PROPERTIES OF DECORTICATED AGAVE AMERICANA
“MARGINATA” FIBRES OF DIFFERENT LEAF LEVELS FROM
LANET AND TIGONI, KENYA.

BY

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PHILOSOPHY (FASHION DESIGN AND MARKETING) IN THE SCHOOL
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NOVEMBER 2014
DECLARATION

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

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I dedicate this work to my entire family who supported me throughout my study.
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OPERATIONAL DEFINITION OF TERMS

Chemical properties: The characteristics of fibres which include the effect of chemical agents including acids, bases, biological agents etc on the fibre and the composition within the fibres

Colourfastness: The ability of fibres to retain their colour after exposure to elements such as sunlight, cleaning processes or other materials.

Composite material: Refers to engineered materials or natural occurring materials made from two or more constituent materials with significantly different physical or chemical properties.

Conventional retting: This is a fermentation process whereby natural microorganisms are encouraged to grow on the stem or leaf by sprinkling or soaking it for a period of time in water, so that the enzymes can degrade parenchymatous non-cellulosic biomass in order to release the fibres

Decortication: This is the process whereby the cuticles and other extraneous matters of plant portion are separated from fibres.

Delta- E (∆E): The measure that represents the difference between two colour space.

Dyeability: Refers to fibre receptivity to colouration by dyes and dye affinity; determines the aesthetic and colour fastness.

Dye-affinity: Refers to preferential attraction of the dye for the fibre rather than for the solution of the dye bath

Eco-friendly: Refers to products that are not harmful to the environment e.g. fibres from plants that do not require the use of any pesticides, chemicals and a lot of water to grow

Elongation: The amount of stretch or extension that a fibre/yarn or fabric will accept before breaking.
Fibre properties: The characteristics inherent in the composition of the fibre, construction of the yarn and fabric and finishing of the textile.

Geographical locations: This will refer to a designated place or area on the earth’s surface from where the plant leaves will be harvested e.g. Lanet and Limuru locations.

Geo-textiles: These are permeable fabrics which when used in association with soil have the ability to separate, filter, reinforce protection, or drain in civil engineering and agricultural drainage.

Mechanical properties: The properties of a fibre/fabrics that are associated with elastic and inelastic reaction when force is applied or that involves the relationship between stress and strain.

Monocarpic: These are plants that take several years to flower and die soon after flowering.

Physical properties: The fibre characteristics that can be viewed with naked eyes or under a microscope: These properties affect the end use such as serviceability, aesthetics, durability, comfort and care.

Plant levels: Refers to the position of leaves on the stem of a plant either from the base to the apex of the plant or vice versa.

Tenacity: The maximum specific strength of a fibre/yarn that an individual fibre posses.

Variegated: The appearance of differently coloured zones on the leaves and sometimes the stem of plant.

KEBS Textile Standards: This specifies the requirements and prescribes methods of obtaining laboratory test samples and gives general direction of testing the fibres in accordance with the procedures of Kenya Bureau of Standards.
Tami Dye: This is a natural organic dye obtained from Tagetes Minutas inflorescences, which results into a golden yellow shade.

The International Standards of testing fibres: Refers to the specifications and test methods for the fibre properties that ensure acceptable characteristics towards proper end use.
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>AGOA</td>
<td>African Growth Opportunity Act</td>
</tr>
<tr>
<td>cN</td>
<td>Centi-Newton</td>
</tr>
<tr>
<td>CSIR</td>
<td>The Council for Science and Industrial Research (South Africa)</td>
</tr>
<tr>
<td>EPZ</td>
<td>Export Processing Zone</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organization (of the United Nations)</td>
</tr>
<tr>
<td>IYNF</td>
<td>International Year of Natural Fibres</td>
</tr>
<tr>
<td>KEBS</td>
<td>Kenya Bureau of Standards</td>
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<tr>
<td>OTEXA</td>
<td>Office of Textiles and Apparel</td>
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Natural fibres have intrinsic properties: mechanical strength, low weight and low cost. These properties have made natural fibres important especially to the automotive industry. The leaves of Agave plants are rich in textile fibres and the most common species include the *agave sisalana*, *agave americana* and *agave anguistifolia*. The *agave americana* “Marginata” is the most common variegated plant and is widely cultivated for its aesthetic appearance and has commercial and industrial potential. This study aimed at analysing the physical, mechanical and chemical properties of decorticated *agave americana* “Marginata” fibres from three plant leaf levels from Lanet and Tigoni areas. The results of this study could contribute to the development of new textile options in Kenya. The findings generated data that can be used as reference for future research. For the purpose of this study, the leaves were purposively harvested from each plant ensuring they were sampled from three levels in both locations. The leaves were then subjected to a decortication process to extract the fibres and randomly assigned to experimental tests. Descriptive statistics and Analysis of Variance (ANOVA) were utilized in analysis to establish whether there was any significant difference in fibre properties. Results in this study established that there was significant difference in fibre length across the three levels in Tigoni and Lanet at \( p < 0.05 \) (\( p=0.0015 \)) and (\( p=0.0051 \)) respectively. The mean lengths of fibres from both locations showed no statistical difference. The findings therefore confirmed that the fibre length is not dependent upon the location where the plant is grown but on the leaf position on the plant. It was further observed that the linear density of raw fibres from Tigoni was significantly different across the levels (\( p < 0.05 \), \( p=0.0073 \)). However fibres from Lanet were not significantly different in linear density across the three levels (\( p=0.0945 \)). There was significant difference in tenacity between fibres harvested from the three levels in Tigoni and Lanet at \( p < 0.05 \) (\( p=0.0177 \)) and (\( p=0.0073 \)) respectively. However comparing the mean tenacity from the two locations, it was found that it was not significantly different (\( p \geq 0.05 \), \( p=0.5009 \)). The average force required to break fibres from the three levels from Tigoni was significantly different while that for Lanet was not significantly different across the levels. The results also indicate that the fibres are hydrophilic. There was a minimum difference in pectin and lignin content in fibres within the levels and locations. Hemicellulose content reduced as leaf age increased in both locations. Application of dyes had minimal effect on mechanical properties, therefore statistically there was no significant difference between the raw and dyed fibres. Colourfastness to light, rubbing and washing was satisfactory in the case of most of the dyes used in this study. From the research findings, it can be concluded that the locations did not have much influence on the fibre properties, though both locations were ideal for healthy plant growth. However the fibre properties were influenced by the position of leaf on the plant. The fibres could be dyed effectively with most dyes because the dyed fibres performed well in most tests for colourfastness. This study recommends cultivation of the plant by farmers as a commercial crop for its economic potential and to reduce over-reliance on imports by textile industries. This study recommends further research focussing on properties of *agave americana* “Marginata” fibres extracted during two different seasons (dry and wet) and also at different stages of plant growth.
CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Currently, Kenya imports most of the vegetable fibres e.g. cotton, flax and jute. In 2011 Kenya imported 40,000 bales of raw cotton (NationMaster Statistics, 2012). For this reason there has been an increase in production costs that have influenced consumer prices. Over the last half century, natural fibres have also been displaced in clothing and household furnishing by man-made fibres such as polyester, acrylic and nylon among others (Hugo, 2009). However, natural fibres have good possibilities of increasing their market share and importance due to their low price, eco-friendly character and technical properties (Manonyane, 2006). Their use as new industrial products is a part of a new conception of environmental governance called product-oriented environmental management (Jan, 2009).

Global environmental concerns such as climatic change and sustainability are encouraging development of totally green materials that can deliver eco-social system change, while discouraging the use of synthetics (Ashad, Azman, Nazir, 2010). The International Year of natural fibres 2009 (IYNF, 2009) aimed at raising awareness of importance of the natural fibres not only to the producers and industry, but also to consumers (Hugo, 2009).

In the tropical regions, there are a number of natural fibres, which have not been fully exploited commercially. Sources such as Agave (Sisalana and americana), banana and pineapple among others have huge potential as a source of textile fibres (Chongwen, 2005). The leaves of the Agave plants have been reported to be rich in textile fibres (Verloore, 2005; Msahli, Drean, Sakli, 2007). Further there is increased
research on agave plants and new species have been discovered. Increase in research is due to the role played by these plants in improving man's economy (Verloore, 2005; Udeani, 2009). Some of the most common species of the agave plant are A. sisalana, A. americana, and A. angustifolia. A. americana “Marginata” is one of the most sought after variegated succulent in existence because of its aesthetic appearance (Edward, 1999). In the variegated forms, the leaf has a white or yellow marginal or central stripe (Medio-Picta) from the base to apex. The plant is widely cultivated for its aesthetic appearance and has become a favourite decorative plant in botanical and private gardens around the world (Msahli et al., 2007).

The A. americana “Marginata” can become a coveted source of utilizations ranging from paper making, composites for the automotive industry to the pharmaceutical and food industry. The fibres can be used for the production of non-woven with two main applications: geo-textiles and composite materials for the automotive industry (CSIR, 2007). A. americana fibres have been used in other countries to make ropes, and for other uses such as sacks, paper making or clothing (Zwane, 2011). However it has not been utilised in Kenya and neither has any commercialization been done.

Currently Kenya imports 70% of its vegetable fibres and the future of the industry depends on the availability of raw materials (Bedi, 2011). Therefore there is potential that the plant can be utilised in Kenya as a supplement source of natural fibres in reviving its textile industries. Kenya aims at being industrialized by the year 2030 with the major objective of creating employment opportunities for the rapidly growing labour-force. This calls for the utilization of materials and services that are less expensive, locally available yet internationally competitive.
Today, dyeing is a specialized science and nearly all dye-stuffs are now produced from synthetic compounds. This means that, costs have been greatly reduced and certain application and wear characteristics have been greatly enhanced (Cindy, 2010). However, many practitioners of the craft of natural dyeing maintain that natural dyes have a far superior aesthetic quality which is much more pleasing to the eye. Jean (1994) argues that, natural dyes not only offer a rich and varied source of dye stuff, but also the possibility of an income through sustainable harvest and sale of these dye plants. Many dyes are available from tree waste and can be used on most types of materials or fibre. However the level of success in terms of fastness and clarity of colour varies considerably (Melo, 2009). With this background the study sought to ascertain the physical, mechanical and chemical properties of decorticated A. americana “Marginata” fibres from different plant leaf levels and locations.

1.2 Problem Statement

New demand for natural fibres today opens a potentially promising avenue for economic opportunities. Agave americana “Marginata” plant could be a cheap and eco-friendly alternative fibre to cotton, sisal and other natural fibres. It is a common plant which is valued as an ornamental plant in Kenya and when pruned the leaves are disposed off as waste. Due to different climatic and soil conditions prevalent in Lanet and Tigoni, the fibre properties of A. americana “Marginata” may be potentially different. Kenny (2001) indicates that, due to differences in climatic and growing seasons, the physical, mechanical and chemical properties of natural fibres can be highly variable. Joseph (1986) emphasizes that, the method of fibre extraction, stage of growth and different climate conditions such as weather and soil conditions can significantly affect the fibre properties.
The *A. Americana* “*Marginata*” fibres can be extracted through various ways, including retting process, mechanical process (decortication) and chemical process (Msahli et al., 2005). Laura (2010) argues that, microbiological retted fibres and decorticated *A. Americana* fibres are of higher quality than water retted fibres due to better separation of the fibres and sheaves. A study carried out by Mbugua (2009), indicates that the water retted *A. americana* “*Marginata*” fibres can be used as a textile in Kenya, though other methods of fibre extraction have not been tried. Therefore, there is need to evaluate the fibre properties of decorticated fibres extracted from different leaf levels and locations.

Katarzynan and Jakub (2008) indicates that different dyes and dyeing process can result in the change of mechanical fibre properties and also have an effect on the colour fastness. It was therefore worthwhile to evaluate the fibre properties (raw and dyed) of decorticated *A. americana* “*Marginata*” fibres from different plant levels grown in Lanet and Tigoni locations, in order to determine the suitability for use as textile fibres in Kenya.

1.3 Purpose of the Study

The aim of the study was to analyse the physical, mechanical and chemical fibre properties of decorticated *A. americana* “*Marginata*” fibres extracted from three plant leaf levels from Lanet and Tigoni areas. The plant could be a potential source of industrial and commercial fibres.
1.4 Research Objectives

The objectives of the research were to:

1. Determine the effect of soil properties and climate conditions on *A. americana* “Marginata” fibre properties extracted from Lanet and Tigoni locations.

2. Establish the physical, mechanical and chemical properties of *A. americana* “Marginata” fibres of the same plant from three plant leaf levels from both locations.

3. Verify the physical, mechanical and chemical properties of *A. americana* “Marginata” fibres against each level and from both locations.

4. Evaluate the effect of natural and synthetic dyes on the mechanical properties of *A. americana* “Marginata” fibres from the three leaf levels of the plant and from both locations.

5. Evaluate the colour fastness properties of *A. americana* “Marginata” fibres dyed with natural and synthetic dyes from the three leaf levels of the plant and from both locations.

1.5 Research Hypothesis

The following hypotheses were tested:

\( H_{01} \) There is no significant difference in mechanical properties between fibres from different plant leaf levels.

\( H_{02} \) There is no significant difference in mechanical and chemical properties between the fibres from the two locations

\( H_{03} \) There is no significant difference in mechanical properties between raw and dyed fibres from different plant leaf levels and locations.
1.6 Significance of the Study

The research findings will form a basis for developing a general concept for commercializing the *A. americana* “Marginata” plant in Kenya. This will promote the growth of the plant and also provide a means of livelihood for plant producers, hundreds of unemployed youths and entrepreneurs. Textile and apparel industries in Kenya would benefit from the findings of this study as they could use *A. americana* “Marginata” fibres as a supplement to the imported expensive raw textile fibres. To compete effectively with other countries, the Kenyan textile industries may adopt the use of these fibres in the production of textile products, geo-textiles, cement manufacture and composite materials for the automotive industry. Small scale enterprises may use the fibre in the manufacture of handcrafts such as handbags, mats and apparel which will also benefit consumers.

This study will be of benefit for research in Kenya as the data would act as a guide for further research and reference. The study will act as a reference to textile manufacturers and entrepreneurs regarding the use of dyes on fibres and their characteristics such as colourfastness. This will eventually enhance the quality of the end products.

1.7 Scope of the Study

The study focused on *Agave americana* “Marginata” plants growing in only Lanet and Tigoni areas in Kenya. This is due to the distinctive differences in soil and climate conditions in the two areas (Wamicha, Gatahi, Mungai, 2009). The research analysed the physical, mechanical and chemical properties of decorticated *A.*
americana “Marginata” fibres from three plant leaf levels from both locations. The plants were sampled to ensure that only mature leaves were harvested for the study.

1.8 Limitation of the Study

The study confined itself to fibres extracted from three leaf levels from the base of the plant. Fibres were extracted from leaves harvested during the hot and dry season of the year. The study was limited to fibres from leaves that were manually harvested from only two locations. The study employed only the decortication process to extract the fibres. Evaluation on the effect of dyes on mechanical properties of fibres was limited to some selected dyes.

1.9 Conceptual Framework

Natural fibres are obtained from various parts of plants i.e. leaves, stem, fruit and seed. These fibres are produced in a range of qualities due to variable growing conditions. The performance of a fibre in a given application depends on physical, mechanical and chemical composition of a fibre. Different environmental conditions such as soil properties and climate conditions can significantly affect these properties.

Blackburn (2005) noted that geometrical dimensions of fibres especially the fibre length depends on the fibre location within the plant. Further he argues that the cross-sectional view depends on plant growth conditions and maturity of the leaves. The maturity of the leaves also affects the lustre and the tensile strength of a fibre. The mechanical properties on the other hand are significantly related to the degree of polymerisation of the fibre, which is a direct result of its molecular structure.
The chemical compositions of agave fibres vary in percentage depending on growing conditions, maturity, part from which the fibre is extracted and the method of fibre extraction (Bledzki and Gassan, 1999). The chemical properties on the other hand have an influence on the mechanical properties of the fibres. Joseph (1986) revealed that fibres from the same origin can differ in fibre quality. This indicates that properties of fibres extracted from the same plant but from different plant leaf levels may be significantly different due to the stage of growth and conditions the plant is subjected to in the process of growth.

Consequently independent (geographical location, level of plant leaves and dyes) and dependent variables (fibre properties) were identified and a framework on the interaction of these variables formulated. The conceptual framework for this study therefore asserts that, the geographical location and level from where the plant leaves are extracted determine the properties of the fibre and hence the quality of the A. americana “Marginata” fibres.
Figure 1.1 Relationships between Geographical Location, Level of Plant Leaves and the Fibre Properties

Source: Researcher 2014
CHAPTER TWO: LITERATURE REVIEW

2.1 Growing Conditions of *Agave americana* Plant

One of the common species of agave plant is *A. americana*, a native of tropical America. Common names include century plant, maguey or American aloe. The name century plant refers to the long time the plant takes to flower, although the number of years depends on the vigour of individual plant, the richness of the soil and the climate conditions (Msahli et al., 2006). Most species of the agave are monocarpic, although a few can flower several times during their life. The flowers have both male and female parts, the male anther which produces pollen and the female stigma which receives it. Many species of agave are bat pollinated. Most agaves consist of rosettes of thick hard, rigid leaves with marginal teeth and with a leathery sharp terminal spine. *A. americana* “*Marginata*” has a yellow marginal strip from the base to the apex (Msahli et al., 2006).

