fibre was noted at different positions: the reaction of the fibre approximately 5mm from the flame, the reaction of the fibre in the flame and after the removal of the fibre from the flame. After the sample had cooled the residue was examined under a microscope. The form, hardness and colour of the ash were noted.

(iv). **Fibres length**

This was to help determine the average fibre length. The length must be considerably greater than the diameter. A minimum ratio of 100:1 is usually

considered essential, Joseph, (1986). This property dictates such characteristics of yarn and fabric in terms of appearance, evenness and strength. Nkatha (1998), referring to El Mogahzy (1992) said that the longer the fibre is the less the fibre per cross- section required for a given strength.

Procedure:

One hundred single fibres were drawn at random and each fibre was straightened out over a meter-ruler. The length was recorded in centimetres.

(v) Moisture content and regain:

This test was to determine the percentage of moisture contained by a fibre sample at moisture equilibrium in standard atmosphere for textile testing. It helped determine the percentage moisture regain by a dry sample of *A. americana* fibres. Since textile are hygroscopic in their natural state and moisture content increases as humidity increases its important to determine this quality. Fibres with good moisture regain accept dyes and finishes more readily and hence produce a variety of attractive yarns and fabrics for consumer end use. However, fibre with low moisture regain will wash and dry quickly.

Procedures:

Ten samples of different weights were placed in an oven set at 100°C and dried for at least four hours after which they were cooled in a desiccator. The samples were then quickly transferred into a weighing scale and oven dry weight was recorded.

Formula to be used:

$$(i) \text{ Moisture content} = \left[\frac{a - b}{a} \right] 100$$

a = original mass of sample (in grams)

b = the oven dry mass of sample (in grams)

$$(ii) \text{ Moisture Regain} = \left[\frac{a - b}{b} \right] 100$$

(vi) Breaking Tenacity and Elongation (wet and dry)

This test was to determine the mean breaking load per denier and percentage elongation at break, and compare the breaking tenacity and elongation at break for dry and wet fibres. Constant rate of extension (CRE) tensile testing machine was used. The test is important since this property contributes to the durability of fabric and versatility in end use. During the spinning process the fibres can also withstand mechanical friction. The elongation of a fibre is an important factor in evaluating the quality of the fibre in terms of durability and elastic recovery.

Procedures:

Forty strands of dried *A. americana* fibres were held and straightened out together and the length measured. A uniform length of 45cm was used. Each fibre sample was then weighed and the weight was recorded. The specimen were mounted individually between the jaws of the clamps (of tensile testing machine) to remove slack without stretching the specimen. The machine was started and the specimens pulled to a break point. The tenacity, elongation at break (rupture), force at break were recorded. A similar test was carried out for testing wet breaking tenacity and elongation at break. However, for this test the samples were first immersed in distilled water for 1 hour.

(b). Chemical Test**iv) Chemical reactions:**

The aim of this test was to test reaction of the fibres to various chemicals. Test procedures were to determine the susceptibility of the fibre to; alkalis, acids, and organic solvents. The reactions observed included swelling and dissolution, dissolution without swelling, disintegration, colour reaction and changes and duration taken for the changes to occur. This test is very important since chemical reactions are utilized in the manufacturer processes of the fibre. According to Tortora (1992) and Nkatha (1998) the application of finishes and dye stuffs on textile must take into account the effect of acids and alkalis on textile fibres.

The chemicals used included strong acids; such as concentrated sulphuric acid, nitric acid and hydrochloric acid. Weak acids includes; acetic acid and citric acid. Strong alkalis such as sodium hydroxide, potassium hydroxide, and weak alkalis such as ammonium hydroxide and sodium hydrogen carbonate were also used.

Procedures

Different types and concentrations of each acid/alkalis were placed in Petri dishes. Several *A. americana* fibres were dropped into the acid/alkalis. The fibres were left for between five minutes to thirty minutes this was important to determine duration of reaction of the fibre in different chemicals. The changes were then noted.

3.8 Yarn spinning and construction of articles

The fibres were spun into yarns using hand spinning. The spun yarns were dyed and sample articles were made using different methods of fabric construction e.g. weaving, crocheting and braiding.

3.9 Data Analysis

The data analysis was both qualitative and quantitative. The observation during fibre extractions was recorded. It also involved observation of the fibre behaviour towards chemicals, heat and other tests mentioned above. Descriptive and inferential statistics were used for the parameters to be tested. These included the mean of the fibre length, moisture content, moisture regain, elongation at break and breaking tenacity.

The data results were compared to known standard of plant fibres and to properties of other common textile fibres (examples cotton, pineapple, aramina, linen and jute) to determine whether the *A. americana* fibre qualifies to be used as textile. The data is presented in form of reports, tables and graphs.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Introduction

The knowledge of the fibre properties helps to anticipate the contribution of the fibres to the performance of a fabric and the textile products of it. The fibre properties of *Agave americana* plants were investigated for their potential as a new source of textile fibres. The following tests were carried out:

1. Soil analysis
2. Physical tests of the fibre
 - a). Microscopic examination
 - b). Burning tests
 - c). Fibre length
 - d). Fibre diameter
 - e). Moisture content and regain
 - f). Breaking tenacity and elongation
3. Chemical tests
 - (a). Strong acids
 - (b). Weak acids
 - (c). Strong alkalis
 - (d). Weak alkalis

4.2. Soil Analysis

According to a soil analysis report received from KARI, the prevailing soil type in the area of plant extraction is sandy clay loam. The soil is well drained, brown to dark

brown in colour. The soil pH was found to be 4.5 to 5. This was an indication that the soil was acidic. The essential elements in soil nitrogen, organic carbon, phosphorus, sulphur, calcium and magnesium content is high apart from potassium and nitrate which are low.

Moris (2006), states that the plants grow well in acidic neutral or basic alkaline soils that are well drained. The plant requires mainly calcium, magnesium and sulphur nutrients for healthy growth. According to the above results the *A. Americana* requires well drained soils and sunny conditions.

4.3 Fibre Extraction

The chosen leaves were ripped off the plant using a sharp knife. Microbial retting process was conducted by placing leaves in water at room temperature for twenty six days in a coated metal container. During retting, bacteria and fungi broke down the intercellular material loosening the fibres. The plant juice was irritating to the skin and caused rashes and reddening of the skin. This required one to change the water several times before washing the fibres. The fibres were then washed in plenty of water to remove the remaining green slime residue. Drying in the shade was done as a final step in the extraction process. The fibres were dried under a shade to avoid bleaching by direct sun light. The fibres produced were smooth, flexible, lustrous and softer than sisal fibres. The colour of the fibre was off white.

Plate 4.1

i. Soaked leaves for retting



→ Metal container

→ Americana leaves placed in water for retting process

Plate 4.2

ii. Fibres after washing, drying and brushing



4.4 Fibre Tests

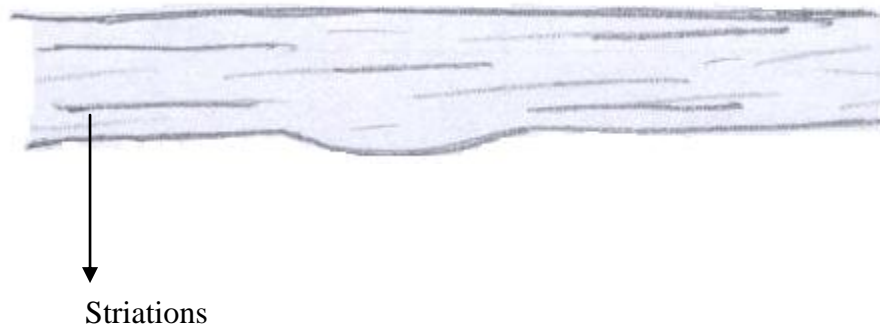
A mass of fibre samples were conditioned in a conditioning chamber, to a temperature $20 \pm 2^\circ\text{C}$ and relative humidity of $65 \pm 2\%$ for at least 24 hours, in compliance with Kenya standard, KS 08-32. The conditioned fibre samples were then picked at random and subjected to tests as indicated in chapter 3. The results obtained were as follows:

2. Physical test

4.4.1 Microscopic examination

The longitudinal appearance of the fibre was a straight tube which was slightly round. Longitudinal striations (horizontal lines) were visible which are characteristic of long vegetable fibres. No apparent nodes were noticed as in the case of linen fibres. The striations (horizontal lines) are shadows that appear as dark lines caused by the valleys in between the lobes. Their presence is important because they increase the ability of the fibre to hide soil which is an important aspect for products such as carpets and mats. Apparently the fibre surface looked smooth and lustrous. The lustre of a fibre has an important effect on its ultimate use and provides opportunity to market products that satisfy demands by consumer for choices based on appearance and aesthetic factors.

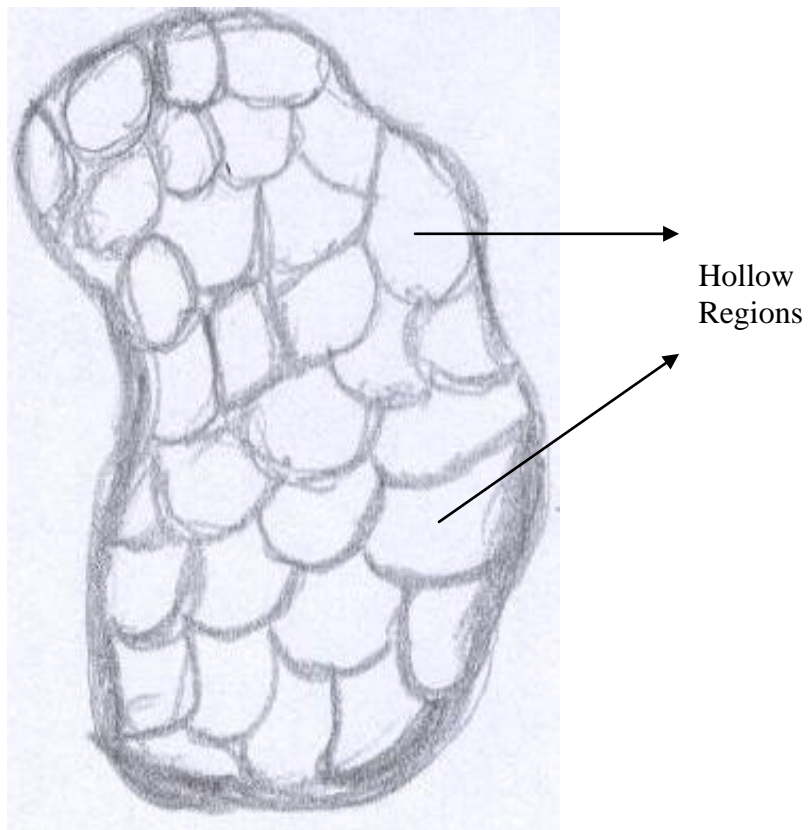
Figure 4.1 Longitudinal view under microscope



Cross sectional view

The cross sectional of the fibre appeared lace-like, with hollow regions, the edges looked irregular, with an oval shape, this contributed largely to the luster of the fibre. Tortora (1992) and Nkatha (1998), note that cross-section appearance varies from fibre to fibre ranging from circular to oval, triangular, u-shaped and hollow. Msahli (2006), notes that Tunisian *A. americana* fibres show an oval and irregular section with a large lumen. This analysis shows a typical characteristic of Natural Cellulosic fibres. The observation made indicates that light rays reflected by the fibre are broken up due to the high number of fibre surfaces that face each other. This in turn contributes to the lustre of the fibre as shown in figure 4.2.

Figure 4.2 Cross-sectional view



4.4.2. Burning Test

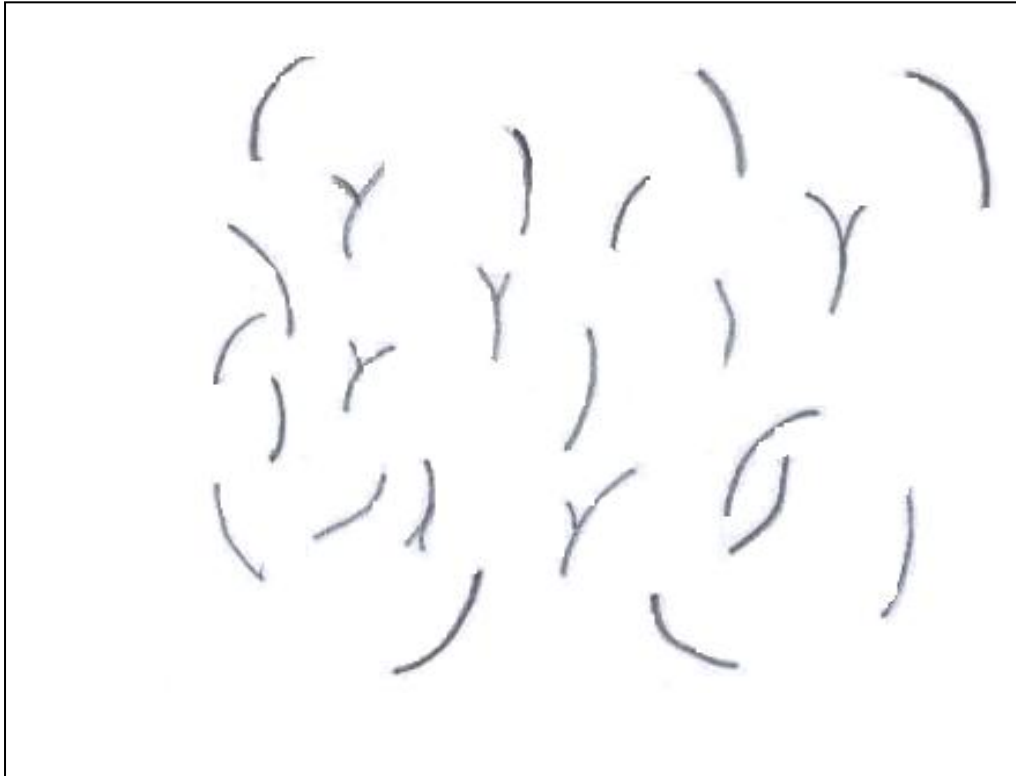
When the fibre sample was brought near the flame, it flared up. In the flame the fibre continued burning readily with a yellow-bright flame. After the removal of the fibre from the flame, it continued burning. The smell emitted was like of burning paper. When the flame died, the fibre continued to glow until put out. This indicated that the fibres are not self-extinguishing and for them to be used safely near fire, they require an appropriate fire-retardant and protective finishes to be fire-proof.