Moris (2006) states that *A. americana* “*Marginata*” plant grows well in acidic, neutral and basic alkaline soils that are well drained, either light (sandy) or medium (loamy). Msahli and Sakli (2006) argue that *A. americana* “*Marginata*” is extremely tolerant to drought and most soils. Since most of the agave genus are succulent, they are water retaining plants adapted to arid climate and soil conditions. According to Joseph (1986), natural fibres are produced in a range of qualities due to variable growing conditions which prevents uniformity. This is an indication that even fibres from the same origin can differ in quality depending on the conditions the plants have been subjected to in the process of growth.
2.1.1 Fibre Properties in Relation to Soil and Climate Conditions

Fibre quality is dependent on growing and climate factors which influence the plant growth and eventually affect the fibre growth and development. Climate and soil content affect fibre properties and eventually the fabrics made of them (Hungate et al., 2003). According to Pettigrew (2008), water is an important factor in fibre growth and development since it influences fibre length. Further Abuza et al. (2012) argue that water stress and potassium (K) deficiency decreases the length growth of the fibres while on the other hand increase the fibre strength and elongation. Potassium is important for normal growth of the plant, while on the other hand nitrogen deficiency causes retardation of plant growth. Phosphorus (K) deficiency results in reduction of leaf expansion and photosynthesis which eventually affects the quality of leaves and fibre yield. According to Jiang et al. (2006) low temperature cause fibre thickening and this leads to lower fibre tenacity.

2.2 Extraction Processes of Agave Fibre

The purpose of fibre extraction is to separate the fibres from the cellular tissues. This can either be done through mechanical separation or the retting process. Decortication process is a mechanical separation of fibres, whereby the leaves are crushed and scrapped by metal rolls exposing the fibres. The fibres are washed to remove the waste parts, dried and then brushed to align them (Rowell et al., 2010). In the alternative water retting process, it employs the action of bacteria and moisture on the stalk to rot away the cellular tissues and gummy substances that hold the fibres and loosen them from the leaf (Billie et al., 2009). The process takes 15 to 21 days for a single cycle of extraction.
Timothy and Caroline (2009) point out that, decortication process is the cheapest method of fibre extraction in Lesotho. Laura (2010) further argues that mechanical process produces fibres with a higher quality than water retting. However the disadvantages of water retting process are; it is water intensive, unhygienic and not eco-friendly. It also degrades the quality of fibres if the fibres are over retted (Laura, 2009). According to Oudiani (2009) and Msahli et al. (2005) A. americana fibres can be extracted using water retting, chemical treatment and by mechanical extraction. In this study decorticated method of fibre extraction will be employed on A. americana “Marginata” plant since it is cheap, faster, yields better quality fibres and has not been used on A. americana “Marginata” plant in Kenya.

2.3 Essential Fibre Properties

Fibre properties are determined by the nature of the physical structure, mechanical and the chemical composition. There are several basic properties of a polymeric material to make an adequate fibre (Kadolph et al., 2009).

2.3.1 Physical Properties

Physical properties includes: colour and physical shape (length, surface, texture and cross-section).

2.3.1.1 Physical Shape

The shape of the fibre includes surface contours, shape of the cross section, width and length of the fibre. The surface contour affects cohesiveness, resiliency and thickness of the fibre. It also contributes to the resistance to abrasion and pilling as well as comfort of the fabric, including warmth (Tortora et al., 2009). 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 lustre cohesiveness and resiliency. Cross-section contributes to characteristics such as appearance, hand or feel and surface texture of fabric. Retted *A. americana* “Marginata” fibre has a smooth and lustrous appearance (Mbugua, 2009).

### 2.3.1.2 Fibre Length

The length of the fibre has an effect on the appearance of the yarn into which it is constituted. According to a study by Mbugua (2009) on retted *A. americana* “Marginata” fibre from Mbaruk, the fibres were found to be of a mean length of 65.2cm. Hatch (1993) and Manonyane (2006) point out that, longer fibres can be spun at faster speed requiring less twist to produce commercial yarns. The length of individual fibre is expressed in millimetres while the fineness is expressed as a diameter in micrometer units or as a linear density. Longer fibres produce yarns which are shinny in appearance and this enables fancy yarns to be produced. According to Kadolph et al. (2009), 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.

### 2.3.2 Mechanical Properties

Mechanical properties include tenacity, elastic-recovery and elongation, linear density and force at break. These properties are essential for a textile fibre for the manufacture into fabric (Morton and Hearle 2008).
2.3.2.1 Tenacity

This is the ability of a textile to withstand the mechanical forces that are encountered for a reasonable period of time (Hatch, 1993). The retted *A. americana* “Marginata” fibres has a tenacity of 2.94g/d (25.96 cN/Tex) when dry and 2.3g/d (20.60cN/Tex) when wet. A previous study indicated that the fibre lost its tenacity when wet (Mbugua, 2009); a property was inconsistent with cellulosic fibres. However, the fibres were generally quite strong when dry. The Tenacity is defined as force per unit linear density necessary to break a known unit of that fibre. The breaking tenacity is measured in gram per denier or gram per tex or Newton per tex. While denier is the mass in grams of 9000 yarns, tex is the mass in grams of 1000m of a fibre (Wynne, 1997). However, a fibre must possess adequate strength to be processed into a textile fabric. It is important that the resultant textile must have sufficient strength to provide adequate durability during end use. According to Hatch (1993), a textile which is not durable enough is of little value even if it has other performance attributes.

2.3.2.2 Elastic Recovery and Elongation

Elastic recovery is the ability of a fibre to return to its original dimensions after being stressed or elongated. The more fully a textile can recover from an applied stress, the more likely it will withstand the next stress it encounters (Kadolph & Langford, 2009). Kroschwitz (1990) records that in general, baste fibres are typically low in elongation and recovery from stretch. Elongation at break is the amount of stretch a fibre will withstand before it breaks. A fibre which will stretch or elongate more before breaking shows greater toughness and durability than a stiffer fibre that breaks at the same load but at low elongation. The elongation of a fibre is an important factor
in evaluating the quality of the fibre in terms of durability and elastic recovery. (Billie, Martin, Tortora, 2008).

2.3.2.3 Linear Density
This compares the mass of a fibre to an equal volume of water. Linear density is the weight per unit length and is the most commonly used parameter to characterise fineness of the textile fibres. The property of fineness or coarseness of a textile fibre has been recognised as one of the most important fibre characteristics affecting processing behaviour of yarn properties. Fineness helps determine the bending or rigidity of fibres (Sarah, 2010). The density of natural fibres is considerably low compared to man-made fibres. Reinforcing potential at low cost and low density is part of the reasons why they are attractive to industry such as the automotive industries.

2.3.3 Chemical Properties
The chemical properties include: absorbency, chemical composition, dyeing and colourfastness. They are desirable and may frequently increase the value and desirability of the fibre in its intended end use (Mbugua, 2009; Morton et al., 2008).

2.3.3.1 Moisture Content and Moisture Regain
Textiles in their natural state are hygroscopic and the moisture content of the fibre increases as the humidity increases. Raul (2011) states that moisture regain influences the fibre properties and also the relative humidity affects the regain of textile material. He further argues that mechanical properties and temperature time the fibre is exposed to atmosphere are some of the factors that affect the moisture regain. Rowell (2010)
had notes that moisture content can vary greatly depending on method of fibre processing. The retted *A. americana* fibre had a moisture regain of 9.98% and a moisture content of 9.19% which was comparable to other cellulosic fibres (Mbugua, 2009). According to Msahli et al., (2006) the *A. americana* fibres are more hydrophilic than cotton, flax and other vegetable fibres.

Fibres with good moisture regain accept dyes and finishes more readily than fibres with low regain and hence produce a variety of attractive yarns and fabrics for consumer end use. Fibres with low moisture regain will wash and dry quickly (Joseph, 1986; Makokha, 1990). Tortora (1992) states that a fibre that permits some moisture absorption is comfortable to wear especially during the hot weather. However, they dry slowly and may be stained by water-borne soil. Tortora argues that the strength of the some fibres is affected by the moisture they contain; for example cotton is stronger when wet than dry, whereas rayon and wool are weaker when wet than dry.

Absorbency is one of the several factors that determine the suitability of a fibre for a particular purpose. These characteristics are important in fibres or fabrics that are to be dyed since the completeness and uniformity of the dyeing are dependent upon absorbency (Kadolph et al., 2009; Tortora, 1992). Hatch (1993) argues that absorbency is related to static build up. Absorbent fibres are apt to be more comfortable and less prone to problems of cling, crackle, and static building than hydrophobic synthetics.
2.3.3.2 Chemical Composition of Cellulosic Fibres

The structure and chemical make-up of natural fibres varies greatly and depends on their source and many processing variables. The main components of natural fibres are cellulose, hemicelluloses, lignin, pectins and waxes (Saxena et al., 2011). A number of studies of fibre composition and morphology have found that cellulose and micro fibril angle tend to control the mechanical properties of cellulosic fibres (Young & Rowell, 1986).

The chemical structure of cellulose is important in determining the properties of cellulosic fibres. Plant fibres are organic and so are cellulosic fibres. Therefore, they contain Carbon (C), Hydrogen (H) and Oxygen (O) with chemically reactive hydroxyl groups (-OH). However, the group may undergo substitution on procedures to modify the cellulose fibres or in the application of some dye stuffs, (Kadolph et al., 2009).

The bonding together of monomers to form a polymer is referred to as polymerization (Joseph, 1986). Kleimn (2005) states that many properties of cellulosic fibres depend on its chain length or degree of polymerization. The degree of polymerization of natural fibres is determined by nature during the growth of the plant (Wynn, 1997).

Hemicelluloses are polymers of five to six-carbon sugars. Hemicelluloses, lignin and pectins collectively function as matrix and adhesive, helping to hold together the cellulosic framework structure of the natural fibres. Hemicellulose is hydrophilic, soluble in alkali and easily hydrolyzed in acid. Lignin is an amorphous, cross-linked polymer network consisting of five hydroxyls and five methoxyl groups per unit. It has a role in cementing the polysaccharide components in cells as a composite material and it has moderate decay resistance towards micro organisms (Kirk et al.,
Bismarck et al. (2005) noted that lignin is the compound that gives rigidity to the plant. Lignin content is expected to increase with age of leaf and it is suggested to be highest in the leaf base and lower at the top of the leaves. Pectins are complex polysaccharides which provide flexibility to plant. The chemical composition of the fibres is the variable that most determines the overall properties of the fibres Saxena et al. (2011) and Taj et al. (2007).

2.4 Dyeing

Dyeing is the process of adding dyes and pigments which are commonly referred to as colorant to the fibres, yarn and fabrics (Kadolph et al., 2009). They further state that dyeability is an important performance property of fibre appearance retention. Manonyane (2006) notes that few natural dyes are colour fast with fibres therefore mordants should be used when dyeing. Kadolph et al. (2009) states that dye molecules dissolve in water and other carriers to penetrate into fibre. Undissolved particles remain on the surface of the fibre which bleeds. Mordants are substances which are used to fix a dye to the fibre. They also improve the take up quality of the fabric and help improve colour and light fastness. However, some natural dyes e.g. indigo will fix without the aid of a mordant. When a dye colours a fabric directly with one operation of impregnation, without the aid of an affixing agent, the dye is said to be a direct dye (substantive dye) for that fibre (Hatch, 1993).

According to Hatch (1993), direct dyes are easiest to produce and the simplest to apply. They are water soluble and suitable for a range of cellulosic textile fibres where high wet fastness is not so essential. Raul (2011) argues that dark shades of direct colours bleed in boiling soapy water. Cellulosic fibres can successfully be dyed
with vat dyes because they form bonds with the fibres. The chemical bonds are much stronger than physical attraction, so these dyes are essentially permanent. Vat dyes exhibit an excellent colour fastness to light, washing and bleaching and are used for quality textile goods (Raul, 2011).

Samanta and Agarwal (2011) argue that there is high demand of natural dyes. This is because they are eco-friendly and bio-degradable. Tortora (2009) states that natural/vegetable dyes may be produced from many sources. Among the natural fibres is “Tami dye” that it is produced from Mexican marigold weed and its scientific name is Tagetes minutas (Mibey et al., 2009).

2.5 Colour Fastness

Colour fastness is the measure of how permanent a colour is on fabric. Dyes that are fast for the purpose for which the fabric is intended are termed fast dyes. However, dyes of different colours have diverse degrees of fastness in various conditions. Colourfast can be affected by such factors as perspiration, dry cleaning, bleaching, swimming pool additives or atmospheric gases. Further Kadolph et al. (2009) state that colourfastness is influenced by chemical composition of the fibres, chemical nature of dyes, penetration of dyes into the fibres and fixation of the dyes in the fibres. Colour fastness is not solely a property of the dye. Fastness properties are also affected by the material on which the dye stuff is used. Colour fastness of a dye is also dependent on depth of shade. Deep shades resist better than pale shades of the same dye (GreenStone, 2010).
Kadolph et al. (2009) state that certain dyes may bleed or run when wet and that some dyes can rub off due to the friction in wear; therefore selection of the proper dye is crucial to its ultimate use. Fastness to light is also important, especially to draperies as they must stand light daily. Similarly fastness to washing is essential especially to clothing that requires frequent washing.

2.6 Application and Market Potential of Natural Fibres

Due to the widespread use of synthetic fibres, natural fibres have faced increased competition in the market, and in many cases the traditional markets for natural fibres have eroded or have disappeared. Natural fibres face the challenge of developing and maintaining markets where they can compete effectively with synthetics. Therefore, this calls for defining market niches, development of new technology to facilitate the use of new natural fibres in new applications, where their advantages will allow them to compete effectively with synthetic fibres (FAO, 2009). However natural fibres have intrinsic properties, that is, mechanical strength, low weight and low cost. These properties have made the natural fibres particularly attractive to the automotive industry. In Europe, car makers are using mats made of albaca, flax and hemp in press-moulding thermoplastic panels for doors, drivers parcel shelves, seat backs, engine shield and headrests (FAO, 2009).

Museew (2009) points out that for consumers, natural fibre composites in automobiles provide better thermal and acoustic insulation than fibre glass, and reduce irritation of the skin and respiratory system. Museew (2009) further states that low density of plant fibres also reduces vehicle weight, which cuts fuel consumption. According to the International Year of Natural Fibre (IYNF) coordination unit, car manufacturers
are “going green” in Indonesia, by utilizing environmentally friendly natural fibres to protect the environment. Toyota manufactures door trims made of kenaf fibres and Mazda are using a bioplastic made with kenaf fibres for car interiors.

Museew (2009) notes that, worldwide, the construction industry is moving towards the natural fibres for a range of products. Among the recent innovations are cement blocks reinforced with sisal fibres, now being manufactured in Tanzania and Brazil. Geo-textiles are another promising new outlet for natural fibre producers. Geo-textiles nets made from hard natural fibres strengthen earthworks and encourage the growth of plants and trees. The Agave fibre, such as sisalana and A. americana have been traditionally used to make twines and ropes, due to its strength.

However, in recent times it is being used for making specialty paper, filters, geo-textiles, mattresses, carpets and wall coverings. It is also used for reinforcement in plastic, composite materials and in furniture. In addition, the by-products from A. americana fibre extraction can be used in production of bio-gas, pharmaceutical ingredients and building materials (Museew, 2009). The leaves also yield fiber known as pita which is suitable for making rope, matting and coarse cloth. Pita is also used for embroidery of leather in a technique known as piteaodo (Irish, 2000).

2.7 Current Status of Textile Industry in Kenya

The textile and clothing industry in Kenya faces significant challenges. This is as a result of massive dumping of used clothes and cheap imports among other issues (EPZA 2005). Local textile manufacturers supply only 45% of Kenya’s textile market requirements, while imported new, used garments and imported fabrics account for
55% of the market (Ikiara & Lydia, 2004). However the new demand for natural fibres today opens a potentially promising avenue for opportunities for the Kenyan textile industry.

The use of natural fibres in composite material in new industrial products is part of a new conception of environmental management (Jan, 2009). The US African Growth Opportunity Act (AGOA) offers significant potential for the local textile and apparel industry with a duty and quota free access to the US for products made up of either US or Sub-Saharan African produced fabric and yarn (OTEXA, 2012). In most developed countries such as Europe, car makers are using an estimated 80,000 tonnes of natural fibres a year to reinforce thermoplastic panels (IYNF, 2009) while hemp wastes are used in cement manufacture. In Brazil roofing materials are reinforced with sisal.

### 2.8 Fibres in the Fashion Industry

Common textile fibres used in global fashion today include cotton, linen, silk, wool, Cashmere, hemp and jute (IYNF, 2009). Celebrities, models and designers have recently drawn attention to environmentally friendly fashion. Burke (2008) noted that many designers are making use of natural renewable sourced fibers. Further, he argued that organic cotton has become popular in fashion especially for baby clothes. This is due to the fact that organic cotton is considered as a suitable choice of fabric given that it is free from destructive toxics, pesticides and fertilizers (Copenhagen fashion summit, 2008). Another cellulosic fibre that designers are experimenting on is the bamboo fibre because it grows quickly and in abundance.
According to Frank (2001), silk continues to be the ideal mode of expression by top designers. This is because of its unique quality of texture, lustre and pleasant appearance. He further argues that top designers always include a considerable percentage of silk dresses in their collections and this is considered as their highlights. Another natural protein fibre that the designers are making use of is Alpaca fleece fibre due to its softness, durability and warmth. Similarly designers also use merino wool in their creations since the fibre provides unique qualities of fineness, skin comfort and superior texture (Frank, 2001).

According to Gachara (2014), fashion industry in Kenya is on the rise due to consumers focusing on what they wear and where they shop. Rift Valley Textile (RIVATEX) produces kanga and kitenge cotton fabrics which are popular in fashion. The increased appreciation of these traditional fabrics by Kenyans has made them become common forms of street wear (Elung’ata, 2013; Mangiera, 2008). However designers are moving away from the eclectic prints of Ankara to ready-to-wear garments of cotton, silk and chiffon (Gachara, 2014).