Table 4.1: Analysis of the burning test

Fibre	Approaching flame	In Flame	Residue	Other properties
<i>A. Americana</i>	Burns readily without shrinking	Continues burning readily	Fine fair grey crushable ash	Odour similar to burning paper

Natural cellulosic fibres (example; cotton, linen) exhibit similar behaviour when subjected to similar test. This indicates that cellulosic fibres are not thermoplastic and will not melt (Cook, 1968). Exposure to dry heat at temperature above 150 °C however does cause gradual decomposition of the fibre. Excessive high ironing temperature causes the fibre to scorch or turn yellow. The fibre can stand great heat since its scorching point is high. Therefore, hot ironing temperatures can be used safely on the fibre.

Figure 4.3 Ash structure under a microscope



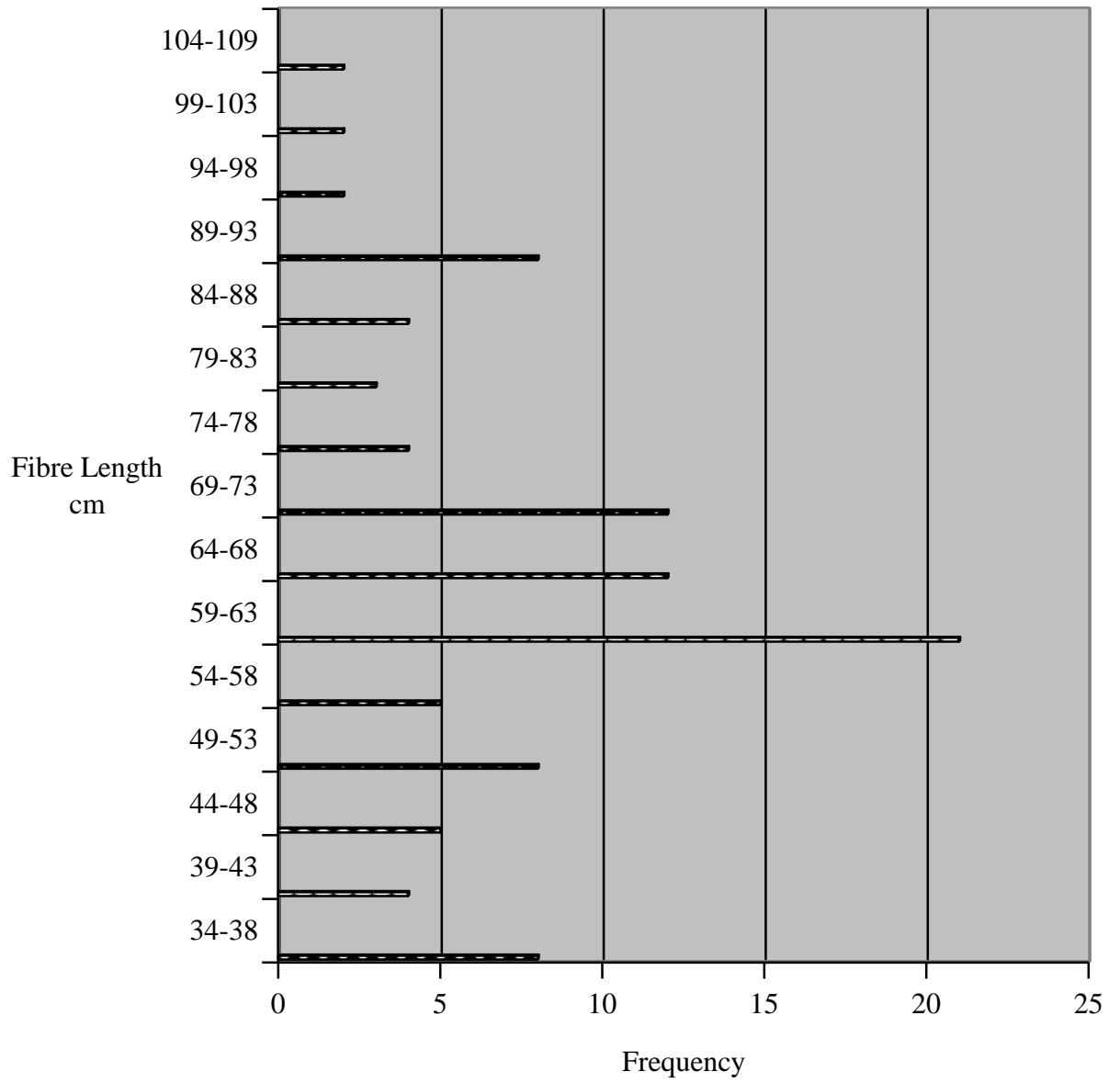
A very fine, grey ash was left behind after burning. It was crushable to dust under slight touch. Under the microscope the ash looked like fibrous waste or vegetable waste. The colour varied from white to black.

4.4.3 Fibre length

The fibre length data is presented in a group frequency distribution table (Table 4.1) and graphically presented as in frequency distribution chart below. A fibre must possess adequate length for good spinability, length attributes to the characteristics of a yarn in terms of appearance, evenness and strength.

Table 4.2 Fibre Length analysis

Length (cm)	Frequency (f)	Cum (freq)	Mid- point x	X²	fx	f(x)²
34-38	8	8	36	1296	288	10368
39-43	4	12	41	1681	164	6724
44-48	5	17	46	2116	230	10580
49-53	8	25	51	2601	408	20808
54-58	5	30	56	3136	280	15680
59-63	21	51	61	3721	1281	78141
64-68	12	63	66	4356	792	52272
69-73	12	75	71	5041	852	60492
74-78	4	79	76	5776	304	23104
79-83	3	82	81	6561	243	19683
84-88	4	86	86	7396	344	29584
89-93	8	94	91	8281	728	66248
94-98	2	96	96	9216	192	18432
99-103	2	98	101	10201	202	20402
104-108	2	100	106	11236	212	22472
					$\sum fx=6520$	$\sum f(x)^2=454990.0$

Figure 4.4 Frequency Distribution of Fibre Length

$$\begin{aligned}
 \text{The mean length is given by} &= \frac{\sum fx}{\sum f} \\
 &= \frac{6520}{100} \\
 &= 65.2 \text{ cm}
 \end{aligned}$$

$$\text{The median is given as} = L + \left[\frac{\frac{n-c}{2}}{f} \right] i$$

Where L = lower class limit of class containing the median

n = number of fibres

c = cumulative frequency of class below the median class

i = class interval

f = frequency of class containing the median

$$\begin{aligned}
 \text{Median} &= 59 + \frac{(50-30)5}{21} \\
 &= 63.76 \text{ cm}
 \end{aligned}$$

$$\begin{aligned}
 \text{Standard deviation is given as} &= \sqrt{\frac{\sum fx - x}{\sum f}} \\
 &= \sqrt{\frac{454990 - 4251}{100}} \\
 &= \sqrt{298.860} \\
 &= 17.29
 \end{aligned}$$

The coefficient of variation is given as

$$\begin{aligned}
 &\frac{\text{Sd}}{\text{Mean}} \times 100 \% \\
 &= \frac{17.29}{65.2} \times 100 \\
 &= 26.52\%
 \end{aligned}$$

The length of the fibre ranged between 33.6 cm to 107.0cm. This gave the range of the fibre as 73.4 cm. The range was high, due to the different sizes of leaves and fibre extraction process that resulted in a few fibres breaking. The median length was 63.76cm and the mean length was 65.2cm with a standard deviation of 17.29cm. The co-efficient of random variation was 26.52%.

However, the relative dispersion in length of the fibre was relatively low. Most fibres were generally almost of equivalent length. According to Hall (1975), fibres length varies considerably within any sample. This shows that the fibre length goes beyond the boundaries of a typical fibre. The length of the fibre strands depends on the length of the sheath (Msahli, 2006). From the above data it shows that the *A americana* fibre is of a length that can be spun. This also indicates that yarns spun from this fibre will be of considerable strength and hence produce durable textile products.

4.4.4 Fibre diameter

The tests were conducted in accordance with Kenya Standards ks 08 – 268, method of determining diameter. The data in the table (4.2) illustrate the diameter of the fibre.

Table 4.3 Diameter in mm

Sample No.	Diameter mm	$x - \bar{x}$	$(x - \bar{x})^2$
1	0.15	0	0
2	0.17	0.02	0.0004
3	0.15	0	0
4	0.16	0.01	0.0001
5	0.15	0	0
6	0.18	0.03	0.0009
7	0.15	0	0
8	0.11	-0.04	0.0016
9	0.16	0.01	0.0001
10	0.12	-0.03	0.0009
11	0.14	-0.01	0.0001
12	0.15	0	0
13	0.16	0.01	0.0001
14	0.15	0	0
15	0.12	-0.03	0.0009
16	0.13	-0.02	0.0004
17	0.15	0	0
18	0.14	-0.01	0.0001
19	0.15	0	0
20	0.16	0.01	0.0001
	$\sum x = 2.950$		$\sum (x - \bar{x})^2 = 0.0057$

Mean diameter is given as $\frac{\sum x}{n}$

$$\frac{2.95}{20}$$

$$= 0.15\text{mm}$$

$$\begin{aligned}
 \text{Standard deviation given as } & \sqrt{\frac{\sum x(x-x)^2}{n}} \\
 & = \sqrt{\frac{0.0057}{20}} \\
 & = 0.017
 \end{aligned}$$

$$\begin{aligned}
 \text{Coefficient of variation} & = \frac{\text{Sd} \times 100}{\text{mean}} \\
 & = \frac{0.017 \times 100}{0.15} \\
 & = 11.33\%
 \end{aligned}$$

The mean diameter of the fibre was 0.15mm, with a standard deviation of 0.017mm and a coefficient of variation of 11.33%. The fibre variation in diameter is low. The fibres were generally of almost equal diameter. The uniformity of fibre width is an important aspect in spinning quality and flexibility. The finer the fibre the better the spinning quality (Morton, et al. 1985). Fibre diameter's importance is largely due to its contribution to softness and to the fact that finer fibre generates fibre yarns which produce light weight fabrics. This is critical in modern textile industry as the demand by modern consumer is to seek comfort and enjoyment in wear, which is found in light weight fabrics.

4.4.5 Moisture content and regain

The test was performed in compliance with Ks 08-508, (1998) part1 method of determining moisture content and regain. The data in the table 4.4, illustrates the results. The formulae used to determine the moisture content and regain is as indicated in chapter 3.

Table 4.4 Moisture content and regain

Sample No.	Original weight in g (a)	Oven-dry weight in g (b)	Moisture content % $c = \frac{(a-b)}{a} \times 100$	Moisture regain % $c = \frac{(a-b)}{b} \times 100$
1	2.2502	2.0589	8.514	9.291
2.	1.7815	1.6214	8.987	9.874
3.	1.7548	1.6071	8.417	9.190
4.	1.4108	1.2603	10.655	11.902
5.	2.0479	1.8555	9.395	10.369
6.	2.6204	2.3826	9.075	9.981
7.	2.4015	2.2145	7.993	8.459
8.	1.9247	1.7562	8.755	9.595
9.	2.3681	2.1675	9.555	9.255
10.	1.7813	1.5923	10.595	11.875
			$\Sigma = 91.939\%$ $X = 9.19\%$	$\Sigma = 99.786\%$ $X = 9.98\%$

The moisture content is 9.19%. It is also comparable to other cellulosic fibre for example aramina 8.86%, pineapple 9.45%. The overall moisture regain is 9.98%. Its comparable to moisture regain of other cellulosic fibres for example ramie 6%, cotton 8.5%, linen 12%, pineapple 10.4% and aramina 9.73%. The fibre shows hydrophilic properties. This implies that it absorbs enough water to prevent static build-up. Moisture regains influences comfort and fibres with good moisture regain accept dyes and finishes more readily than fibres with low regain (Joseph, 1986). Therefore this is an indication that the water-borne dyes and finishes can be applied on the fibre. This attribute was further confirmed when the fibres were dyed. They accepted dyes very readily.

4.4.6 Breaking Tenacity and Elongation at break (Dry and Wet)

The test were performed in compliance with Kenya standard, KS 08-630, (1987) part 2, of method for determination of tenacity of textile fibres and yarns . The tenacity of the fibre was obtained directly from a computer connected to the textile testing machine which had been adjusted to indicate tenacity instead of breaking load for specimen of known linear density. Therefore the linear density was first obtained. The results are presented in tables 4.5, 4.6 and 4.7.

Table 4.5 Linear density

Sample No	Fibre length in metres	Fibre weight in g
1	0.701	0.0079
2	0.910	0.0183
3	0.867	0.0125
4	0.836	0.0129
5	0.901	0.0127
6	0.859	0.0146
7	0.663	0.0078
8	0.672	0.0087
9	0.800	0.0080
10	0.674	0.0064
11	0.738	0.0072
12	0.976	0.0165
13	0.651	0.0123
14	0.960	0.0100
15	0.691	0.0099
16	0.963	0.0172
17	0.739	0.0088
18	0.858	0.0134
19	0.931	0.0154
20	0.651	0.0132
	$\Sigma=16.04$ $X=\frac{16.041}{20}$ $=0.80205$	$\Sigma=0.2337$ $X=\frac{0.2337}{20}$ $=0.011685$

The linear density was calculated using the formular:

$$\begin{aligned}
 \text{Linear density} &= \frac{\text{weight x1000}}{\text{Length}} \\
 &= \frac{0.011685 \times 1000}{0.80205} \\
 &= 14.569 \text{ tex}
 \end{aligned}$$

The linear density of the fibre was found to be 14.569 tex which was used to calculate the tenacity of the fibres. The higher the tex the coarser the fibre or yarn.