2.9 Summary of Literature Review

Currently, Kenya imports most of the vegetable fibres and the future of the textile industry depends on the availability of raw materials. There is need for utilization of materials and services that are less expensive, locally available yet internationally competitive. The *A. americana “Marginata”* plant could be a potential source of industrial and commercial fibres and it’s utilization will reduce reliance on importation of fibres and yarns. Thus the need to determine the physical, mechanical
and chemical properties *A. americana* fibres, harvested from different plant levels and locations.
CHAPTER THREE: METHODOLOGY

3.1 Research Design

The pure experimental research design was employed for this study (Kothari, 2004). The design dealt with laboratory experiments, which were carried out in a simulated setting. The design helped to examine cause and relationship between the independent and dependent variables. Geographical location and level of plant leaves were independent variables while the fibre properties are dependent. The principle of replication was applied for all experiments conducted. This increased the precision of the study hence increased the accuracy of results. Observations were made on various tests. The control for this research was the KEBS and the International standards of fibre testing.

3.2 Measurement of Variables

The independent variables in this study were geographical areas and the level of plant leaves while the dependent variables were physical, mechanical, chemical properties of raw and dyed *A. americana* “Marginata” fibres.

3.3 Study Areas

Lanet (Nakuru, county) and Tigoni (Kiambu, County) in Kenya were identified for this study. The two locations were selected because *A. americana* “Marginata” plants were available and are planted as ornamental plants. The two areas have distinctive soil and climatic conditions. Lanet is located within the region of Great Rift Valley, 160km North West of Nairobi. It is situated at an altitude of 1857m above sea level and has a dry sub-humid equatorial climate with an average temperature ranging between 10-20°C. The soil type is predominantly loamy (Wamicha et al., 2009). On
the other hand Tigoni has a cooler climate, with no dry season or warm summer due to its high altitude. It is situated at an altitude of 2500m above sea level. The soil is well drained, dark reddish brown and moderately fertile. The temperature ranges between 12-24°C with an average annual rainfall of 1096mm (Makokha, Kimani, Mwangi, Verkuijl, Musembi, 2001).

The fibre testing was carried out at the Textile Testing Service Department at the Kenya Bureau of Standards, Nairobi and the Moi University textile testing laboratory, Eldoret. The samples for SEM (Scanning Electron Microscopy) were prepared at the International Centre for Insect Physiology and Ecology (ICIPE). Electron Microscopy and the imaging were done at E.L.I Microscopy Laboratory, Charleroi Belgium. Soil analysis was conducted at the Kenya Forestry Research Institute (KARI), Nairobi. Fibres were decorticated at Mogotio sisal estate. The research centres were selected because they had facilities to carry out the necessary experiments efficiently.

3.4 Target Population

The target population of *A. americana “Marginata”* was 20 plants from the two locations; Lanet and Tigoni. The plants which had six leaf levels were selected for the study (Appendix A). Menachem (2006) states that the first cutting of agave leaves should take place between 2 to 3 years after planting. Further Menachem (2006) argues that the mature leaves are those at the base of the plant and fibres extracted from immature leaves are weak to undergo fibre processing. When ready for harvesting the lower 2 to 3 leaf levels are cut whereby 15 to 20 leaves are harvested annually for fibre extraction. For the purpose of this study three leaf levels from the
base of the plant were selected for harvesting. Plants with more or less than six leaf levels were excluded from the study.

3.5 Sampling Technique

*A. americana* leaves were harvested from the two locations, Lanet (Nakuru, county) and Tigoni (Kiambu, County). A total of twelve leaves were purposively harvested from each plant ensuring that four leaves were harvested from each level of the same plant. The position of the extracted leaves was from three leaf levels of each plant, that is, the first, second and third level from the base towards the apex of each plant. This ensured that only mature leaves were sampled for the study. Leaves sampled from Tigoni were labelled as level 1 (T1), level 2 (T2), level 3 (T3) while those from Lanet were level 1 (L1), level 2 (L2) and level 3 (L3).

3.6 Sample Size

A total of 120 leaves from 10 plants from each location were collected (i.e. 4 leaves from each level per plant selected). In total 240 leaves were harvested from both Locations. The plants were harvested within a radius of 500 metres to ensure that the site had same soil and climate condition. Only those plants with six leaf levels were selected for the study in order to obtain leaves of similar age.

3.7 Research Instruments

The research instruments from Kenya Bureau Standards (KEBS) and Moi University textile laboratory were used in this study. KEBS and Moi University textile laboratories were selected because they provide internationally recognised conformity services. The instruments included an Instron-tensile tester to record tenacity and
elongation (Plate 3.3), environmental chamber for analysing textile at standard testing conditions, precision balance (Appendix IIb), desiccators for cooling the fibre (Appendix IIa), spectrophotometer for assessing any change in colour on dyed fibre (Appendix IIc), a raspador to extract the fibres at Mogotio extraction firm (Plate 3.1) and a Scanning Electron Microscopy (SEM) to obtain micrographs of cross and longitudinal views of the fibres.

3.8 Pre-Testing

The instruments for data collection were pre-tested at KEBS to determine their validity and reliability. The test-pretest methods were used to establish the reliability index of the instruments. Sample fibres were subjected to the experimental test to evaluate the reliability of results. The study procedure were tested no modification was required.

3.9 Validity and Reliability

To ensure validity and reliability of findings, all experimental tests were carried out at the Textile Testing Service Department laboratory of the Kenya Bureau of Standards in Nairobi and Moi University textile laboratory whose testing equipment were accurate and meet international standards. The laboratories are managed in accordance to International Standards ISO/IEC/7025 on general requirements for competence testing and calibration laboratories. All tests were performed in compliance with the set standards of Kenya Bureau of standards for each of the parameters tested to ensure that random errors were minimised. No modification was required on the Test instruments and measuring procedures.
3.10 Climate and Soils Analysis

Ten soil samples were collected within the area the plants were growing in each of the two sites. The soil was sampled at a depth of 0-30 cm. Once sampled, the ten samples from each site were bulked together, mixed thoroughly and 250g sub-sampled for analysis for each location (Kinfermichael, 2011). The soil samples were taken to Kenya Forestry Research Institute (KEFRI) Nairobi for determination of soil chemical attributes. The soil attributes analysis included the soil pH (HO), potassium (P), organic carbon (OC), electrical conductivity (EC), magnesium (Mg) and calcium (Ca). The average annual climate conditions were established with the help of meteorologist department of Kenya.

3.11 Data Collection Procedures

3.11.1 Fibre Extraction

According to Rehms and Espig (1991), the process of fibre extraction has the greatest influence on the quality of fibres. Therefore this study employed the decortication process and evaluation of the properties of A. americana fibres was done. The leaves were cut from the plant and the thorns on the leaf margin and spines at the tip of the leaf were removed with a sharp knife at the harvest areas (Lanet and Tigoni). The leaves were transported to Mogotio sisal extraction plant where they were subjected to the decortication process and washed to removes the pulp matter on fibre surface. The fibres were dried and brushed which aligned and further removed any foreign matters from the fibres (Plate 3.2). The fibres were then packed and labelled according to location and plant levels from which they were extracted.
Plate 3.1 Agave Americana “Marginata” decortication process

Leaves being fed into the decorticating machine for fibre extraction

Plate 3.2 Brushing of Agave Americana “Marginata” fibres

Brushing and straightening of fibres
3.11.2 Fibre Testing Procedure

A sample from each level and location, weighing 50gm was conditioned to reach the standard testing conditions of relative humidity 65% ± 2 and at a temperature of 20°C ± 2 to ensure accuracy and reliability of results (Msahli et al., 2007). This was done at the Kenya Bureau of standards. From the conditioned fibres, samples were picked randomly from each category and then assigned for the experimental treatments as follows;

3.11.3 Physical Properties

3.11.3.1 Physical Shape

The morphology of the fibres was studied using a Scanning Electron Microscope (Jeol Model JSM-6100 SEM, Tokyo, Japan). The samples of the A. americana “Marginata” fibers for longitudinal views were cut 1cm from the base of the fibers. Samples of 5mm lengths were obtained and mounted longitudinally on aluminum strips using double sided adhesive conductive carbon tape. A total of 5-7 fibers were mounted for each batch (T1, T2, T3, L1, L2 and L3). For cross sectional views, 2mm samples of each batch bundles were wrapped together in aluminum strips, 1.5cm from the fiber base and mounted for cross sectional view. The prepared samples for both longitudinal and the cross sectional were dried for 48 hours in a desiccator. The dried samples were sputter coated with gold at 10 mA ion current for 9 minutes in Jeol JFC-1100 Ion Sputter. At 200x and 2000x (2kx) magnifications, the samples were viewed under Scanning Electron Microscope at 5kv acceleration voltage using secondary electron imaging. The fibre images (micrographs) were captured (in black and white) using Orion Saturn Image Acquisition System, (E.L.I. sprl Belgium)
3.11.3.2 Fibre Length

This test helps in determining the average fibre length. Thirty single strands were drawn at random from every sample from each level and location and straightened out over a meter-ruler. The lengths were recorded in centimetres.

3.11.4 Mechanical Properties

3.11.4.1 Linear Density

This is defined as the weight per unit length. It is the most commonly used parameter to characterize fineness of textile fibres. The linear density was measured using the gravimetric method (ISO: 1973:1995), where individual length of the fibres from each sample were measured and weighed using a precision balance and the weight was recorded from which the linear density was calculated. Twenty fibres were used to calculate the linear density of each sample using the formula below;

\[
\text{Linear density (Tex)} = \frac{\text{weight}}{\text{Length}} \times 100
\]

3.11.4.2 Fibre Strength and Elongation (Wet and Dry)

The test was performed in compliance with the Kenya standard, KS 08-630, (1987) Part 2. Fibre strength and elongation measurement were performed in terms of grams per tex and percentage elongation respectively. The fibre strength and elongation properties for this research were measured on a Universal Tensile testing instrument. Twenty strands of dried A. americana fibres were held and straightened out together and a length of 45cm measured and cut from each sample. The specimen fibres were mounted individually between the jaws of the clamps (of tensile testing machine) to remove slack without stretching the specimen (Plate 3.3). The machine was started and the specimens pulled to a break point. The tenacity, elongation at break (rupture)
and force at break were recorded for fibres from each level and location. A similar test was carried on wet fibres to test wet breaking tenacity and elongation at break. However, for this test the samples were first immersed in cold distilled water for 20 minutes.
Plate 3.3 Sample Mounted on a Tensile Testing Machine

Fibre mounted to test tenacity and elongation
3.11.5 Chemical Properties

3.11.5.1 Moisture Content and Regain:

The test was performed in compliance with KS 08- 1037; 1990 ICS 59 (2005) Part 1 and determined the percent moisture regain of dry *A. americana* “Marginata” fibres samples. Ten fibre samples were placed in an oven set at 105°C and dried for at least four hours and cooled for 30 minutes in desiccators thereafter. The samples were then quickly transferred into a weighing scale and the oven dry weight recorded. Similar tests were carried out for each level from each location. Moisture content and regain was calculated according to the following formula;

Moisture content %

\[
\frac{(\text{Conditioned air dry weight of fibres } - \text{Oven weight of dried fibres})}{\text{Conditioned air dry weight of fibres}} \times 100
\]

Moisture regain %

\[
\frac{(\text{Oven dry weight of fibres } - \text{Conditioned air dry weight of fibres})}{\text{Oven dry weight of fibres}} \times 100
\]

3.11.5.2 Determination of Chemical Composition

According to Reddy (2005) the chemical composition (lignin, pectin and hemicelluloses) give fibres a rough and irregular surface. Therefore the chemical components of *A. americana* “Marginata” fibres was evaluated. The test was performed in compliance with 20A-211 Chemical composition test methods

3.11.5.2.1 Pectin

To analyse the percentage of pectin in the fibres, they were weighed to get the conditioned weight (W1) and boiled in ammonium oxalate solution for 3 hours to
dissolve the pectin. The bone weight of the fibre was determined (W2) and the pectin percentage calculated using the following formula;

\[
Pectin \% = \frac{(W1 - W2) 
}{W1} 
\]

### 3.11.5.2.2 Hemicellulose

The percentage of Hemicellulose in the fibre was analysed by boiling the fibres in Sodium Hydroxide for 3½ hrs. The bone weight of the fibre (W3) was determined. Hemicelluloses percentage was calculated using the following formula;

\[
Hemicellulose \% = \frac{(W1 - W3) 
}{W1} 
\]

### 3.11.5.2.3 Lignin

The percentage of lignin in the fibre was analysed as follows. The fibres dissolved in concentrated sulphuric acid (H\(_2\)SO\(_4\)) for 24 hrs. The mixture was stirred and 150 ml of distilled water was added to the mixture which was boiled for 1 hour and cooled in a desiccator. The residue (lignin) was filtered, collected and weighed (W5). The lignin percentage weight was determined using the following formula;

\[
Lignin \% = \frac{(W5) 
}{W1} 
\]

### 3.11.6 Fibre Dyeing Procedures

The fibres samples were dyed using natural and synthetic dyes and their dye uptake determined. The fibres were dyed with natural dyes (Tami dye, Iron-rust dye) and synthetics dyes (disperse dye and vat dye). The receptivity of each dye on different fibre samples were observed and evaluated by use of a grey scale at Kenya Bureau of Standards.
3.11.6.1 Natural Dyes

3.11.6.1.1 Tami (Tagetes minuta) Dyeing

The fibres were first mordanted in 25gm of potassium aluminium in 3 litres of water. The solution with the fibres was boiled for 1½ hrs. As it boiled a pinch by pinch of sodium carbonate was added. To dye the fibre a dye bath was first obtained by adding 200gms of inflorescences of tagetes minuta (Tami) in 5 litres of water. The dye bath was simmered for 1hr. The dye bath obtained was left to cool and then strained. The mordanted fibres were added to the dye bath and simmered for 1 hr. The fibres were rinsed in warm water and let to dry (Mibey et al., 2009). A golden yellow fibre colour was obtained (Plate 3.4)

Plate 3.4 Sample of Fibre Dyed with Tami Dye

3.11.6.1.2 Iron-rust (Ferrous Ammonium sulphate) Dyeing

Under stable condition the iron-rust produces a light green colour on natural fibres/fabrics but oxidizes readily upon exposure to open air to produce an amber brown colour. To dye the fibres a solution of 3 litres of water and 2½ tablespoonfuls of caustic soda was prepared and 20gms of ferrous ammonium sulphate was added to
it. To mordant the fibres 2 tablespoonful of sodium hydrosulphate was added to the solution and stirred until it dissolved. The fibres were immersed in the dye bath and evenly wetted with the dye liquor to ensure that the fibres are evenly dyed. After 45 minutes the fibre were removed and oxidized for 30 minutes. The fibres were rinsed and boiled in soapy water for another 30 minutes, then rinsed again and dried. An amber brown fibre colour was obtained as shown in Plate 3.6

Plate 3.5 Sample of Fibre Dyed with Iron-rust Dye

3.11.6.2 Synthetic Dyes

3.11.6.2.1 Disperse Dyeing

The disperse dye can be used on most natural fibres such as sisal among others. To prepare the dye bath, 50gms of green disperse dye was mixed with warm water to make a paste. The dye paste was added into 5 litres of water and stirred. Common salt was added to the dye bath and stirred until it was dissolved. The fibres were immersed in the dye bath and turned occasionally to get them thoroughly and evenly wetted with the dye solution. An already prepared solution of soda ash in ½ litre of water was added to the fibre dye bath and stirred for 45 minutes. The fibres were removed from the dye bath and rinsed in cold water. The fibres were put in boiling soapy water for
10 minutes, rinsed well in cold water and dried. A green fibre was obtained as shown in Plate 3.5

Plate 3.6 Sample of Fibre Dyed with Disperse Dye

3.11.6.2.2 Vat Dyeing

To dye the fibres, 2½ tablespoonful of caustic soda were added to 5 litres of water. To get a dye bath, ½ teaspoonful of vat dye was added to the mixture. To mordant the fibres 2 tablespoonful of sodium hydrosulphate were added to the dye bath and stirred until it dissolved. The dye bath was heated to temperature of 60°C and the fibres immersed in the dye bath and stirred occasionally for 30 minutes. They were removed and oxidized for 30 minutes by exposure to air to produce a pink colour was obtained as shown on Plate 3.7. The fibres were rinsed and boiled in soapy water for another 30 minutes and then rinsed again and dried.
3.11.7 Colour Fastness

The testing of colour fastness was performed on the dyed fibres. The test was to determine how permanent the colour was on the fibres. Major parameters tested included; fastness to light, water and rubbing.

3.11.7.1 Light Fastness

The test was performed in compliance with the Kenya Standards, KS-08-359 (2007). The surface of the fibre samples was exposed to ultraviolet light. An evaluation was done on the exposed sample against an unexposed control sample to determine the degree of colour fastness to light.

3.11.7.2 Water Fastness

The test was performed in compliance with Kenya Standards, KS-08-123 (2007). A sample of *A. americana* “Marginata” fibres (approx. 15cm) dyed with natural and synthetic dyes were attached to multifibres swatches by stitching. A washing solution was prepared using 2g of sodium carbonate and 5g of washing soap in one litre of water. The attached fibre samples were put in washing wheel pots containing the prepared solution. The wheel was then run for 30min at 60°C. The samples were then
removed washed and dried indoors. A standard grey scale was used to assess the degree of change or loss of shade if any.

### 3.11.7.3 Rubbing Fastness

The test was performed in accordance with the Kenya Standards KS-08-266 (1997). This was to determine how permanent colour was on the dyed fibre. The sample was subjected to rubbing with a standard of undyed fabrics in order to check for colour transfer. Two tests were involved, one using the rubbing the fibres whilst dry and the other while wetted. The rubbing fabric was placed on the finger of the crock meter and moved back and forth across the fibre samples ten times at a steady speed. A spectrophotometer was used to assess whether there was any change in colour and colour transfer to the undyed fabric.