Table 4.6 Breaking Tenacity and Elongation of Dry Fibre

Test No	Tenacity (cN/tex)	Force@ Peak (N)	Strain Rupture (%)	Force Rupture (%)	Strain Peak (%)	Elong. @ Rupture (mm)	Tenacity@ Rupture (cN/tex)
1	28.320	4.1260	8.328	2.8990	8.289	37.48	19.898
2	25.053	3.6500	11.937	1.9290	11.899	53.72	13.240
3	26.254	3.8250	10.985	1.6600	10.905	49.43	11.394
4	29.906	4.3570	11.317	2.7630	11.278	50.93	18.966
5	29.316	4.2710	8.772	2.5320	8.695	39.47	17.379
6	28.382	4.1350	11.828	2.9060	11.750	53.23	19.946
7	28.348	4.1300	12.576	2.8300	12.537	56.59	19.425
8	29.069	4.2350	7.656	2.6450	7.579	34.45	18.155
9	28.465	4.1470	8.442	1.9500	8.403	37.99	13.385
10	32.521	4.7380	11.070	2.8360	11.030	49.81	19.466
11	23.900	3.4820	11.400	1.3710	11.322	51.30	9.410
12	22.527	3.2820	12.267	2.1200	12.189	56.31	8.690
13	23.358	3.4030	12.267	2.1200	12.189	55.20	14.551
14	29.062	4.2340	17.611	1.4360	17.532	79.25	9.827
15	33.455	4.8740	10325	2.2310	10.247	46.46	15.313
16	30.572	4.4540	13.310	2.3930	13.271	59.89	16.425
17	26.234	3.8220	10.361	1.4460	10.004	46.62	9.925
18	24.648	3.5910	13.752	1.2270	13.675	61.88	8.422
19	36.090	5.2580	22.030	1.7620	21.951	99.14	12.094
20	27.196	3.9620	17.261	1.3570	17.183	77.68	9.314
21	26.755	3.8980	9.310	2.9710	9.232	41.89	20.393
22	30.579	4.4550	24.267	3.0330	24.229	109.20	20.818
23	17.098	2.4910	12.529	0.7720	11.877	56.38	5.299
24	19.528	2.8450	12.590	1.8980	12.279	56.65	13.028
25	31.601	4.6040	9.950	2.5650	9.873	44.77	17.606
26	29.618	4.3150	18.515	2.7030	18.477	83.32	18.553
27	32.041	4.6680	23.628	2.6150	23.550	106.32	17.949
28	18.944	2.7600	16.260	2.0260	16.183	73.17	13.899
29	21.161	3.0830	12.518	1.6280	12.480	56.33	11.174
30	24.161	3.5200	16.084	3.4950	16.006	72.38	23.989
31	34.923	5.0080	13.887	2.5000	13.849	62.49	17.160
32	26.385	3.8440	15.585	1.9860	15.547	70.13	13.632
33	16.549	2.4110	12.551	1.6490	12.512	56.48	11.319
34	18.285	2.6640	7.076	1.6080	6.998	31.84	11.037
35	25.753	3.7520	16.589	1.4130	16.512	74.65	9.699
36	28.238	28.238	4.1140	9.371	1.2880	9.294	42.17
37	17.626	2.5680	10.691	1.7570	10.614	48.11	12.060
38	20.550	2.9940	12.909	1.8280	12.870	58.09	12.647
39	17.791	2.5920	6.937	1.3750	6.898	31.22	9.438
40	17.977	2.6190	15.035	1.0350	14.958	67.66	7.104
Min	16.549	2.4110	6.937	0.7720	6.898	31.22	5.299
Mean	25.956	3.7815	13.000	2.0426	12.910	58.50	14.020
Max	36.090	5.2580	24.267	3.4950	24.229	109.20	23.989
S.D.	5.266	0.7872	4.146	0.6618	4.154	18.66	4.542

Fig. 4.5 Breaking Tenacity and Elongation of Dry Fibre

Force (cN)

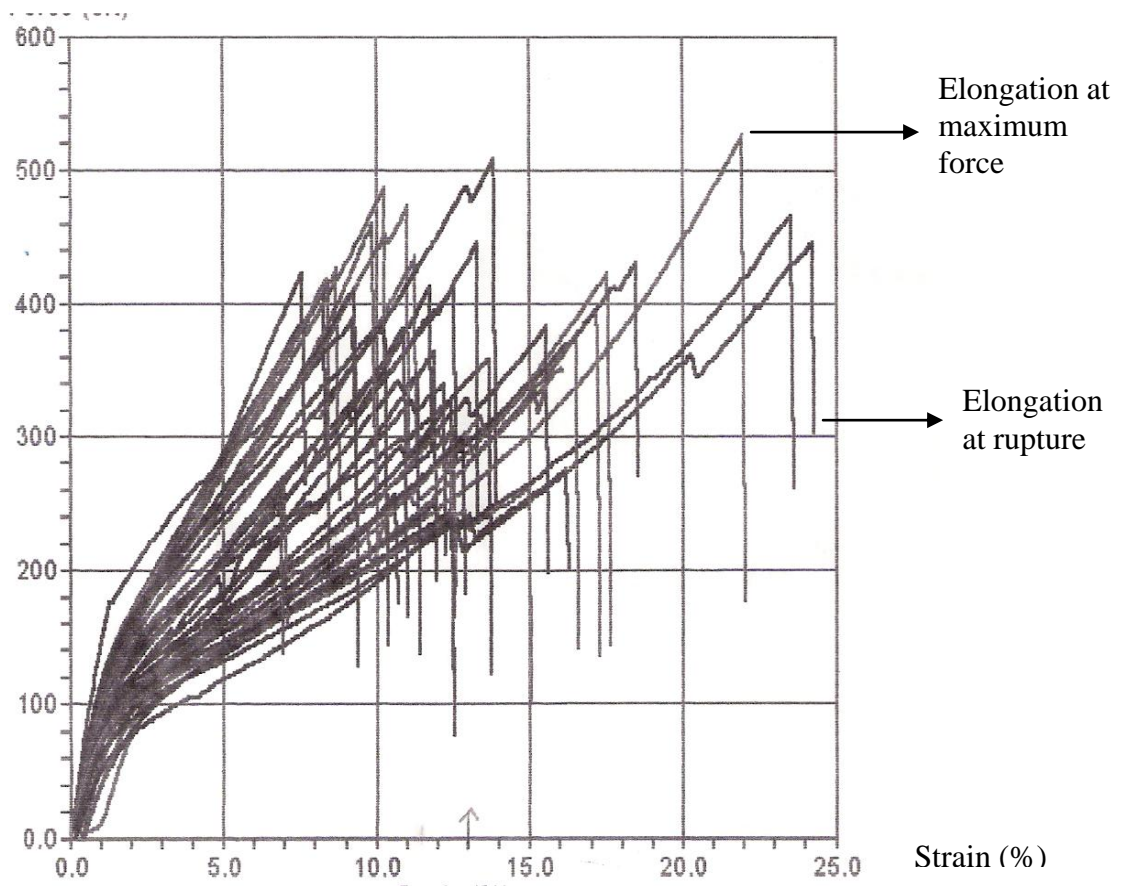
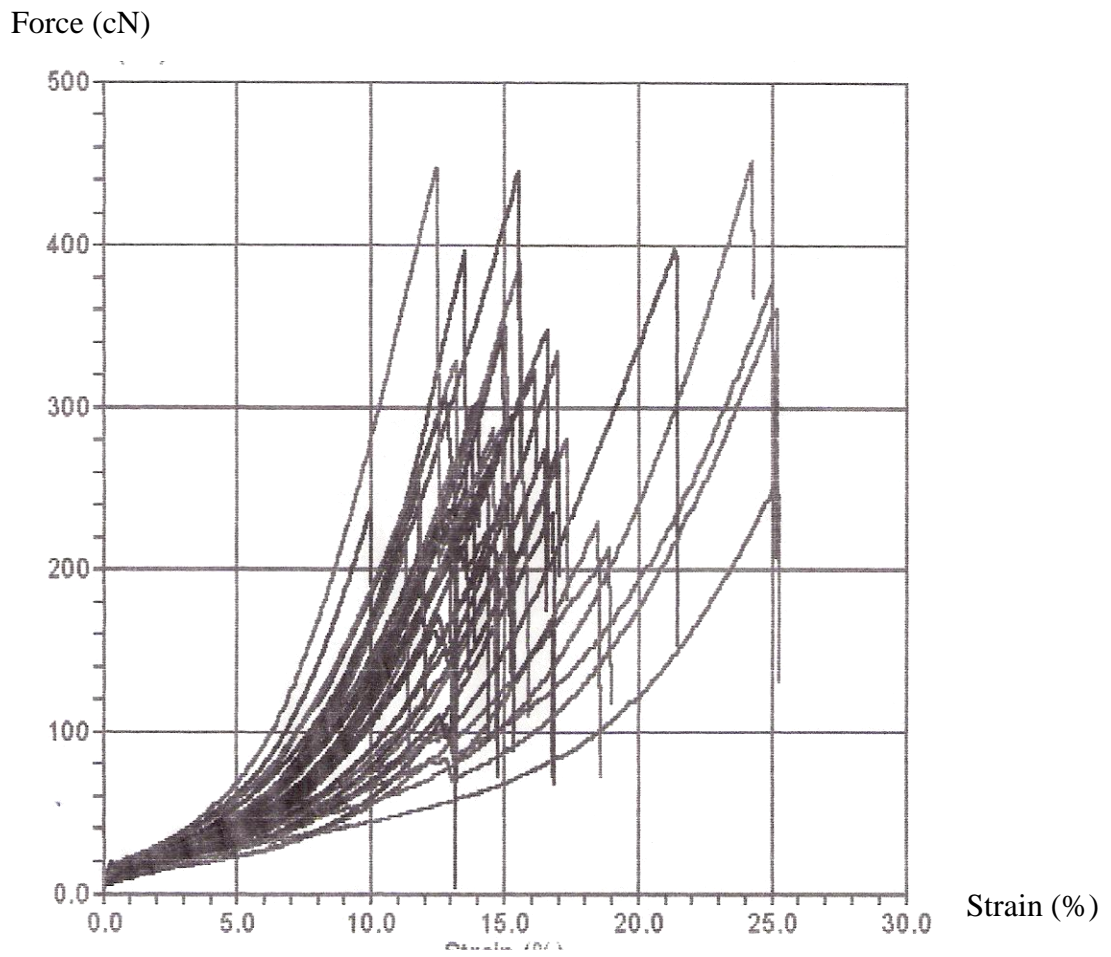


Table 4.7: Breaking Tenacity and Elongation of Wet Fibres.

Test No.	Tenacity (cN/tex)	Force@ Peak (N)	Strain@ Rupture (%)	Force@ Rupture (N)	Strain@ Peak (%)	Elong. @ Rupture (mm)	Tenacity @ Rupture (cN/tex)
1	20.894	3.0440	14.063	2.2730	14.025	63.28	15.602
2	16.178	2.3570	16.876	0.6770	16.799	75.94	4.647
3	20.303	2.9580	15.345	1.2590	15.306	69.05	8.642
4	19.734	2.8750	14.680	0.9550	14.604	66.06	6.555
5	16.947	2.4690	15.885	1.1030	15.809	71.48	7.571
6	20.653	3.0090	13.847	1.5570	13.809	62.31	10.687
7	22.115	3.2220	16.175	2.5620	16.137	72.79	17.585
8	27.263	3.9720	13.559	2.0310	13.621	61.01	13.941
9	26.755	3.8980	15.698	2.0930	15.622	70.64	14.366
10	22.520	3.2810	13.220	2.5080	13.181	59.49	17.215
11	30.551	4.4510	15.598	2.6400	15.521	70.19	18.121
12	23.866	3.4770	16.624	2.0040	16.586	74.81	13.755
13	17.132	2.4960	11.803	1.8280	11.764	53.12	12.547
14	17.626	2.5680	25.232	1.9140	25.194	113.54	13.137
15	30.977	4.5130	24.323	3.5840	24.244	109.45	25.287
16	14.881	2.1680	13.236	0.6940	13.123	59.56	4.764
17	21.134	3.0790	13.156	0.0350	12.774	59.20	0.240
18	15.684	2.2850	13.023	0.9430	12.908	58.60	6.473
19	25.918	3.7760	25.122	2.0730	25.045	113.05	14.229
20	14.764	2.1510	11.414	0.7180	11.300	51.36	4.928
21	17.221	2.5090	13.639	1.3840	13.464	61.38	9.500
22	16.892	2.4610	15.372	0.8840	15.297	69.18	6.068
23	16.274	2.3710	10.006	1.4860	9.969	45.03	10.200
24	23.996	3.4960	15.123	2.8840	15.044	68.06	19.795
25	14.675	2.1380	18.970	1.1820	18.894	85.37	8.113
26	22.953	3.3440	17.035	2.1100	16.997	76.66	14.483
27	23.879	3.4790	15.000	2.6520	14.961	67.50	18.203
28	27.277	3.9740	21.457	1.6390	21.340	96.56	10.564
29	19.301	2.8120	17.344	1.8220	17.305	78.05	12.506
30	30.716	4.4750	12.538	1.9360	12.461	56.42	13.288
31	18.807	2.7400	17.045	1.9660	16.968	76.70	13.494
32	14.819	2.1590	11.989	1.1510	11.961	53.95	7.900
33	17.654	2.5720	14.418	0.9470	14.304	64.88	6.500
34	24.779	3.6100	25.257	1.3160	25.179	113.66	9.028
35	15.759	2.2960	18.563	0.7340	18.448	83.53	5.038
36	18.836	2.7440	16.555	1.7460	16.516	74.60	11.984
37	17.366	2.5300	16.798	0.7310	15.113	75.59	5.018
38	15.004	2.1860	14.779	0.7280	14.665	66.51	4.997
39	18.093	2.6360	11.872	1.7150	11.795	53.42	11.772
40	19.816	2.8870	14.986	1.8360	14.946	67.43	12.595
Min	14.675	2.1380	10.006	0.0350	9.969	45.03	0.240
Mean	20.500	2.9867	15.941	1.6075	15.826	71.73	11.033
Max	30.977	4.5130	25.257	3.6840	25.194	113.66	25.287
S.D.	4.731	0.6892	3.776	0.7482	3.779	16.99	5.136
CV	23.08	23.08	23.69	46.54	23.88	23.69	46.54
LCL	18.987	2.7663	14.733	1.3682	14.616	66.30	9.391
VCL	22.013	3.207	17.148	1.8467	17.033	77.17	12.676

Fig. 4.6 Breaking Tenacity and Elongation of Wet Fibres

The tenacity of dry fibres ranged between 16.549cN/tex (1.87g/d) and 36.090cN/tex (4.09g/d) with a mean of 25.956cN/tex (2.9g/d). The standard deviation was 5.27cN/tex while the coefficient variation was 20.29%. The elongation at rupture was 58.50mm, with a standard deviation of 18.66 mm and a coefficient of variation of 31.89%. The percentage elongation at break (strain@ rupture) was 13% with a standard deviation of 4.15% and coefficient of variation 31.89%.

The tenacity of wet fibres ranged between 14.675cN/tex (1.67g/d) and 30.977cN/tex (3.5g/d) with a mean of 20.50cN/tex (2.3g/d). The standard deviation was 4.76cN/tex with a coefficient of variation of 23.08%. The elongation at rupture was 73.73mm with a standard deviation of 16.99mm and coefficient of variation at 23.69%, the percentage elongation at break (strain@ rupture) was 15.94% and a standard deviation 3.78% and coefficient of variation at 23.69%.