### 3.12 Data Analysis and Presentation

Descriptive statistics and Analysis of Variance (ANOVA) were applied. This was the most suitable analysis technique for the study since multiple samples and parameters were involved. The ANOVA method of analysis tested whether there was any significant difference between fibre properties from the different levels and from the two locations. The results were presented in reports, tables and graphical modes to show comparative analysis.

### 3.13 Logistical and Ethical Consideration

An approval letter was sought from Post Graduate School Kenyatta University to carry out the study. A research permit was obtained from National Commission of Science, Technology and Innovation (NACOSTI). Verbal Permission to harvest the
plant leaves was obtained from the community from the two areas. The researcher also obtained permission to use facilities at KEBS, Moi University Textile Laboratory and Mogotio Sisal estate.
CHAPTER FOUR: FINDINGS AND DISCUSSION

4.1 Effect of Soil properties and Climate Conditions on A. americana “Marginata” Fibre properties

4.1.1 Soil Analysis

The soil in the two areas was analyzed for several attributes (Table 4.1). The pH CaCl\textsubscript{2} was 5.54 for Tigoni and 5.42 for Lanet. Tigoni soil was found to be moderately acidic whereas Lanet was more acid pH (H\textsubscript{2}O). The pH (H\textsubscript{2}O) for both areas was slightly acidic with 6.64 and 6.75 for Tigoni and Lanet respectively. The Electro-Conductivity (E.C.) of the soil was 0.054 ms/cm for Tigoni and 0.056 ms/cm for Lanet. The findings indicated that dissolved salts were low, demonstrating these areas were salt free thus the soil was porous. The results revealed that Organic Carbon (C) % from Tigoni area was 1.75% which was moderate, while Lanet had 1.14% which is not adequate for healthy plant growth (Table 4.1). Phosphorous (P) level of soil sample from Tigoni was found to be slightly lower than that from Lanet at 0.71 and 1.74ppm respectively.

<table>
<thead>
<tr>
<th>Location</th>
<th>pH \textsubscript{H\textsubscript{2}O}</th>
<th>E.C. \textsubscript{ms/cm}</th>
<th>pH CaCl\textsubscript{2}</th>
<th>C % (ppm)</th>
<th>P (ppm)</th>
<th>K (ppm)</th>
<th>Ca (ppm)</th>
<th>Mg (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tigoni</td>
<td>6.64</td>
<td>0.054</td>
<td>5.54</td>
<td>1.75</td>
<td>0.71</td>
<td>601.67</td>
<td>1222.97</td>
<td>563.69</td>
</tr>
<tr>
<td>Lanet</td>
<td>6.75</td>
<td>0.056</td>
<td>5.42</td>
<td>1.14</td>
<td>1.74</td>
<td>212.24</td>
<td>2220.14</td>
<td>349.2</td>
</tr>
</tbody>
</table>

Potassium (K) is involved in osmotic regulation of cells in its ionic form regulating the turgor of non-woody plants organs and stomata functions. Plants are able to
readily extract the available K from soil through bulk flow and selective uptake and the nutrient is very mobile within plant tissue. Tigoni soil had K levels of 601.67 ppm whereas Lanet had 212.24 ppm. More than 300 ppm of potassium is considered very high and between 175-300 ppm is adequate. Calcium (Ca) is essential for plant growth, cell division and enlargement. The major causes of calcium deficiency in soils are low pH, water shortage and excess of magnesium. Tigoni soil had medium levels of Ca at 1222.97 ppm whereas Lanet was high at 2220.14 ppm.

Magnesium (Mg) is an ionic component of chlorophyll, the substance which gives green colour to plants. Deficiency is commonly found in sandy soils or in highly weathered acidic soils. Tigoni soil had Mg levels of 563.69 ppm while Lanet had 349.2 ppm. More than 180 ppm of Mg is considered high hence the two areas have very high Mg content for plant growth.

4.2.2 Climate Conditions
Climate conditions in Tigoni and Lanet differed significantly. Tigoni is at a higher altitude compared to Lanet. The annual average maximum and minimum temperature for Lanet is 26.5°C and 10°C respectively while for Tigoni is 25°C and 13°C respectively. Lanet is therefore, on average, hotter during the day and cooler during the night compared to Tigoni. For both locations the hottest months are January and February while the highest precipitation (rainfall) occurs between April and May. The months with the least precipitation are January and February for Lanet and June and July for Tigoni. Lanet has a higher annual average rainfall of 917mm compared to Tigoni at 810mm even though Lanet has a drier appearance possibly due to the nature
of its soil. For the purpose of this study, plant leaves were harvested in the month of January, when the climate was hot and dry in both locations but cooler in Tigoni.

4.2 Fibre Properties of *A. americana* “*Marginata*” Fibres

4.2.1 Physical Properties

4.2.1.1 Longitudinal View Micrographs of the Fibres

The microscopic analysis of the fibre as shown in plate 4.1a-c and 4.2a-c is characterised by lengthwise striations on the fibre surface. The fibres from all levels in both locations have irregular or rough surfaces since they are covered by extraneous matters on the fibre surfaces. However there are no cross markings or nodes on the fibre surface. From observation, fibres from Lanet leaf level 1 and Tigoni leaf level 1 demonstrate more pronounced striations than all the other levels.

**Plate 4.1a Longitudinal View for Lanet Level 1 Fibres at 200x**

![Image of longitudinal view micrograph](image)

**Extraneous matter**

**Striations**
Plate 4.1b Longitudinal View for Lanet Level 2 Fibres at 200x

Plate 4.1c Longitudinal View for Lanet Level 3 Fibres at 200x
Plate 4.2a Longitudinal View for Tigoni Level 1 Fibres at 200x

Plate 4.2b Longitudinal View for Tigoni Level 2 Fibres at 200x
Plate 4.2c Longitudinal View for Tigoni Level 3 Fibres at 200x

4.2.1.2 Cross-sectional View Micrographs of the Fibres

The findings show that fibres from Lanet fibres exhibited cylindrical shaped appearance while those from Tigoni were oval in shape. Plate 4.3a-c and 4.4a-c of the cross-section view of the fibres show lumen regions. Under higher magnification (Plate 4.3a(ii) - c(ii) and 4.4a(ii) - c(ii), the lumen varies in size and shape according to the level of the plant leaf. Fibres from Lanet leaf level 2 and 3 exhibit larger lumen than in leaf level 1. Similarly fibres from Tigoni leaf level 2 and 3 have larger lumen than those from leaf level 1.
Plate 4.3a(i) and (ii) Cross-sectional View for Lanet 1 Fibres at 200x and 2kx Magnification

Plate 4.3b(i) and (ii) Cross-sectional View for Lanet 2 Fibres at 200x and 2kx Magnification
Plate 4.3c(i) and (ii) Cross-sectional View for Lanet 3 Fibres at 200x and 2kx Magnification

Plate 4.4a(i) and (ii) Cross-sectional View for Tigoni 1 Fibres at 200x and 2kx Magnification
Plate 4.4b(i) and (ii) Cross-sectional View for Tigoni 2 Fibres at 200x and 2kx Magnification

Plate 4.4c(i) and (ii) Cross-sectional View for Tigoni 3 Fibres at 200x and 2kx Magnification
4.2.2 Fibre Length

The findings showed that *A. americana* “Marginata” fibres extracted from Tigoni leaf level (T3) with a mean length of 0.955m exhibited longest length as compared to other levels from the same area while level (T1) fibres with a mean length of 0.798m had the shortest length (Table 4.2). From analysis, the results revealed that there was a significant difference in length between fibres from different leaf levels harvested from Tigoni (p=0.0015, p < 0.05).

Similarly Lanet featured the same trend where leaf level (L3) had the highest mean length at 0.865m and (L1) at 0.716 had the lowest mean length. The findings revealed that there was a significant difference in fibre length across the three levels from Lanet (p < 0.05, p= 0.0051).

<table>
<thead>
<tr>
<th>Location</th>
<th>Tigoni</th>
<th>Lanet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levels</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T1</td>
<td>T2</td>
</tr>
<tr>
<td>Fibre length (Metres)</td>
<td>0.798a</td>
<td>0.826b</td>
</tr>
</tbody>
</table>

Means followed by the same letter in the same row are not significantly different (p<0.05)

For both locations, fibres from corresponding levels were compared. With Tigoni level (T1) having a mean length of 0.798m and Lanet (L1) with 0.716m. It was noted there was a significant difference in fibre length between (T1) and (L1) (p=0.0192, p < 0.05) (Table 4.2). Statistical analysis showed that there was a significant difference in mean fibre lengths between the third levels (T3) and (L3) since p=0.0322, P < 0.05. However there was no significant difference in fibre length between level (T2) and
(L2) (p=0.6162, p > 0.05). Mean length of fibres from all levels from both locations show no significant difference (p=0.3382, p > 0.05). In general, findings showed that fibre length was not dependent upon the location where the plant was grown but depended on position of leaves on the plant.

4.3 Mechanical Properties

4.3.1 Linear Density

Results in this study indicate that in Lanet location, *A. americana* “Marginata” raw fibres extracted from leaf level (L2) had the highest linear density at 26.808tex while level (L1) had the lowest at 21.67tex, (L3) had 25.017tex. Similarly fibres extracted from Tigoni leaf level (T2) had the highest linear density of 26.341tex while (T1) had the lowest at 20.057tex as shown in Table 4.3.

<table>
<thead>
<tr>
<th>Locations</th>
<th>Tigoni</th>
<th>Lanet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levels</td>
<td>T1</td>
<td>T2</td>
</tr>
</tbody>
</table>

Mean followed by the same letters in the same row are not significantly different (p>0.05)

Statistically the study revealed no significant difference in linear density between fibres from the different leaf levels from Lanet location (p>0.05, p=0.0945), (Table 4.4)
Table 4.4 ANOVA Summary of Differences in Linear Density between L1, L2 and L3

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Square</th>
<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>P-value</th>
<th>F critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>321.184</td>
<td>2</td>
<td>160.592</td>
<td>2.4588</td>
<td>0.0945***</td>
<td>3.15884</td>
</tr>
<tr>
<td>Within groups</td>
<td>3722.744</td>
<td>57</td>
<td>65.3113</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4043.929</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. *** = p >0.05

The differences in linear density of raw A. americana “Marginata” fibres from Tigoni Level (T2), (T3) and Lanet level (L2) and (L3) were minimal. The results in table 4.5, show significant difference in linear density between fibres from the different leaf level from Tigoni location (p<0.05, p=0.0073). The results also indicated that there was no significant difference in linear density between fibres from the two locations at p>0.05, p=0.8221 (Table 4.6). It was concluded that the location of fibre growth did not influence the linear density of the fibre.

Table 4.5 ANOVA Summary of Differences in Linear Density between T1, T2 and T3

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Sum of Square</th>
<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>P-value</th>
<th>F critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>546.5191</td>
<td>2</td>
<td>273.259</td>
<td>5.3636</td>
<td>0.0073***</td>
<td>3.15884</td>
</tr>
<tr>
<td>Within groups</td>
<td>2903.946</td>
<td>57</td>
<td>50.9464</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>3450.465</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. *** = p <0.05
4.3.2 Fibre Tenacity and Elongation of Dry and Wet Raw *A. americana* “Marginata” Fibres

The study revealed that analysed dry tenacity and elongation (EL) for Tigoni raw *A. americana* “Marginata” fibres level (T1) was $26.53 \pm 1.22$ cN/tex and $14.12 \pm 1.35\%$, level (T2) $22.49 \pm 1.36$ cN/tex and $13.42 \pm 1.17\%$, level (T3) $25.69 \pm 1.23$ cN/tex and $15.42 \pm 1.25\%$ respectively (Table 4.7). It was noted that (T1) had the highest tenacity while (T2) had the lowest. Statistically Tigoni fibres from the three levels had a significant difference in tenacity ($p < 0.05$, $p=0.0177$).
Table 4.7 Mean Tenacity (cN/tex) and Elongation (El) of Dry and Wet A. americana “Marginata” Fibres

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Tenacity cN/tex</th>
<th>El %</th>
<th>Tenacity cN/tex</th>
<th>El %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>Wet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tigoni(T1)</td>
<td>26.53±1.22a</td>
<td>14.12±1.35</td>
<td>24.25±1.38a</td>
<td>14.89±0.64</td>
</tr>
<tr>
<td>Tigoni(T2)</td>
<td>22.49±1.36b</td>
<td>13.42±1.17</td>
<td>19.72±0.94a</td>
<td>16.46±0.90</td>
</tr>
<tr>
<td>Tigoni(T3)</td>
<td>25.69±1.23c</td>
<td>15.42±1.25</td>
<td>21.54±0.90a</td>
<td>16.16±0.87</td>
</tr>
<tr>
<td>Lanet(L1)</td>
<td>27.33±1.62a</td>
<td>12.46±0.66</td>
<td>23.57±0.72a</td>
<td>13.47±0.56</td>
</tr>
<tr>
<td>Lanet(L2)</td>
<td>19.78±0.99b</td>
<td>13.68±0.96</td>
<td>18.98±0.74a</td>
<td>14.89±0.75</td>
</tr>
<tr>
<td>Lanet(L3)</td>
<td>23.65±0.88c</td>
<td>13.78±1.11</td>
<td>18.34±0.87a</td>
<td>15.75±0.97</td>
</tr>
</tbody>
</table>

Mean followed by the same letter (lower case) in the same column are not significantly different (p<0.05)

While on the other hand it was noted that tenacity and elongation percentage for Lanet raw dry A. americana “Marginata” fibres level (L1) was 27.33±1.62cN/tex and 12.46±0.66%, level (L2) 19.78±0.99cN/tex and 13.68±0.96%, level (L3) 23.65±0.88cN/tex and 13.78±1.11% respectively. Leaf level (L1) fibres exhibited the highest tenacity while (L2) fibres had the lowest tenacity (Table 4.7). It was established that there was significant difference in tenacity between fibres harvested from the three plant leaf levels of Lanet (p<0.05, p= 0.0003). This indicates that the position of plant leaf levels influenced fibre tenacity.

Comparing fibres from the two locations the results indicated that Lanet raw dry fibres level (L1) and Tigoni raw dry fibres level (T1) had the highest tenacity in their respective locations while Lanet (L2) fibres and Tigoni (T2) fibres had the lowest tenacity. To verify if the location of harvesting the fibres affected the fibre tenacity comparison was done between mean of T1, T2, T3 verses mean of L1, L2, L3 using
the analysis of variance (ANOVA). It was established that the fibre tenacity from both
locations was not significantly different ($p > 0.05, p=0.5009$). This indicates that the
location of growing the fibre did not have an influence on fibre tenacity.

It was established that tenacity and elongation (EL) of wet fibres from Lanet A.
*americana “Marginata”* fibres samples was $23.57\pm0.72\text{cN/tex}$ and $13.47\pm0.56\%$;
$18.98\pm0.74\text{cN/tex}$ and $14.89\pm0.75\%$; $18.34\pm0.87\text{cN/tex}$ and $15.75\pm0.97\%$ for levels
L1, L2 and L3 respectively. While on the other hand it was noted wet tenacity and
elongation for Tigoni raw fibres was $24.25\pm1.38\text{cN/tex}$ and $14.89\pm0.64\%$;
$19.72\pm0.94\text{cN/tex}$ and $16.46\pm0.90\%$; $21.54\pm0.90\text{cN/tex}$ and $16.16\pm0.87\%$ for levels
T1 T2 and T3 respectively as shown in table 4.7.

The results of this study indicate that application of moisture decreased the tenacity of
the *A. americana “Marginata”* fibres across the levels in both locations. It was noted
that in Tigoni location, there was significant difference in wet fibre tenacity across the
three levels ($p<0.05, p= 0.0106$). Similarly in Lanet the wet fibre tenacity was
significantly different between the three levels ($p<0.05, p= 0.00001$).

The results indicated that moisture increased the elongation and decreased the tenacity
of the *A. americana “Marginata”* fibres across the levels for both locations as (Figure
4.7). It is evident from the results that the dry elongation for Tigoni raw *A. americana
“Marginata”* fibres level (T3) with $15.42\pm1.25\%$ was the highest recorded percentage
compared to levels (T2) and (T1) fibres. On the other hand it was noted that the Lanet
raw *A. americana “Marginata”* fibres level (L3) recorded the highest elongation
percentage while level (L2) had the lowest percentage in that location. It was
observed that statistically there was no significant difference in the elongation of dry fibres from the two locations (p>0.05, p=0.2339). Similarly wet fibre elongation was not significantly different between fibres from the two locations (p>0.05, p=0.3308).

### 4.3.3 Force at Break and Elongation of Raw Dry and Wet *A. americana* “*Marginata*” Fibres

The result in this study, revealed that the average dry force at break and elongation at break for *A. americana* “*Marginata*” fibres from Lanet were $5.481\pm0.32$N and $56.076\pm2.99$mm; $5.305\pm0.26$N and $61.547\pm4.30$mm; $5.916\pm0.22$N and $61.994\pm4.99$mm for levels L1, L2 and L3 respectively (Table 4.8 and Figures 4.1a-c).

Statistically it was observed that there was no significant difference in force at break (p>0.05, p=0.3076) between the three different leaf levels from Lanet.