From the above result the fibre lost its tenacity when wet. This means that the fibre is stronger when dry than when wet. Therefore the fibre needs gentle handling when washing so as not to injure the fibres. The elongation at rupture (break) was 58.50mm, for dry fibre while for the wet fibre was 71.73mm this means that the wet fibre elongated more before rupture than dry fibres. The elongation at rupture percentage (break) was higher than that of cotton, linen, pineapple and aramina fibres.

Cellulosic fibres have a low elongation. An individual fibre must be able to undergo slight extension of 1–5 % in length without breakage of the fibre (Cook, 1984). Booth (1968), describes flax as a fibre with very low elongation of approximately 7% and poor elasticity with 65 % recovery at elongation of 2%. Linen is the least elastic of the natural fibres. This property is of great importance since a fibre with good

extension and elasticity resists tearing and can withstand spinning processes. The amount of elongation is an important factor in evaluating elastic recovery. From the above results it is indicated that the fibre has sufficient strength to produce adequately durable textile products. However, the fibre requires gentle handling when washing since it loses its strength when wet.

Table 4.8 Summary Comparison – breaking Tenacity Test dry/wet fibres

	Parameter	Tenacity cN/tex	Force at peak (N)	Strain at rupture (%)	Force at rupture (N)	Strain at peak %	Elongation at rupture (mm)	Tenacity at rupture cN/tex
Dry Fibres	Mean	25.956	3.7815	13.000	2.0426	12.910	58.50	14.020
	Std d	5.266	0.7872	4.146	0.6618	4.154	18.66	4.542
	C of V	20.29	20.29	31.89	32.40	32.18	31.89	32.40
Wet fibres	Mean	20.600	2.9867	15.941	1.6076	15.826	71.73	11.033
	S.D	4.731	0.6892	03.776	0.7482	3.779	16.99	6.136
	C of V	23.08	23.08	23.69	46.54	23.88	23.69	46.54

3. Chemical Tests

4.4.7 Chemical reactions.

The aim was to observe and document the reaction of the fibres with different selected chemicals. The chemicals were categorized into four groups, strong acids, weak acids, strong alkalis and weak alkalis. All the chemicals were concentrated and used while cold. The sample fibres were placed in Petri-dishes and chemicals poured into them until the fibres were completely covered. The results are as indicated on table 4.9.

Table 4.9 Chemical Analysis on Fibres

Observed Reaction			
Category	Chemical	Immediate	After 30min
Strong Acids	Conc. Sulphuric acid	The fibres tend to disintegrate and fibres start to dissolve. Fibres changed colour from white to brown.	Fibres disintegrate and then completely dissolved.
	Conc. Nitric Acid	No visible change on the fibre. Colour of the fibres changed from white to brown and then the fibre was bleached to white.	A marked weakening and tendering of fibres resulted-The fibre partially dissolved.
	Conc. hydrochloric acid	The fibre did not change colour or size	The fibre weakened and partially dissolved
	Sodium Hydrochloride	The fibre bleached	Fibres weakened and disintegrated
	Acetic acid	No visible change on the fibre on both colour and shape.	Fibre remained strong, no change in size, colour.
Weak acids	Citric Acid	The fibre bleached no	Fibre remained strong

		change in size.	and bleached.
	Oxalic Acid	The fibre bleached	Fibre did not change in size, colour and strength.
Strong Alkalis	Sodium hydroxide	Fibres did not change in colour or size.	Folding and curling of fibre. There was visible distortion of fibres.
	Sodium hypochlorite	Fibre bleached	Fibre weakened and disintegrated
	Potassium hydroxide	Slow dissolution of fibres noted	Barely visible fibres left.
Weak alkalis	Ammonium hydroxide	No reaction noted	No reaction noted
	Sodium hydrogen carbonate	No reaction noted	No reaction noted

From the observation in table 4.9 the fibre remained stable in weak acids and weak alkalis. Most commonly occurring reagents used and applied on fibres at room temperature such as bleaches, detergents and dyes are weak basic or weak acidic and this means they can be safely used on the fibre, since they have no effect on the structure and tenacity of the fibre. The fibres were dissolved or distorted by strong bases.

The fibres were disintegrated by concentrated sulphuric acid, and dissolved by both concentrated hydrochloric acid and nitric acids. This indicates that cellulosic fibres are damaged by strong acids. The bonds connecting the sub- units are unstable to acid and the result is a loss of tensile strength. When reacted with concentrated sodium

hypochlorite, the fibres bleached but after prolonged exposure, the fibre weakened and disintegrated. This indicates that oxidizing solutions like sodium hypochlorite should only be used when cold and diluted and according to instructions given by the manufacturer. Therefore chlorine bleaches should be used for a short period of time and must be rinsed out thoroughly to avoid further damage to the fibre.

4.4.8 Spinning and weaving

The fibres were spun into yarns by hand. The yarns were bleached and then dyed using dylon dyes. Different clothing construction methods (weaving, crocheting) were used to come up with some textile articles. The spinning of yarn was done by hand, by putting the required amount of twist. The purpose of spinning was to bind the fibres together and to hold in the fibres ends. In weaving two sets of yarns were interlaced at right angles and operation done by hand as in basket weaving. Crocheting was another method used to construct the small bag. The construction was done with just one hook and a chain of loops were formed from a single yarn. The textile articles constructed are shown below:-

Plate4.3. Dyed Yarns**Plate 4.4 Table mat****Plate 4.5. Hand Bag.**

The quality of cloth is not entirely judged by knowledge of its fibres but also by the method by which the fibres have been combined to form a yarn. This influences its suitability for different purpose and its performance in wear and cleaning.

4.5 Comparative Characteristics

Agave americana fibres are smooth and lustrous. The fibres are long, the long fibres produce smooth yarns, which help give an attractive lustre to the finished cloth, the *Agave americana* fibres have a mean length of 65.2 cm. The fibre is flexible and this enables the fibre to be spun into yarn easily. The *A. americana* fibre has a tenacity comparative to other cellulosic fibres. The fibre has a tenacity of 2.94g/d (25.96 cN/Tex) when dry and 2.3g/d (20.60cN/Tex) when wet. The fibres were found to weaken when wet since, the strength decreased when soaked in water. This property (when wet) is inconsistent with other cellulose fibres except pineapple which also tends to lose its strength when wet (Kariuki 1993). However the fibre is generally quite strong when dry, though even when wet it still has a higher tenacity (2.3g/d) than that of dry aramina of 1.4g/d and almost equivalent to that of dry pineapple 25.4g/d.

The fibre has a mean diameter of 0.15mm. The fibres were found to have uniformity of width and this improved their ability to absorb dyes evenly and gave an attractive appearance.

Vegetable fibres are hydrophilic in nature, and this was evident with *A. Americana* fibre which can absorb up to 9.98% of its own weight without feeling damp. This means that the fibre can accept the dyes and finishes more readily.

The fibres were dissolved by strong bases and strong acids and this indicates that they cannot be dyed using dye-stuffs that require the presence of strong acid. However the fibre did not react to weak acid and weak alkalis, therefore household reagents such as detergents and bleaches can be safely used on the fibre.