**Table 4.8 Force at Break (N) and Elongation (mm) of Dry and Wet *A. americana* “*Marginata*” Fibres**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Force at break (N)</th>
<th>El mm</th>
<th>Force at break (N)</th>
<th>El mm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dry</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lanet (L1)</td>
<td>5.481±0.32a</td>
<td>56.076±2.99</td>
<td>4.728±2.99a</td>
<td>60.628±2.52</td>
</tr>
<tr>
<td>Lanet (L2)</td>
<td>5.305±0.26a</td>
<td>61.547±4.30</td>
<td>5.088±4.29a</td>
<td>67.014±3.38</td>
</tr>
<tr>
<td>Lanet (L3)</td>
<td>5.916±0.22a</td>
<td>61.994±4.99</td>
<td>4.588±4.29a</td>
<td>70.883±4.35</td>
</tr>
<tr>
<td><strong>Wet</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tigoni (T1)</td>
<td>5.748±0.26a</td>
<td>63.524±6.09</td>
<td>5.254±6.09b</td>
<td>65.204±2.88</td>
</tr>
<tr>
<td>Tigoni (T2)</td>
<td>5.925±0.35b</td>
<td>60.377±5.28</td>
<td>5.287±5.28b</td>
<td>74.059±4.04</td>
</tr>
<tr>
<td>Tigoni (T3)</td>
<td>6.975±0.31c</td>
<td>69.398±5.63</td>
<td>5.424±5.62b</td>
<td>72.701±3.92</td>
</tr>
</tbody>
</table>

Mean followed by the same letter in the same column are not significantly different (p>0.05)
While dry force at break and elongation for *A. americana “Marginata”* fibres from Tigoni were 5.748±0.26N and 63.524±6.09mm; 5.925±0.35N and 60.377±5.28mm; 6.975±0.31N and 69.398±5.63mm for levels T1, T2 and T3 respectively (Table 4.8 and figure 4.1d-f). Tigoni exhibited a different trend from Lanet as it was observed that there was a significant difference in fibre force at break across the three different leaf levels (p≤ 0.05, p= 0.0197). There was also no significant difference in force at break between fibres from two locations (p > 0.05, p=0.1990). The elongation of dry fibres showed that there was no significant difference between the two locations (p>0.05, p=0.2340).

However dry *A. americana “Marginata”* fibres from Tigoni required a higher break at force load than those from Lanet. Despite a higher force at break the fibres from Tigoni had slightly lower tenacity in some levels compared to those from Lanet.

![Figure 4.1a Force at Break (N) and Elongation (mm) Curve of Dry Raw Fibres from Tigoni Leaf Level T1](image-url)

*Figure 4.1a Force at Break (N) and Elongation (mm) Curve of Dry Raw Fibres from Tigoni Leaf Level T1*
Figure 4.1b Force at Break (N) and Elongation (mm) Curve of Dry Raw Fibres from Tigoni Leaf Level T2

Figure 2.1c Force at Break (N) and Elongation (mm) Curve of Dry Raw Fibres from Tigoni Leaf Level T3
Figure 4.1d Force at Break (N) and Elongation (mm) Curve of Dry Raw Fibres from Lanet Leaf Level L1

Figure 4.1e Force at Break (N) and Elongation (mm) Curve of Dry Raw Fibres from Lanet Leaf Level L2
For wet *A. americana* “*Marginata*” fibres from both locations, all levels required a lower force at break and a higher extensibility to be ruptured (Table 4.8 and Figure 4.2a-f). Force at break and elongation for wet fibres from Lanet were 4.728±2.99N and 60.628±2.52mm; 5.088±4.29N and 67.014±3.38mm; and 4.588±4.29N and 70.883±4.35mm for levels L1, L2 and L3 respectively. The results showed that force at break between wet fibres from Lanet was not significantly different (p>0.05, p=0.1387). *A. Americana* “*Marginata*” fibres from Tigoni indicated force at break and elongation as 5.254±6.09N and 65.204±2.88mm; 5.287±5.28N and 74.059±4.04mm; 5.424±5.62N and 72.701±3.92mm for levels T1, T2 and T3 respectively.

Statistically the results showed there was no significant difference in force at break between wet fibres from Tigoni location (p>0.05, p=0.1304). However results indicate that there was significant difference in force at break between wet fibres from the two locations (p<0.05, p=0.0359). From the results it’s evident that Tigoni level (T2) fibres had the highest wet elongation at break and (T1) had the lowest elongation.
at break in that location. On the hand Lanet level (L3) had the highest elongation while (L1) had the lowest elongation in that location. The results indicate that the fibres are affected by the presence of moisture resulting to reduced force at break and increased elongation at break.

Figure 4.2a Force at Break (N) and Elongation (mm) Curve of Wet Raw Fibres from Tigoni Leaf Level T1

Figure 4.2b Force at Break (N) and Elongation (mm) Curve of Wet Raw Fibres from Tigoni Leaf Level T2
Figure 4.2c Force at Break (N) and Elongation (mm) Curve of Wet Raw Fibres from Tigoni Leaf Level T3

Figure 4.2d Force at Break (N) and Elongation (mm) Curve of Wet Raw Fibres from Lanet Leaf Level L1
4.4 Chemical Properties

4.4.1 Moisture Content and Regain of Raw Fibres

The findings in Table 4.9 shows that moisture content of *A. americana* “Marginata” fibres from Tigon was 6.92%; 6.89%; 6.93% for levels T1, T2 and T3 respectively. While from Lanet moisture content was 7.04%; 6.9%; 7.08% for levels L1, L2 and L3 respectively. In comparison, these observations show that in Lanet leaf level (L3)
fibres had the highest moisture content while leaf level (L2) fibres had the lowest moisture content. In Tigoni level (T3) had the highest moisture content while level (T2) had lowest percentage moisture content.

However moisture content from Lanet was higher as compared to the corresponding leaf levels from Tigoni. A comparative study of moisture content between the two locations revealed that there was no significant difference (p>0.05, p=0.1701) between the two locations.

Table 4.9 Moisture Content and Regain Percentages for each Level and Location

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Tigoni</th>
<th>Lanet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(T1)</td>
<td>(T2)</td>
</tr>
<tr>
<td>Moisture Content %</td>
<td>6.92</td>
<td>6.89</td>
</tr>
<tr>
<td>Moisture Regain %</td>
<td>7.43</td>
<td>7.42</td>
</tr>
</tbody>
</table>

Moisture regain of A. americana fibres from Lanet was noticeably higher at 7.61%; 6.43%; 7.51% for levels L1, L2 and L3 respectively compared to fibres from Tigoni with 7.43%; 7.42%; 7.44% for levels T1, T2 and T3 respectively. There was minimal difference in moisture regain across all levels for both locations. Fibres from Lanet had a higher moisture regain compared to corresponding levels from Tigoni. However fibres from both levels (L3) and (T3) from both locations had the highest moisture content and regain. With all these foregoing the fibre moisture regain between the two locations revealed that there was no significant difference (p > 0.05, p=0.1734). Though there is minimal difference in the moisture content and regain from all levels.
in both locations, the results indicate that fibres from Lanet are more hydrophilic than those from Tigoni.

4.4.2 Determination of Chemical Composition

4.4.2.1 Pectin Content

The percentage of pectin is important in determining the overall properties of fibres, as it provides flexibility to the fibres. Figure 4.3 demonstrates that A. americana “Marginata” fibres from Lanet level (L1) presented the highest percentage of pectin with 11.1%, compared to Lanet level (L2) with 10.6% and level (L3) at 9.8% which had the lowest percentage of pectin in that location. Similarly, Tigoni level (T2) with 8.9% had the lowest percentage of pectin, compared to level (T1) with 9.5%, and level (T3) with 10.5% having the highest percentage in that location.

![Figure 3.3 Pectin Percentages for each Level and Location](image)

From the results it’s noticeable that there are minimal differences in pectin percentage within levels in each location and across the two locations. However comparing respective levels from the two locations, Tigoni level (T1), (T2) and (T3) had lower
pectin percentage than Lanet level (L1), (L2) and (L3) correspondingly. This means that fibres from Lanet may be slightly more flexible than those from Tigoni location. However fibres from the two locations were not significantly different in pectin percentage (p > 0.05, p=0.2227).

4.4.2.2 Hemicellulose Content

The obtained results in this study show that fibres from Tigoni had lower hemicellulose content compared to those from Lanet as summarized in Figure 4.4. It was observed that the hemicellulose content is dependent on leaf age in both locations. Fibres from Tigoni level (T1) had 15.2%, level (T2) with 17.1% and level (T3) with 22.4%, while fibres from Lanet level (L1) had 20.4%, level (L2) 25.9% and level (L3) 26.5% (figure 4.6). Tigoni (T1) and Lanet (L1) had the lowest values from both locations, while Lanet (L3) and Tigoni (T3) had the highest values respectively this being consistent with plant age in both locations.

Figure 4.4 Hemicellulose Percentages for each Level and Location
The results from this study indicate that hemicellulose content decreased as the fibres mature. The results also indicate that fibres from Lanet had a higher hemicellulose content compared to those from Tigoni.

### 4.4.2.3 Lignin Content

Figure 4.5 indicates the percentage of lignin found in the various fibre levels. The results show that there was a consistent pattern for both locations in relation to lignin percentage. Tigoni level (T2) with 14.6% had the highest percentage, followed closely by level (T3) with 14.1% and (T1) with 11.5%. Lanet (L2) with 12.8% had the highest lignin content followed by level (L3) with 12.3% while (L1) with 11.9% had the lowest percentage lignin content.

![Lignin Percentages for each Level and Location](image)

**Figure 4.5 Lignin Percentages for each Level and Location**

From observation there were minimum differences between the percentages of lignin in fibres from both locations. However, comparing corresponding levels across the locations fibres from Tigoni had higher amount of lignin than those from Lanet.
4.5 Effect of Natural and Synthetic Dyes on the Mechanical Properties of A. americana “Marginata” Fibres

4.5.1 Linear Density of Dyed Fibres

Results in this study indicate that raw (R) A. americana “Marginata” fibres had higher linear density as compared to dyed fibres from all corresponding levels and locations. Tami-dyed (TD) A. americana “Marginata” fibres leaf level three (TTD3) with 23.079tex had the highest linear density while Tami dyed fibres from leaf level one (LTD1) had the lowest with 20.002tex. Similarly, vat dyed (VD) A. americana “Marginata” fibres from Lanet leaf level two (LVD2) had the lowest mean linear density of 17.390tex while those from Tigoni leaf level three (TVD3) had the highest with 23.009tex.

Disperse dyed (DD) fibres from Lanet leaf level three (LDD3) with 22.309tex recorded the highest linear density while those from leaf level one (LDD1) had the lowest linear density. Tigoni disperse dyed A. americana “Marginata” fibres level two (TDD2) with 23.773tex had the highest linear density while leaf level three (TDD3) fibres with 20.85tex had the lowest linear density. It was noted that iron-rust dyed (IRD) fibres from Tigoni leaf level three (TIRD3) with 24.737tex had higher linear density than level two (TIRD2) with 23.827tex and level one (TIRD1) fibres with 20.932tex had the lowest linear density. Similarly for iron-rust dyed fibres from Lanet level one (LIRD1) with 17.579tex had lower linear density compared with fibres from level three (LIRD3) with 19.772tex and level two (LIRD2) with 23.796tex having the highest linear density (Table 4.10).
The findings show that dyed fibres had decreased linear density across all levels from both locations compared to raw fibres. However from analysis of variance (ANOVA) between corresponding raw and dyed fibres from both locations showed there were no significant differences in linear density since in each case \( p \geq 0.05 \).

### 4.5.2 Fibre Tenacity and Elongation of Dyed *A. americana* “Marginata” Fibres

#### 4.5.2.1 Effect of Tami Dye (TD) on Fibre Tenacity and Elongation (El)

It was observed that compared to raw fibres, the tenacity of TD fibres were lower except in LTD3 where it increased. The results indicate that tenacity and elongation for Tigon Tami dyed dry fibres from TTD3 had the highest tenacity and elongation at 28.95±0.93cN/tex and 14.94±0.87\% while TDT2 fibres with 21.29±1.14cN/tex and 13.60±0.79\% had the lowest. Fibres from TTD1 had tenacity and elongation of 24.34±1.21cN/tex and 15.14±1.13\%. In Lanet, LTD1 fibres had the highest tenacity of 25.06±0.87cN/tex and an elongation of 12.79±0.69\%, LTD3 had 24.92±0.80cN/tex and 15.44±0.73\% while LTD2 had the lowest tenacity and elongation of 23.31±0.66cN/tex and 13.20±0.95\% respectively (Table 4.11 and 4.7).
Table 4.11 Tenacity and Elongation (El) of Tami Dyed (TD) Fibres

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Dry Tenacity cN/tex</th>
<th>El %</th>
<th>Wet Tenacity cN/tex</th>
<th>El %</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTD1</td>
<td>24.34±1.21</td>
<td>15.14±1.13</td>
<td>23.67±0.82</td>
<td>16.02±0.98</td>
</tr>
<tr>
<td>TTD2</td>
<td>21.29±1.14</td>
<td>13.60±0.79</td>
<td>20.85±0.72</td>
<td>15.24±0.86</td>
</tr>
<tr>
<td>TTD3</td>
<td>28.95±0.93</td>
<td>14.94±0.87</td>
<td>20.55±1.10</td>
<td>15.31±1.07</td>
</tr>
<tr>
<td>LTD1</td>
<td>25.06±0.87</td>
<td>12.79±0.69</td>
<td>21.35±0.71</td>
<td>13.62±0.39</td>
</tr>
<tr>
<td>LTD2</td>
<td>23.31±0.66</td>
<td>13.20±0.95</td>
<td>20.21±0.62</td>
<td>14.41±0.76</td>
</tr>
<tr>
<td>LTD3</td>
<td>24.92±0.80</td>
<td>15.44±0.73</td>
<td>23.99±3.39</td>
<td>17.12±0.88</td>
</tr>
</tbody>
</table>

It was generally observed that fibres from all levels in both locations had lower tenacity after dyeing with Tami dye compared to raw fibres. Statistically it was observed that there was no significant difference in tenacity between Lanet Tami dyed (LTD) and Lanet raw fibres (p > 0.05, p=0.7269). Similarly the results show no significant difference in tenacity between Tigoni Tami dyed (TTD) and Tigoni raw fibres (p > 0.05, p=0.8059). This implied that the dyes, chemicals used and process of dyeing did have a degree of influence on tenacity of A. americana “Marginata” fibres.

It was also evident from the results that the wet tenacity of Tami dyed fibres was lower than that of dry Tami dyed fibres for all corresponding levels in both locations. However it was noted that for all levels and in both locations wet % elongation of the fibres increased.
Tigoni TTD1 fibres with a wet tenacity and elongation of 23.67±0.82cN/tex and 16.02±0.98% was the highest in that location; TTD2 had 20.85±0.72cN/tex and 15.24±0.86% and level TTD3 with 20.55±1.10cN/tex and 15.31±1.07% was the lowest tenacity. In Lanet, LTD3 fibres exhibited highest values of wet tenacity and elongation at 23.99±3.39cN/tex and 17.12±0.88%, LTD1 had 21.35±0.71cN/tex and 13.62±0.39% and LTD2 had the lowest tenacity of 20.21±0.62cN/tex and 14.410.76% elongation.

However it was noted that there was no significant difference in tenacity between Lanet wet Tami dyed fibres and Lanet wet raw fibres (p > 0.05, p=0.4839). The results also indicate no significant difference in tenacity between Tigoni wet Tami dyed and Tigoni wet raw fibres (p > 0.05, p=0.9334). However despite loss of tenacity in the wet fibres elongation of wet Tami dyed fibre was higher in all levels in both locations.

4.5.2.2 Effect of Disperse Dye (DD) on Fibre Tenacity and Elongation

The findings in Table 4.12 show that tenacity for dry and wet disperse dyed fibres was highest and lowest in corresponding levels in Tigoni. Disperse dyed dry fibres from Tigoni recorded tenacity and elongation of 27.24±1.32cN/tex and 15.14±1.13%; 21.37±0.88cN/tex and 17.631.18%; 27.49±1.11cN/tex and 13.91±1.29% for TDD1, TDD2 and TDD3 respectively. The above values when compared with raw fibres indicate that Tigoni disperse dyed fibres TDD3 similarly had the highest tenacity, while level TDD2 had the lowest. Statistically it was noted that there was no significant difference in tenacity between dry dispersed dyed and dry raw fibres from Tigoni (p > 0.05, p=0.9382).
On the other hand, LDD2 fibres had the highest dry tenacity with 28.69±1.87cN/tex and an elongation of 9.07±0.98% compared with LDD3 which had the lowest value. LDD1 fibres had tenacity and elongation of 26.04±1.59cN/tex and 10.25±0.01% and LDD3 had 24.61±1.22cN/tex and 11.96±0.95% respectively. The result shows that not all levels of disperse dyed fibres decreased in tenacity compared to raw fibres as shown in Table 4.7 and 4.12. This may have been due to the dyed fibres having a lower linear density in those same levels. However statistically the results indicate no significant difference in tenacity between dry disperse dyed and dry raw fibres from Lanet (p > 0.05, p=0.3140).