Generally the fibres were strong and pliable and could easily be spun into yarns to construct textile articles such as special clothing, lady's handbags. Baskets could also be constructed.

Table 4.10 Comparison of *Agave americana* fibre and other cellulose fibres

Parameters		Cotton	Linens	Pineapple	Jute	Aramina	Agave Americana
Length(cm)		6.25	56	70	-	46	65.2
Colour		White	Cream	White	Light to dark brown	Light brown	White to off white
Tenacity (dry)g/d cN/Tex	g/d	3.0-5.0	3.0-5.8	2.4	3.8-5.8	1.4	2.94
	cN/Tex	26.48-44.14	26.48-51.2	21.18	33.54-51.2	12.21	26.97
Elongation Dry %		3-10	2.7-2.3	1.82	1.2-1.19	1.03	13.0
Elongation % wet		5-13	2.2	1.97	-	1.3	15.9
Moisture Regain		8.5	12	10.4	13.7	9.7	9.98
Lustre		Low	High	-	-	-	Medium lustre

Sources: Joseph 1981, Kariuki 1993, Nkatha 1998, G. Mbugua, 2008.

4.6. Maintenance of the Product and end use

In the criteria of selecting textile products, the consumer must consider such factors as the length of time the product is expected to last and maintenance procedures that would be used. The behaviour of textiles in relation to appearance, comfort, durability and maintenance therefore becomes specific to the consumer.

According to the findings, the *A. americana* fibres are strong, flexible and lustrous, therefore the articles made would have good durability. However, to improve on its drapability and bulkness the fibres should undergo special processes such as combing, carding and mercerization. These would improve on its appearance and comfort. The fibre lost its strength when wet, therefore the fibre needs gentle handling when washing so as not to damage the fibre. The fibre lost its strength when wet, therefore the fibre needs gentle handling when washing so as not to damage the fibre. The fibre is therefore not ideal for textile articles such as towels. However, the fibre can be fairly used for clothing, upholstery etcetera. Commonly used reagent such as bleaches and detergents can safely be used on the textile products made of *A. americana* fibres. The fibres are hydrophilic and will readily absorb moisture from the atmosphere. This means they will take dyes easily. However, the fibres take long to dry. The *A americana* fibres burn readily and care needs to be taken when in use near fire.

CHAPTER V

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

The purpose of the study was to investigate the quality of the *Agave americana* fibre as a source of textile fibre. Both the physical and chemical properties of the fibres were examined at the Kenya Bureau of Standards (Textile quality control laboratory). Sample articles were made using the extracted fibres. This chapter includes the summary of the findings, conclusion and recommendation.

5.2 Summary

In order to obtain the fibres, the leaves were ripped off the plant and subjected to retting process for 26 days. The fibres produced were found to be smooth, lustrous and soft. The colour of the fibre was white. The longitudinal appearance of the fibre showed straight tubes with longitudinal striations. The burning properties were similar to other cellulosic fibres. The fibre flared up in flame, with a yellow flame, and emitted a smell of burning paper. A fine grey ash was left as a residue. The fibre length ranged between 33.6 cm to 107.0 cm with a mean length of 65.2cm. This showed that the fibre has a longer length as compared to cotton (6.25), linen (56cm) and aramina (46 cm). The fibre had a mean diameter of 0.15 mm, which is comparable to silk fibre with same diameter 0.15 mm. Hence good for spinning

The fibre had a moisture regain of 9.98% and moisture content of 9.19% which was comparable to other cellulosic fibre. The regain was higher than that of cotton, linen and aramina but less than that of pineapple and jute. The fibre was found to have a

linear density of 14.59 tex, and a tenacity of 25.956 cN/tex (2.94 g/d) when dry and 20.60.cN/tex (2.3 g/d) when wet. The fibre was found to lose its strength when wet. The strain at rupture (elongation at break) for dry fibre was 13% while for the wet fibres was 15.94%. The elongation at break was found to increase in wetness and has great extensibility than most commonly used cellulosic fibre, for example cotton is recorded to have 3-10 %, pineapple 1.82% and aramina 1.03%. The fibres were disintegrated, distorted and dissolved by strong bases and strong acids but withstood weak acids and weak alkalis. The fibres qualified as textile fibres, and samples of yarns and fabric were made using the fibres. Apparently, if the fibre could undergo more processing for example; combing and drawing to produce a more finer fibre, the fabric produced could be more appropriate for clothing, soft furnishing and even for traditional wedding attire.

5.3 Conclusion

From the results obtained the *A. americana* fibre has the ability to withstand all fibre processes since it is strong with a tenacity of 2.9 g/d. The fibre also has a high length to width ratio with a mean length of 65.2 cm and a mean diameter of 0.15mm. According to Nkatha (1998) and Joseph (1986), the minimum required ratio of length-to-width is of 100:1. That of *A. Americana* is 4545:1

Based on the findings and discussion the *A Americana* fibres qualify as a good source of quality textile fibres. This will help reduce reliance on imported fibres and yarns, especially for our textile industries. The fibre is cheap to grow and is locally available in most areas of our country. This could be of great benefit to small scale entrepreneurs because they can be able to make a variety of special textile articles other than using sisal fibres which are coarser. The *Agave americana* fibre is strong,

soft, has smooth surface and is lustrous. The fibre exhibits good dyeing properties therefore this adds to its value and potential use in making household textiles.

The natural retting process is lengthy, and may cause environmental problems e.g., a pungent smell is released during retting. However, the produced fibres had many desirable characteristics, as compared to known standard properties of plant fibres.

5.4 Recommendations

Based on the findings, the following recommendation and suggestions for further research are made.

5.4.1 Recommendations

1. Since the *A. americana* fibre qualifies as a textile fibre, it can be utilized to provide textile products for exports to the U.S. This will help Kenya meet the requirements of the AGOA for the production of textile products made from locally produced yarns and fabrics.
2. The fibres can be utilized locally by textile industries and Jua kali sectors to supplement other existing natural vegetable fibres and importation of expensive raw textile fibres.
3. Since the natural retting process was lengthy other methods should be developed for easier production of the fibres, for example use of industrial machines to extract and process the fibres.
4. The fibre can be used as raw materials for the production of cellulosic man-made fibres.
5. Managed projects of cultivating the plant for fibres will assume in some areas an important economic role, such as a source of employment, and income generation for many entrepreneurs.

5.4.2 Suggestions for Further Research

1. Comparison study should be carried out on different plants of agave species for their quality as potential textile fibres.
2. Research is needed to find out if the physical and chemical properties of the fibres differ in relation to different levels of leaves and maturity stages of the plant.
3. Other fibre qualities that have a significant effect on the yarn and fabric such as specific gravity, fibre dimensions (molecular structure, molecular weight etc), uniformity and effect of various dyes and dyeing techniques need to be investigated.

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CONVERSION AND FORMULAE

- i. Strain @ rupture = $\frac{\text{Elongation @ rupture mm}}{450(\text{gauge length})} \times 100$
- ii. Tenacity = $\frac{\text{Force @ peak(N)} \times 100}{\text{Tex}}$
- iii. Tenacity @ rupture = $\frac{\text{Force @ rupture (N)} \times 100}{\text{Tex}}$
- iv. 1 gram/Denier (g/d) = 8.827 Centinewtons/Tex. (cN/tex)
- v. 1 centinewtons/Tex(cN/tex) = 0.113 gram/denier(g/d)