**Table 4.12 Tenacity and Elongation of Disperse Dyed (DD) Fibres**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Tenacity cN/tex</th>
<th>El %</th>
<th>Tenacity cN/tex</th>
<th>El %</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDD1</td>
<td>27.24±1.32</td>
<td>15.14±1.37</td>
<td>25.01±1.08</td>
<td>15.50±0.83</td>
</tr>
<tr>
<td>TDD2</td>
<td>21.37±0.88</td>
<td>17.63±1.18</td>
<td>21.15±1.92</td>
<td>20.59±1.22</td>
</tr>
<tr>
<td>TDD3</td>
<td>27.49±1.11</td>
<td>13.91±1.29</td>
<td>24.35±1.00</td>
<td>18.46±1.23</td>
</tr>
<tr>
<td>LDD1</td>
<td>26.04±1.59</td>
<td>10.25±1.01</td>
<td>22.87±0.92</td>
<td>13.83±0.84</td>
</tr>
<tr>
<td>LDD2</td>
<td>28.69±1.87</td>
<td>9.07±0.98</td>
<td>23.93±0.86</td>
<td>14.79±0.95</td>
</tr>
<tr>
<td>LDD3</td>
<td>24.61±1.22</td>
<td>11.96±1.95</td>
<td>24.22±0.79</td>
<td>16.99±1.29</td>
</tr>
</tbody>
</table>

The results illustrate that tenacity of dispersed dyed wet fibres decreased compared with dry dispersed dyed fibres but had an increase in elongation. The tenacity and elongation recorded for Tigoni fibres was 25.01±1.08cN/tex and 15.50±0.83%; 21.15±1.92cN/tex and 20.59±1.22%; 24.35±1.00cN/tex and 18.46±1.23% for TDD1, TDD2, and TDD3 respectively. Lanet fibres recorded tenacity and elongation of
22.87±0.92cN/tex and 13.83±0.83%; 23.93±0.86cN/tex and 14.79±0.95%; 24.22±0.79cN/tex and 16.99±1.29% for LDD1, LDD2 and LDD3 respectively.

Compared with raw wet fibres, it was noticed that disperse dyed wet fibres had a higher tenacity in both locations except for fibres from Lanet level LDD1 which had a lower tenacity (Table 4.12 and 4.7). Using the analysis of variance (ANOVA), Tigoni disperse dyed wet fibres were not significantly different from Tigoni raw wet fibres (p > 0.05, p=0.4010). Similarly Lanet disperse dyed wet fibres were not significantly different from raw wet fibres from same location (p > 0.05, p=0.0988).

4.5.2.3 Effect of Iron-rust Dye (IRD) on Fibre Tenacity and Elongation

The result reported in Table 4.13 indicate that the dry iron-rust (IRD) dyed fibres in the two locations had a higher tenacity and lower elongation than wet IRD dyed fibres. Tigoni iron rust (TIRD) dyed dry fibres recorded tenacity and elongation of 23.89±1.36cN/tex and 15.73±0.88%; 20.69±1.05cN/tex and 15.77±0.86%; 22.86±1.28cN/tex and 16.57±1.29% for TIRD1, TIRD2 and TIRD3 fibres respectively. While Lanet iron-rust dyed (LIRD) fibres recorded tenacity and elongation of 27.65±1.80cN/tex and 14.54±1.25%; 23.92±1.14cN/tex and 16.47±1.03%; 23.30±1.30cN/tex and 14.58±1.29% for LIRD1, LIRD2, LIRD3 fibres respectively. However when the tenacity of dry raw fibres was compared to IRD fibres from corresponding leaf levels the results indicated that TIRD dry fibres had a lower tenacity. However there was no significant difference in tenacity between the iron-rust dry dyed and dry raw fibres from Tigoni (p > 0.05, p=0.1677). Lanet disperse dry dyed fibres also showed no significant difference in tenacity with dry raw fibres (p > 0.05, p=0.6220).
Table 4.13 Tenacity and Elongation of Iron-rust Dyed (IRD) Fibres

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dry</th>
<th>Wet</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tenacity cN/tex</td>
<td>El %</td>
<td>Tenacity cN/tex</td>
</tr>
<tr>
<td>TIRD1</td>
<td>23.89±1.36</td>
<td>15.73±0.88</td>
<td>20.39±0.99</td>
</tr>
<tr>
<td>TIRD2</td>
<td>20.69±1.05</td>
<td>15.77±0.86</td>
<td>20.26±0.98</td>
</tr>
<tr>
<td>TIRD3</td>
<td>22.86±1.28</td>
<td>16.57±1.29</td>
<td>21.96±1.17</td>
</tr>
<tr>
<td>LIRD1</td>
<td>27.65±1.80</td>
<td>14.54±1.25</td>
<td>26.36±1.22</td>
</tr>
<tr>
<td>LIRD2</td>
<td>23.92±1.14</td>
<td>16.47±1.03</td>
<td>19.92±0.98</td>
</tr>
<tr>
<td>LIRD3</td>
<td>23.30±1.30</td>
<td>14.58±1.29</td>
<td>22.70±1.11</td>
</tr>
</tbody>
</table>

The results demonstrate a similar trend with all the wet dyed fibres in both locations. The tenacity of the wet iron-rust dyed fibres decreased as the elongation increased as compared to the dry fibres. However, in comparison to raw fibres wet iron-rust dyed (IRD) fibres from both locations in all levels, except TIRD1 showed an increase in tenacity.

4.5.2.4 Effect of Vat dye (VD) on Fibre Tenacity and Elongation

As the data in Tables 4.14 and 4.7 indicates, the results of fibre tenacity for dry raw and dry vat dyed fibres are within the same range. For Tigoni vat dyed (TVD) dry fibres tenacity and elongation recorded was 27.61±1.26cN/tex and 14.41±0.89%; 20.39±0.41cN/tex and 10.07±0.84%; 25.24±1.06cN/tex and 13.92±1.13% for TVD1, TVD2, and TVD3 respectively. LVD dry fibre tenacity and elongation was 24.66±1.63cN/tex and 12.54±1.27%, 23.34±0.94cN/tex and 13.04±1.50%, 20.45±1.03cN/tex and 10.37±0.93% for levels LVD1, LVD2 and LVD3 respectively.
Tigoni TVD1 exhibited the highest dry and wet tenacity in both locations, while on the other hand Tigoni TVD2 dry fibres had the lowest tenacity and elongation. On analysis between raw dry fibres and vat dyed dry fibres there was no significant difference in tenacity in both locations since for Tigoni p>0.05 (p=0.6831) and Lanet p > 0.05 (p=0.7708).

**Table 4.14 Tenacity and Elongation of Vat Dyed (VD) Fibres**

<table>
<thead>
<tr>
<th>Dyes/parameter</th>
<th>Dry</th>
<th>Wet</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tenacity cN/tex</td>
<td>El %</td>
<td>Tenacity cN/tex</td>
<td>El %</td>
</tr>
<tr>
<td>TVD1</td>
<td>27.61±1.26</td>
<td>14.41±0.89</td>
<td>24.61±1.16</td>
<td>17.06±0.94</td>
</tr>
<tr>
<td>TVD2</td>
<td>20.39±0.41</td>
<td>10.07±0.84</td>
<td>17.40±0.91</td>
<td>13.04±0.99</td>
</tr>
<tr>
<td>TVD3</td>
<td>25.24±1.06</td>
<td>13.92±1.13</td>
<td>21.34±0.95</td>
<td>17.02±1.19</td>
</tr>
<tr>
<td>LVD1</td>
<td>24.66±1.63</td>
<td>12.54±1.27</td>
<td>22.09±1.17</td>
<td>14.54±1.32</td>
</tr>
<tr>
<td>LVD2</td>
<td>23.34±0.94</td>
<td>13.04±1.50</td>
<td>20.74±0.83</td>
<td>15.48±1.39</td>
</tr>
<tr>
<td>LVD3</td>
<td>20.45±1.03</td>
<td>10.37±0.93</td>
<td>18.39±0.93</td>
<td>12.61±1.04</td>
</tr>
</tbody>
</table>

However vat dyed wet fibres showed a decrease in tenacity compared to the dry vat dyed fibres. This means that moisture affected the tenacity of the fibres. Tigoni recorded wet fibre tenacity and elongation of 24.61±1.16cN/tex and 17.06±0.94%; 17.40±0.91cN/tex and 13.04±0.99%; 21.34±0.95cN/tex and 17.02±1.19% for level 1 to 3 respectively. While Lanet wet vat dyed fibres, recorded tenacity and elongation of 22.09±1.17cN/tex and 14.54±1.32%; with 20.74±0.83cN/tex and 15.48±1.39%; 18.39±0.93cN/tex and 12.61±1.04% for levels 1 to 3 respectively.
4.5.3 Force at Break and Elongation for Dry and Wet Dyed Fibres

4.5.3.1 Effect of Tami dye (TD) on Force at Break and Elongation

The results in this study show the dry force at break and elongation for Tigoni Tami dyed (TTD) fibres ranged between 6.392±0.20N to 4.873±0.26N and 67.236±3.92mm to 61.194±3.57mm respectively. It was noted that TTD3 fibres required higher force and elongation to rupture the fibre while TTD2 fibres required the lowest force at break and elongation. Fibres from Lanet required dry force at break between 5.508±0.17N to 5.013±0.17N and an elongation of between 69.479±3.30mm to 57.561mm. LTD3 fibres had the highest dry force at break and elongation, while LTD1 recorded the lowest dry force at break and elongation. It was also noted that both LTD3 and TTD3 had the highest force at break and elongation in both locations (Table 4.15).

Table 4.15  Force at Break (N) and Elongation (mm) of Tami Dyed Fibres

<table>
<thead>
<tr>
<th>Dyes/parameter</th>
<th>Dry</th>
<th></th>
<th>Wet</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Force (N)</td>
<td>El (mm)</td>
<td>Force (N)</td>
<td>El (mm)</td>
</tr>
<tr>
<td>TTD1</td>
<td>5.179±0.25</td>
<td>68.150±5.08</td>
<td>5.037±0.17</td>
<td>72.080±4.39</td>
</tr>
<tr>
<td>TTD2</td>
<td>4.873±0.26</td>
<td>61.194±3.57</td>
<td>4.773±0.16</td>
<td>68.567±3.85</td>
</tr>
<tr>
<td>TTD3</td>
<td>6.392±0.20</td>
<td>67.236±3.92</td>
<td>4.742±0.25</td>
<td>68.877±4.79</td>
</tr>
<tr>
<td>LTD1</td>
<td>5.013±0.17</td>
<td>57.561±3.11</td>
<td>4.270±0.14</td>
<td>61.305±1.76</td>
</tr>
<tr>
<td>LTD2</td>
<td>5.169±0.15</td>
<td>59.402±4.27</td>
<td>4.646±0.14</td>
<td>64.842±3.43</td>
</tr>
<tr>
<td>LTD3</td>
<td>5.508±0.17</td>
<td>69.479±3.30</td>
<td>5.303±0.16</td>
<td>77.023±3.98</td>
</tr>
</tbody>
</table>

In comparison to the raw fibres the results revealed that Tami dyed (TD) fibres required less force at break to rupture for both the dry and wet fibres in all levels. In
Tigoni the force at break and elongation required to rupture wet fibres ranged between 5.037±0.17N to 4.742N±0.25 and 72.080 to 67.236±3.92mm respectively. Lanet recorded force at break and elongation which ranged between 4.270±0.14N to 5.303±0.16N and 77.023±3.98mm to 61.305±1.76mm respectively. It was noted that wet fibres increased in extensibility with less workload.

**4.5.3.2 Effect of Iron-rust Dye (IRD) on Force at Break and Elongation**

The results in Table 4.16 illustrates that force at break of Iron-rust dyed dry fibres compared with raw dry fibres decreased in work load required to rupture an individual fibre but increased in elongation at rupture. The force at break and elongation for Tigoni was between 4.929±0.25N to 5.654±0.31N and 70.794±3.66mm to 74.589±5.83mm respectively. Tigoni TIRD3 was noted to require highest dry force at break and elongation compared to the other levels in that location. On the other hand Lanet recorded force at break and elongation at rupture of between 4.606±0.25N to 5.693±0.27N and 65.425±5.61mm to 74.132±4.62mm respectively (Table 4.16). Lanet LIRD2 recorded the highest dry force at break and the highest elongation in that area. From the results it is evident that the fibres were either affected by the iron-rust dyes, dyeing chemicals or dyeing process used.
Results indicate that wet Iron-rust dyed fibres required less force to break. The force at break for Tigoni Iron-rust dyed wet fibres ranged between 4.268±0.21N to 5.432±0.29N and an elongation of between 72.326±4.84mm and 83.926±5.76mm. Tigoni TIRD2 was noted to have a highest force at break than any other level from both locations. On the other hand wet fibres from Lanet recorded a mean force at break and elongation of between 4.489±0.22N and 4.789±0.21N and 69.396±6.26mm to 78.766±4.92mm respectively. It was observed that LIRD1 wet fibres required highest force at break while LIRD3 fibres required the lowest force at break and elongation.

### 4.5.3.3 Force at Break and Elongation of Vat Dyed (VD) Fibres

The study revealed that the average force required to break an individual dry vat dyed (VD) fibre was lower than the force at break required to rupture raw fibres. This generally indicates that the VD fibres required less workload to break them. The force

---

**Table 4.16 Force at Break (N) and Elongation (mm) of Iron-rust Dyed (IRD) Fibres**

<table>
<thead>
<tr>
<th>Dyes/parameter</th>
<th>Dry Force (N)</th>
<th>Dry El (mm)</th>
<th>Wet Force (N)</th>
<th>Wet El (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIRD1</td>
<td>5.000±0.28</td>
<td>70.794±3.95</td>
<td>4.268±0.21</td>
<td>72.326±4.84</td>
</tr>
<tr>
<td>TIRD2</td>
<td>4.929±0.25</td>
<td>70.949±3.66</td>
<td>4.829±0.23</td>
<td>83.926±5.76</td>
</tr>
<tr>
<td>TIRD3</td>
<td>5.654±0.31</td>
<td>74.589±5.83</td>
<td>5.432±0.29</td>
<td>79.347±5.69</td>
</tr>
<tr>
<td>LIRD1</td>
<td>4.860±0.31</td>
<td>65.425±5.61</td>
<td>4.789±0.21</td>
<td>72.546±6.04</td>
</tr>
<tr>
<td>LIRD2</td>
<td>5.693±0.27</td>
<td>74.132±4.62</td>
<td>4.741±0.23</td>
<td>78.766±4.92</td>
</tr>
<tr>
<td>LIRD3</td>
<td>4.606±0.25</td>
<td>65.614±5.81</td>
<td>4.489±0.22</td>
<td>69.396±6.29</td>
</tr>
</tbody>
</table>
at break and elongation recorded for fibres from Tigoni ranged between 3.574±0.07N to 5.808±0.24N and from 45.322±3.78mm to 64.861±4.00mm respectively. It was noted that TVD3 fibres had the highest force at break while TVD2 had the lowest force at break and elongation.

Fibres from LVD1 demonstrated the highest force at break while LVD2 fibres recorded the lowest force required to break the fibres. The force at break and elongation ranged between 4.481±0.18N to 4.739±0.31N and 46.649±4.17mm to 58.680±6.76mm respectively (Table 4.17). It was evident that Vat dyed dry fibres generally had a lower elongation than the raw fibres.

<table>
<thead>
<tr>
<th>Levels/parameter</th>
<th>Force (N)</th>
<th>El (mm)</th>
<th>Force (N)</th>
<th>El (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVD1</td>
<td>5.376±0.27</td>
<td>64.861±4.00</td>
<td>4.791±0.22</td>
<td>76.781±4.25</td>
</tr>
<tr>
<td>TVD2</td>
<td>3.574±0.07</td>
<td>45.322±3.78</td>
<td>3.051±0.15</td>
<td>58.673±4.47</td>
</tr>
<tr>
<td>TVD3</td>
<td>5.808±0.24</td>
<td>62.659±5.10</td>
<td>4.909±0.22</td>
<td>76.569±5.37</td>
</tr>
<tr>
<td>LVD1</td>
<td>4.739±0.31</td>
<td>56.424±5.70</td>
<td>4.249±0.22</td>
<td>65.424±5.23</td>
</tr>
<tr>
<td>LVD2</td>
<td>4.481±0.18</td>
<td>58.680±6.76</td>
<td>3.982±0.16</td>
<td>69.670±6.26</td>
</tr>
<tr>
<td>LVD3</td>
<td>4.562±0.23</td>
<td>46.649±4.17</td>
<td>4.102±0.20</td>
<td>56.749±4.70</td>
</tr>
</tbody>
</table>

The wet force at break and elongation recorded for TVD3 fibre was 4.909±0.22N and 76.569±5.37mm was highest while TVD2 with 3.051±0.15N and 58.673±4.47mm had lowest values. LVD1 wet fibres with 4.249±0.22N and an elongation of 65.424±5.93mm had highest force at break while LVD2 had lowest force at break. In
comparison to dry fibres it was noted that vat dyed wet fibres generally had lower force at break.

4.5.3.4 Effect of Disperse Dye (DD) on Force at Break and Elongation

Table 4.18 shows that TDD3 dry fibres had the highest force at break 5.732±0.23N compared to other levels in the area while TDD2 with 5.080±0.21N had the lowest value. On the other hand in Lanet, LDD2 had the highest force at break while LDD1 had the lowest values. The results indicate that disperse dyed dry fibres from Lanet had lower elongation at break compared to Tigoni disperse dyed dry fibres. Generally compared to raw fibres it was noted that disperse dyed dry fibres had slightly lower force at break.

Table 4.18 Force at Break and Elongation of Disperse Dyed Fibres

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Dry Force (N)</th>
<th>Dry El (mm)</th>
<th>Wet Force (N)</th>
<th>Wet El (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDD1</td>
<td>5.707±0.27</td>
<td>69.762±6.14</td>
<td>5.238±0.22</td>
<td>68.122±3.72</td>
</tr>
<tr>
<td>TDD2</td>
<td>5.080±0.21</td>
<td>92.674±5.33</td>
<td>5.027±0.22</td>
<td>79.336±5.49</td>
</tr>
<tr>
<td>TDD3</td>
<td>5.732±0.23</td>
<td>62.582±5.79</td>
<td>5.078±0.20</td>
<td>83.060±5.55</td>
</tr>
<tr>
<td>LDD1</td>
<td>4.645±0.28</td>
<td>46.129±4.55</td>
<td>4.083±0.16</td>
<td>62.223±3.77</td>
</tr>
<tr>
<td>LDD2</td>
<td>5.796±0.35</td>
<td>40.809±4.43</td>
<td>4.833±0.16</td>
<td>66.574±4.27</td>
</tr>
<tr>
<td>LDD3</td>
<td>5.490±0.27</td>
<td>53.839±4.26</td>
<td>4.404±0.17</td>
<td>76.465±5.80</td>
</tr>
</tbody>
</table>

The findings indicate that wet DD fibres decrease in force at break and increased in elongation in comparison to dry DD fibres. Lanet fibres had lower wet force at break ranging between 4.083±0.16N and 4.833±0.16N while that of Tigoni was higher.
ranging between 5.027±0.22N and 5.238±0.22N. The elongation at break for disperse dyed wet fibres was generally higher than that of raw wet fibres.

**4.6 Evaluation of Colour Fastness Properties of A. americana “Marginata” Fibres**

The testing of colour fastness was performed on the dyed fibres and the test was to determine how permanent the colour was on the fibres. Major parameters tested included fastness to light, water and rubbing respectively.

**4.6.1 Colour Fastness to Light**

Table 4.19 shows that A. americana “Marginata” fibres in all levels in both locations performed well in colour fastness to light. The observed results in this study show that there was no colour change in those levels that scored grade 8 which is considered as the best grade while those with grade 5 show that there was slight or no change in colour.
### Table 4.19 Ratings for Colour Fastness to Light

<table>
<thead>
<tr>
<th>Type of dye parameters</th>
<th>Tami dyed</th>
<th>Disperse dyed</th>
<th>Vat dyed</th>
<th>Iron-rust dyed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location/levels</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lanet (L1)</td>
<td>Grade 5</td>
<td>5</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>ΔE 2.75</td>
<td>3.46</td>
<td>1.56</td>
<td>0.36</td>
</tr>
<tr>
<td>Lanet (L2)</td>
<td>Grade 8</td>
<td>5</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>ΔE 0.10</td>
<td>3.80</td>
<td>2.7</td>
<td>4.22</td>
</tr>
<tr>
<td>Lanet (L3)</td>
<td>Grade 5</td>
<td>6</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>ΔE 2.77</td>
<td>2.69</td>
<td>2.4</td>
<td>0.73</td>
</tr>
<tr>
<td>Tigoni (T1)</td>
<td>Grade 8</td>
<td>5</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>ΔE 0.07</td>
<td>4.58</td>
<td>0.79</td>
<td>2.62</td>
</tr>
<tr>
<td>Tigoni (T2)</td>
<td>Grade 6</td>
<td>5</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>ΔE 2.34</td>
<td>3.10</td>
<td>1.4</td>
<td>3.40</td>
</tr>
<tr>
<td>Tigoni (T3)</td>
<td>Grade 8</td>
<td>5</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>ΔE 0.17</td>
<td>4.24</td>
<td>1.7</td>
<td>2.79</td>
</tr>
</tbody>
</table>

Rating scale; Excellent = 8 & 7, very good = 6 & 5, good = 4, fair = 3 & 2, poor = 1

Colour difference (ΔE) value measured on a spectrometer and compared with a control sample indicated that Lanet Tami dyed (LTD) *A. Americana “Marginata”* fibres levels recorded ΔE value of 2.75, 0.10 and 2.77 for levels 1-3 respectively while Tigoni Tami dyed (TTD) fibres recorded a ΔE value of 0.07, 2.34 and 0.17 for levels 1-3 respectively. These observations indicate that the colours used to dye the fibres are resistant to sunlight. Vat dye recorded best grades in colour fastness to light throughout the levels and locations. However the results revealed that all dyed fibres; Tami dyed (TD), disperse dyed (DD), vat dyed (VD) and iron-rust dyed (IRD) passed the colour fastness to light test according to colour fastness KEBS standards.
4.6.2 Colour Fastness to Washing

The results in table 4.20 indicate that colour change to washing for Tami dyed A. *americana* “Marginata” fibres from all levels in both locations had a similar grade of between 4-5 to 5. The rate of colour change (ΔE) value was varied in all levels and ranged from 1.29 to 2.07. Similarly disperse dyed fibres from Lanet had a grade of 3-4 in all levels with varying colour change values of between 2.79 to 2.25. While Tigoni dispersed dyed A. *americana* fibres ranged between grades 2 to 4 with colour change ranging between 1.27 to 7.00.

It was noted that vat dyed A. *americana* fibres from Lanet was graded at 4-5 for level LVD1 and LVD2 while LVD3 had a colour grade of 4 and a colour change (ΔE) of between 0.67 to 2.54. Tigoni vat dyed (TVD) A. *americana* fibres had grades between 4 and 3 with colour change ranging from 1.82 to 3.77. From the results it was noted iron dyed A. *americana* fibres had varying grades. In LIRD1 recorded grade 2-3, LIRD2 grade 2 and LIRD3 grade 3-4. While TIRD1 scored very low grade of 1-2, TIRD2 grade 3 and TIRD3 grade 2 while the colour change ranged from 3.23 to 9.87.
### Table 4.20 Ratings for Colour Fastness to Washing

<table>
<thead>
<tr>
<th>Location/levels</th>
<th>Type of dyes parameters</th>
<th>Tami dyed</th>
<th>Disperse dyed</th>
<th>Vat dyed</th>
<th>Iron-Rust dyed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lanet (L1)</td>
<td>Grade</td>
<td>5</td>
<td>3-4</td>
<td>4-5</td>
<td>2-3</td>
</tr>
<tr>
<td></td>
<td>ΔE</td>
<td>1.39</td>
<td>2.25</td>
<td>2.54</td>
<td>5.09</td>
</tr>
<tr>
<td>Lanet (L2)</td>
<td>Grade</td>
<td>4.5</td>
<td>3-4</td>
<td>4-5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>ΔE</td>
<td>2.03</td>
<td>2.79</td>
<td>0.67</td>
<td>7.20</td>
</tr>
<tr>
<td>Lanet (L3)</td>
<td>Grade</td>
<td>4.5</td>
<td>3-4</td>
<td>4</td>
<td>3-4</td>
</tr>
<tr>
<td></td>
<td>ΔE</td>
<td>2.07</td>
<td>2.3</td>
<td>1.56</td>
<td>2.94</td>
</tr>
<tr>
<td>Tigoni (T1)</td>
<td>Grade</td>
<td>5</td>
<td>4</td>
<td>3-4</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>ΔE</td>
<td>1.29</td>
<td>1.27</td>
<td>2.22</td>
<td>9.87</td>
</tr>
<tr>
<td>Tigoni (T2)</td>
<td>Grade</td>
<td>4-5</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>ΔE</td>
<td>1.98</td>
<td>7.00</td>
<td>3.77</td>
<td>3.23</td>
</tr>
<tr>
<td>Tigoni (T3)</td>
<td>Grade</td>
<td>4-5</td>
<td>2-3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>ΔE</td>
<td>2.01</td>
<td>4.48</td>
<td>1.82</td>
<td>6.34</td>
</tr>
</tbody>
</table>

Rating scale: Excellent =5, very good = 4-5 and 4, good =3-4 and 3, fair = 2-3 and 2, poor = 1

In determining colour fastness to washing grades 5 to 4-5 are considered as the best, grade 4 and 3-4 indicates negligible change of colour while grade 1 is considered the lowest grade in colour fastness to washing.

#### 4.6.3 Colour Fastness to Rubbing

As the data in table 4.21 shows, the rating of *A. americana “Marginata”* fibres in all levels for all dyes in both locations recorded good grades of 4 to 5 with an average value ΔE of between 0.42 to 4.91. According to prescribed standard of colour fastness to rubbing the textile products must attain a minimum grade of 4 as acceptable values. The results in this study shows that disperse dyed fibres illustrated the best grades of 5 with low colour difference (ΔE) values of 0.42 to 1.73 in both locations. Similarly vat dyed fibres demonstrated good results of grade 5. However the ΔE values were
higher than those of disperse dyed fibres which ranged from 1.23 to 2.27. Tami dyed fibres in both locations recorded grade 4 to 5 with ΔE values ranging from 1.79 to 4.91 which are observed as good grades. Similarly iron rust dyed fibres had grades of 4 to 5 and ΔE values ranging from 4.26 to 2.42.

Table 4.21 Ratings for Colour Fastness to Rubbing

<table>
<thead>
<tr>
<th>Type of dye parameters</th>
<th>Location/levels</th>
<th>Tami dyed</th>
<th>Disperse dyed</th>
<th>Vat dyed</th>
<th>Iron-Rust dyed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>Lanet (L1)</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>ΔE</td>
<td></td>
<td>4.07</td>
<td>1.72</td>
<td>1.33</td>
<td>3.87</td>
</tr>
<tr>
<td>Grade</td>
<td>Lanet (L2)</td>
<td>4-5</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>ΔE</td>
<td></td>
<td>4.91</td>
<td>0.75</td>
<td>1.48</td>
<td>4.22</td>
</tr>
<tr>
<td>Grade</td>
<td>Lanet (L3)</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>ΔE</td>
<td></td>
<td>1.79</td>
<td>0.51</td>
<td>1.41</td>
<td>4.70</td>
</tr>
<tr>
<td>Grade</td>
<td>Tigoni (T1)</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>ΔE</td>
<td></td>
<td>3.80</td>
<td>1.73</td>
<td>1.23</td>
<td>4.26</td>
</tr>
<tr>
<td>Grade</td>
<td>Tigoni (T2)</td>
<td>4-5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>ΔE</td>
<td></td>
<td>2.73</td>
<td>0.68</td>
<td>1.73</td>
<td>2.42</td>
</tr>
<tr>
<td>Grade</td>
<td>Tigoni (T3)</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4-5</td>
</tr>
<tr>
<td>ΔE</td>
<td></td>
<td>2.47</td>
<td>0.42</td>
<td>2.27</td>
<td>2.80</td>
</tr>
</tbody>
</table>

Rating scale; Excellent =5, very good = 4-5 and 4, good = 3-4 and 3, fair = 2, poor = 1
CHAPTER FIVE: DISCUSSION OF FINDINGS

5.1 Effect of Soil properties and Climate Conditions on A. americana “Marginata” Fibre properties

It has been documented in other related studies that A. americana plants grow well in well drained soil which is either acidic, neutral or basic alkaline (Msahli et al., 2007). Soil pH greatly affects phosphorus (P) availability to the plants. In the current study the soil samples had moderate pH value, indicating that they are moderately acidic (Table 4.1). Zwane et al. (2011) indicate that A. americana plants require a pH of 6 to 7.5. They further argue the plant requires low fertile soils. This implies that the plants grown in both locations will grow well since the plant is tolerant in most soils.

Compared to other nutrients, the level of Phosphorus at 0.71 and 1.74 in Tigoni and Lanet soil samples respectively was found to be deficient for plant growth. Nevertheless this could not have had any effect on the plant since Agave species requires low fertile soils. However the results showed that soil samples from Tigoni had moderate levels of organic carbon (C %), which is sufficient for healthy plant growth while Lanet had low C%. Both soil samples showed that the soils had adequate amount of potassium necessary for plant growth.

Potassium is essential for the strength and elongation of the fibre and deficiency would result to necrosis at the leaf base (Ejaz et al., 2012). Since both locations had adequate potassium of 601.67 and 212.24 in Tigoni and Lanet respectively, could have been the reason, why fibres from the two locations had good tenacity (Table 4.7). It’s important to note that there were minimum differences between most of the soil attributes tested on the samples from these two locations. Based on the
differences in climate and soil results, it was evident that there was a significant
difference in physical and mechanical properties between fibres obtained from
different levels in each location.

5.2 Fibre Properties of A. americana “Marginata” Fibres

5.2.1 Physical Properties

Joseph (1986) states that when the lumen size decreases and the secondary walls of
the fibre increases the fibre strength increases. Based on results from this study, fibres
extracted from Tigoni leaf level 1 with 0.798m and Lanet leaf level 1 with 0.716m
were noted to have smaller lumen than from the other levels in both locations (Plate
4.3a(i) and 4.4a(i). This implies that the lumen size of the fibre had an influence on
the fibre strength since these fibres were found have a higher tenacity than those from
the other levels. Kadolph et al. (2009) states that some fibre properties such as lustre,
handle and texture are affected by the appearance of cross-sectional shape of the fibre.
He further states that surface contours of the fibre also affect the lustre, hand and
texture of the fibre. This could have contributed to the effect of fibres coarseness,
since the fibre surface from all levels in both locations were noted to be irregular.

5.2.2 Fibre Length

According to Kadolph et al. (2009), longer fibres tend to increase yarn tenacity,
shiny appearance and evenness while shorter fibres produce a dull appearance. As
shown in Table 4.1, fibres extracted from the three levels in Tigoni ranging from
0.798m - 0.955m showed that the fibres were longer than those from Lanet which
ranged between 0.716 - 0.865m (Table 4.2). Statistically the results showed that there
was a significant difference in fibre length between across the levels from each
location at (p < 0.05, p= 0.0051) and (p < 0.05, p= 0.0015) for Lanet and Tigoni respectively. This indicates that the length of the fibre depended on position of the leaf on the plant and was not influenced by the location. Mbugua (2009) noted that retted *A. americana “Marginata”* fibre varied in length from 0.336 - 1.07m with a mean of 0.652m and argued that the range varied highly due to the size of the leaves. Kadolph et al. (2009) states that natural fibres are subject to growth irregularities which further affect uniformity and size of fibre even from same plant. For fibres to be spun and produce good quality yarns, they must have sufficient length. Long fibres also produce fabric with a smooth surface which has less attraction to dirt.

**5.3 Mechanical Properties**

**5.3.1 Linear Density of Dry Raw Fibres**

The results revealed that the mean linear density for all leaf levels in both locations ranged between 20.057 - 26.808tex and 21.67 - 26.341tex from Lanet and Tigoni respectively (Table 4.3). This is comparable to linear density of *A. americana* fibres from other studies. Msahli et al. (2006) noted that *A. americana L* from Tunisia had an average linear density of 24 tex. In related studies, Boguslavsky et al. (2007) noted that linear density of *A. americana L* fibres varied from 20.3 - 33.3tex with a mean of 26.9tex from three different farms in south Africa. Mbugua (2009) also noted that retted *A. americana “Marginata”* fibres had a linear density of 14.469tex which was low compared to the findings of this study on decorticated fibres.

However fibres extracted from both Tigoni and Lanet from leaves at the base of the plant exhibited the lowest linear density compared to the other levels. The results however, differ from Boguslavsky (2007), who states that linear density increases
with leaf age. Statistically the results indicate a significant difference in linear density between fibres from the different leaf levels from Tigoni location while those from Lanet were not significantly different. On analysis there was also no significant difference between linear density of fibres from the two locations. This could be as a result of little or no difference in soil conditions in the two locations.

Sarah (2010) states that the higher the tex the coarser the fibre or yarn. The property of fineness and coarseness for a textile fibre is the most important fibre characteristic affecting processing behaviour and yarn processing (Chandral and Sreenrasan, 2011). For instance, fineness is an important factor in determining bending/rigidity (Sarah 2010). Therefore the resistance of a fibre to bending increases as the linear density of the fibre increases. Therefore it could be concluded that the fibres from level one from both locations are less rigid and finer than those from the other two levels which would otherwise produce coarser fibres. This is because fibres extracted from this level in both locations exhibited the lowest linear density compared to those from the other levels.

5.3.2 Tenacity and Elongation of Dry and Wet Raw *A. americana* “Marginata” Fibres

Results of this study established that tenacity of dry *A. americana* fibres varied (Table 4.7). This could have been caused by different leaf levels and influence of soil from the two locations. The tenacity of dry fibres from Tigoni and Lanet varied from 22.49cN/tex - 27.69cN/tex and 19.78cN/tex - 27.33cN/tex respectively. The tenacity results are consistent with other studies since Mbugua (2009), noted tenacity of dry
retted *A. americana* “Marginata” fibres ranged between 16.55 - 36.09cN/tex with a mean of 25.96cN/tex.

The results further compare with Boguslavsky et al. (2007), who noted that the tenacity of *A. americana* *L* fibres from different farms in South Africa ranged from 15 - 28cN/tex with a mean of 25.5cN/tex. The fibre tenacity in the current study is also consistent with a study conducted by Msahli et al. (2007) on *A. americana* *L*, who noted a mean tenacity of 28.29cN/tex. It can be concluded that the fibres are quite strong and therefore can withstand the fibre spinning processes. Kadolph et al. (2009) states that fibre tenacity influences durability of fabrics. Therefore the *A. americana* “Marginata” fibres could produce strong and durable textile products.

It was evident from results in this study that the fibres from all levels in both locations had reduced tenacity when wet. These findings concur with Mbugua (2009), who noted that the average tenacity of wet retted *A. americana* fibres from Mbaruk was 20.50cN/tex and that the fibre had lost tenacity when wet. This indicates that the tenacity of wet *A. americana* “Marginata” fibres is influenced by the application of moisture on the fibres. Therefore care is required when laundering any textile article constructed from *A. americana* “Marginata” fibres.

This study reveals that the elongation of *A. americana* fibres relates to Msahli et al. (2006) results which states that *A. americana* *L* had a high extensibility than most cellulosic fibres which in most cases do not exceed 10% extensibility. Tigoni fibres had elongation ranging from 13.42 - 15.42% while Lanet had between 12.46 - 13.78%. This indicated that the fibres had a high stretch. The findings also revealed
that wet fibres had higher elongation than dry fibres which concur with results from retted fibres by Mbugua (2009).

In comparison to other research on plants from the same family, Msahli et al. (2007) study revealed that *A. americana* *L* had higher work load at rupture than other cellulose fibre. Similarly *A.americana* “Marginata” fibre elongation is higher than that of sisal which ranged from 3 - 7% as recorded by Saxena et al. (2011). In comparison to other textile fibres, Saxena et al. (2011) also reported that jute and flax recorded fibre elongation ranging from 7 - 8% and 1.5 - 2.4% respectively.

### 5.3.3 Force at Break and Elongation of Raw Dry and Wet Fibres

The force at break of *A. amerinana* “Marginata” fibres from Lanet varied from 5.305 - 5.916(N) whereas those from Tigoni were varied from 5.748 - 6.975(N) (Table 4.8). This meant that more force (work load) was required to rupture Tigoni fibres. The fibres from Tigoni had slightly lower tenacity in some levels and a higher force at break compared to fibres from Lanet. This could have been attributed to the effect of a higher linear density. *A. americana* “Marginata” fibres have a high breaking load, a property that is used in evaluating the quality of fibres since fibres with high tenacity will withstand fibre processing.

These results concur with Msahli et al. (2007); who noted that the mean force at break of *A. americana* *L* fibres in Tunisia was 6.92(N). These results also compare to findings by Manonyane (2006) on retted and baked *A. americana* *L* which noted a mean force at break of 7.596 - 12.514(N) and 11.185 - 13.639(N) respectively. This means that fibres from Tigoni and Lanet required lower work force to rupture. This
indicates that Tigoni fibres are tough and durable as compared to fibres from Lanet and may have good abrasion resistance in wear. Fibres from Tigoni recorded the higher elongation as compared to fibres from corresponding levels in Lanet.

5.4 Chemical Properties

5.4.1 Moisture Content and Regain of Raw Fibres

Based on evidence from other researchers, the fibre quality is dependent upon the moisture content percentage of a fibre. The findings from this study showed that moisture content and regain of *A. americana* “Marginata” fibres is comparable to other cellulosic fibres (Msahli et al., 2006). Fibres from Tigoni recorded moisture content ranging from 6.89 - 6.93% while the moisture regain was between 7.42 - 7.44% (Table 4.4). On the other hand fibres from Lanet exhibited moisture content and regain which varied from 6.9 - 7.08 and 7.43 - 7.61% respectively from the three leaf levels. The results show that moisture content and regain is comparable in both locations. This study implies that the fibres are hydrophilic.

In comparison to other research findings from the same family of plant, Mbugua (2009) study revealed that retted *A. americana* “Marginata” fibres had an average moisture content and regain of 9.19% and 9.98% respectively. Comparing the decorticated and retted fibres, the results show that decorticated fibres have lower moisture content and regain than the retted fibres. Msahli et al. (2005) also argues that *A. americana L* had a moisture regain of 17% after which he further states that the fibre is more hydrophilic than other vegetable fibres. Mohanty et al. (2005) noted that sisal had a moisture content of between 10 to 22%.
In comparison to other textile fibres in related studies on jute, flax and cotton, results revealed moisture content of 12.5 - 13.7%, 8 - 12% and 7.8 - 8.5% respectively (Saxena et al., 2011; Taj et al., 2007). With all this foregoing, it can be concluded that the results in this study relate to other studies and that decorticated A. americana “Marginata” fibres from both locations have a good water uptake. It has been documented that the increase of moisture absorbency increases the comfort of a fibre and at the same time its dye affinity is improved (Tortora, 1992; Kadolph et al., 2009). This means that articles made from the A. americana “Marginata” fibre will be comfortable to wear and that they will accept dyes readily.

5.4.2 Hemicellulose, Pectin and Lignin Content of Raw Fibres

The percentage chemical composition of cellulosic fibres varies depending on type of fibre, source, age and method of fibre extraction (Saxena et al., 2011). Result from this study revealed that hemicellulose content from Tigoni and Lanet ranged from 15.2 - 22.4% and 20.4 - 26.5% respectively. The study also recorded a lignin percentage content ranging between 11.5 - 14.1% and 11.9 - 12.8% for Tigoni and Lanet respectively. On the other hand the study showed pectin percentage content ranged from 8.9 - 10.5% and 9.8 - 10.6% for Tigoni and Lanet respectively.

These findings are in line with related studies on agave fibre and other cellulosic fibres. Mylasamy and Rajendran (2010) noted that of A. americana L fibres had a hemicellulose content of 15.7% and a lignin content of 4.9%. Viera et al. (2002) found out that A. Lechuguila had a hemicellulosic content of 11% and 12% lignin content. These findings are also consistent with Mohanty et al. (2005) who states that
sisal contains 10 - 14% hemicelluloses, 10% pectin and 8% lignin content. Other studies on other cellulosic fibres indicated similar results.

The current results further compare with Saxena et al. (2011) and Taj et al. (2007) who noted that jute fibre had a high hemicellulosic content which ranged from 13.6-20.4% while lignin recorded 12 - 13% and pectin was noted to be in very little content of 0.2%. Saxena et al. (2011) and Taj et al. (2007) also noted that flax fibres contain 18.6 - 20.6% hemicellulosic content, 22% lignin content and 2.3% pectin content. This shows that flax fibres have very high percentages of both hemicelluloses and lignin content as compared to A. americana “Marginata” fibres.

According to Saxena et al. (2011) cotton has the least hemicellulosic and pectin content at 5 - 7% and 0 - 1% respectively. However according to Taj et al. (2007) and Wanget et al. (2008), cellulosic fibres contain 5 - 20% lignin. According to literature chemical composition of cellulosic fibres may differ due to the analytical methods used to determine their percentage content. Lignin and hemicelluloses have an effect on the fibre properties for example; hemicelluloses are hydrophilic which mean that fibres with more hemicellulose increases water uptake (Saxena et al. 2011).

Evidence from other researchers has shown that the removal of hemicellulose improves the fibre tenacity and aligns fibre fibrils along one direction of tensile force (Zanner et al., 2013). Therefore from the current study fibres from T1 and L1 are stronger and more aligned than fibres from T3 and L3 levels. On the other hand fibres with more lignin are rigid. High lignin content causes fibres to have a hard touch and
the results imply that *A. americana* fibres from Lanet would feel coarser than those from Tigoni.

5.5 Effect of Natural and Synthetic Dyes on the Mechanical Properties of *A. americana “Marginata”* Fibres

5.5.1 Linear Density of Tami (TD), Disperse (DD), Iron-rust (IRD) and Vat (VD) Dyed Fibres

The findings showed that dyes decreased fibre linear density across all levels from both locations. From the results it was observed that the fibres most affected by the dyes were those dyed with vat dye. However the effect of dyes on the linear density was not statistically significant. The decrease in linear density of dyed fibres could have been contributed by various factors for example the chemical used to dye the fibres may have removed some chemical composition which accounts to the weight of fibres. The type of dyes stuffs, chemicals used as fixatives and mordants and the process of dyeing the fibres could also have affected the linear density. However it also is important to note that since *A. americana “Marginata”* fibres were found to be weak when wet, the boiling of the fibres as a process in dyeing could have also had an effect on the fibre linear density.

Zanner et al. (2013) indicate that the decrease in linear density can be caused by removal of waxy, lignin and hemicellulose deposits on the fibres. This further increases the crystallinity of the fibre which may result in stronger fibres with less extensibility. It could be assumed that the dyed *A. americana “Marginata”* fibres have a better fineness property and are more crystalline than the raw fibres.
5.5.2 Fibre Tenacity and Elongation of Dry and Wet Tami (TD), Disperse (DD), Iron-rust (IRD), and Vat (VD) Dyed Fibres

Similar studies on tenacity and elongation of dyed fibres have not been documented. The result of this study indicates that the tenacity of dyed fibres was slightly lower than that of the raw fibres across all levels and locations. The difference in tenacity noted in this study, though minimal may have been caused by the chemicals, mordants and by the high temperature of water used in the dyeing process. However the tenacity and elongation between the raw and dyed fibres was not statistically significant. This means that the dyed fibres are still as strong as the raw fibres. Literature reveals that dyes improve yarn and fabric strength and also improves durability (Kadolph et al., 2009). It’s important to note that for both raw and dyed wet fibres the tenacity decreased while the elongation increased compared to dry fibres. This indicates that textile products constructed from the dyed fibres require special attention in laundering.

5.5.3 Force at Break and Elongation of Dry and Wet Tami (TD), Disperse (DD), Iron-rust (IRD), and Vat (VD) Dyed Fibres

Evaluation of the effect of dyes on the breaking load and elongation showed there was no statistically significant difference between raw and dyed fibres. However, based on the results, the dyed fibres required less workload to break the fibres across all levels in comparison to the raw fibres. Tables 4.10, 4.11, 4.12 and 4.13 show the breaking force required for TD, IRD, VD and DD fibres decreased after dyeing. This establishes that dyeing causes change to the fibre. It implies that as the dye molecules diffused into the fibres they may have caused damage which could have led to weak spots on the fibre. This makes it easier to break the fibres under less force.
5.6 Colour Fastness Properties of *A. americana* “Marginata” Fibres Dyed with Natural and Synthetic Dyes

5.6.1 Colour Fastness to Light, Washing and Rubbing

According to the ISO: 105 colour fastness standards, grade 8 is considered the best grade which indicates no colour change on the sample fibres. Grade 8-5 indicates that a textile product has passed the colour fastness test while grade 4-1 indicates the product has failed the test while grade 1 is the lowest on the gray scale which would indicate that the fibres faded on exposure to sunlight. According to Kadolph et al. (2009), poor colourfastness creates problems in production, storage and use of fibres and textile products. They further argue that for colour to be fast, the dye must be permanently attached to or within the fibres.

Since light fastness is a key factor in determination of the useful life span of textile products the current results establishes that the *agave americana* “Marginata” fibres may be dyed comfortably with TD, DD, VD and IRD since all the dyes were colourfast to light. This implies that any product made from the dyed fibres will be ultraviolet-light-stabilized.

According to literature, colourfastness to washing is essential to textile products that require frequent washing (Kadolph et al., 2009). From the results on table 4.15, TD and VD dyed *A. americana* “Marginata” fibres were noted to have good resistance to colour fastness to washing since most levels met the minimum requirement on colour fastness to washing. However DD and IRD *A. americana* “Marginata” fibres did not meet the minimum washing colour fastness resistance since the minimum colour change standard requirement for colourfastness to washing is grade 4. Based on the
ΔE iron rust dyed fibres had the lowest washing resistance. This could have been attributed to the lack of dye penetration and fixation into the fibres or other prevailing conditions during dyeing process.

This finding concurs with Kadolph et al. (2009), who state that cellulosic fibres are successfully dyed with vat dyes because of a strong chemical bonding which makes the dyes to be permanently embedded into the fibre. On the other hand, Tami dyed fibres showed very good results which are in line with Mibey et al. (2009) results which rated fabric dyed with the Tami dye at grade scale 5. This implies that dyed A. americana “Marginata” fibres showed no fading and may successfully be dyed with Tami dye which is a natural and eco-friendly dye and the vat dye which is a synthetic dye.

Literature review indicates that colour fastness to rubbing is influenced by the nature of fibres, type of dye stuff, depth of shade and method of dyeing used (Kadolph et al., 2009). The results show that A. americana “Marginata” fibres satisfactorily met the requirements of colour fastness to rubbing. It was evident from analysed results that all fibres from both locations rated good to excellent results of grade 4-5 to 5 on the grey scale. Jothi (2008) argues that fabrics dyed with natural dyes are rated lower than synthetic dyed fabrics since they have weaker bonding with fibres. This was not evident with the natural dyes (TD and IRD) used in this study.

Overall when all dyed fibres were compared, it was evident that TD, VD and DD had better resistance to light and washing compared to IRD fibres. The colourfastness to
washing of fibres dyed with IRD showed inferior performance in comparison to those
dyed with TD, VD and DD dyes.

5.7 Hypotheses Testing

$H_{01}$ There is no significant difference in mechanical properties between fibres
from different plant leaf levels.

Fibre tenacity:
The hypothesis is rejected because the results showed that the position of the leaf
level on the plant influences fibre tenacity in both locations ($p < 0.05$). It was noted
that T1 and L1 exhibited the highest tenacity. Even with a lower tenacity the other
levels (T2, T3, L2 and L3) had adequate strength to be a textile fibre.

Linear density and force at break for Tigoni fibres:
The hypothesis is rejected because the results indicated that there was a significant
difference in fibre linear density between the three levels. Similarly the fibre force at
break was significantly different across the three levels ($p < 0.05$)

Linear density and force at break for Lanet fibres:
The hypothesis is not rejected because there was no significant difference in linear
density between fibres from the three leaf levels from Lanet location. Similarly the
fibre force at break was not significantly different across the levels ($p > 0.05$).

$H_{02}$ There was no significant difference in mechanical and chemical properties
between the fibres from the two locations

Hypothesis is not rejected because the locations did not have any influence on
mechanical and chemical properties of the fibres ($p > 0.05$). This indicates that the
plant could be grown in the two study areas and provide fibres of good quality.
Hypothesis not rejected because the results showed no significant difference between raw and dyed fibres (p > 0.05). This implies that statistically the dyes, chemicals used and the process of dyeing did not have an effect on tenacity, linear density and force at break of the fibre. It is therefore possible to dye the A. americana “Marginata” fibres with variety of dyes which adds its value and desirability in various uses.
CHAPTER SIX: SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 SUMMARY

6.1.1 Effect of Soil properties and Climate Conditions on A. americana “Marginata” Fibre properties

The soil analysis indicated that pH (H₂O) for both areas were very slightly acidic at 6.64 and 6.75 for Tigoni and Lanet respectively. The Organic Carbon (C %) levels of Tigoni area was 1.75% which was moderate, while Lanet had 1.14% which is not adequate for healthy plant growth. Phosphorous level of the soil sample from Tigoni (0.71ppm) was found to be slightly lower than that from Lanet (1.74ppm) respectively. However Tigoni soil had 563.69 ppm and Lanet had 349.2 ppm respectively of magnesium which is adequate for plant growth.

6.1.2 Fibre Properties of A. americana “Marginata” Fibre

6.1.2.1 Mechanicals Properties of Raw Fibres

This study has revealed that fibres extracted from L3 and T3 had the highest mean length while fibres from L1 and T1 had the lowest mean length. This indicated that fibre length is not dependent on location of plant growth but on the position of the leaves on the plant. The mean linear density of fibres from both locations ranged between 20.057 - 26.808tex and 21.67 - 26.341tex for Lanet and Tigoni respectively for the three leaf levels. However the findings established that the location did not influence the linear density of the fibres.

The tenacity and elongation of fibres from Tigoni ranged between 22.49 - 27.69cN/tex and 14.12 - 15.42% and 19.79 - 27.33cN/tex and 12.46 - 13.78% for Lanet fibres. The results established minimal differences in the tenacity and
elongation of the raw fibres from the two locations. However the results of this study indicate that moisture decreased the tenacity and increased the elongation of the A. americana “Marginata” fibres across the levels in both locations. The results show that force at break required to rupture the fibres was minimally different within each of the levels and locations. However there was a significant difference in fibre force at break property across the three different leaf levels in each of the locations. But the force at break was not significant between the two locations.

6.1.2.2 Chemicals Properties

The findings revealed that the moisture content and regain of A. americana “marginata” fibres are comparable to those of other cellulosic fibres. This implied that the fibres are hydrophilic as they have good water uptake. The results further revealed that both the fibre moisture content and regain between the two locations was not significant.

The chemical composition (pectin, lignin and hemicellulose) results were comparable to most of others findings in related studies. Literature revealed that fibres with high hemicellulose content are hydrophilic and this was evident with A. americana “Marginata” fibres since they exhibited a high moisture content in all levels across the locations. The fibres also showed high pectin content which ranged between 8.9 - 10.5% and 9.8 - 11.1% for Tigoni and Lanet respectively. Statistically there was no significant difference in pectin content from the two locations.
6.1.4 Effect of Natural and Synthetic Dyes on the Mechanical Properties

Generally dyeing had minimal effect on mechanical properties of the fibre. Dyed fibres showed minimal decrease in linear density, tenacity and force at break. However dyed fibres showed a decrease in linear density compared to the raw fibres. The study further revealed that tenacity of dyed fibres was slightly lower than that of the raw fibres. Dyed fibres also required less force at break to rupture individual fibres compared with raw fibres. With all these foregoing there was no statistical difference in mechanical properties between raw and dyed fibre across the levels and locations.

6.1.5 Colour Fastness Properties of A. americana “Marginata” Fibres Dyed with Natural and Synthetic Dyes.

The results indicated that the A. americana “Marginata” fibres performed well to light colourfastness in all levels in both locations and therefore the fibre can be dyed comfortably with TD, DD, VD and IRD. However, it was noted that in colourfastness to washing, the TD and VD fibres performed well while DD and IRD fibres did not meet the minimum standard requirement. On the other hand TD, VD, DD and IRD fibres satisfactorily met the requirement for colourfastness to rubbing.

6.2 Conclusions

Based on the findings of this study, the following conclusions were made:

a. Soil and climate conditions were ideal for healthy plant growth in both locations. This implies that A. americana “Marginata” plant could be grown in both study locations and provide fibres of good quality.
b. The position of leaf level on the plant influenced fibre properties. This indicates that fibre properties are dependent on maturity of plant leaves. Therefore harvesting the leaves should take place between 2 to 3 years after planting and only the lower 2 to 3 leaf levels should be harvested.

c. The study identified fibres extracted from the base (Level 1) of the plant provided the best properties. This implies that textile products made from these fibres would be of better quality than those from other levels. However fibres extracted from the three levels could be blended to improve on the fibre properties.

d. The locations did not have any influence on the fibre properties since there was no significant difference in fibre properties from the two locations. This implies that the plant could be cultivated in a variety of areas with different soils and climates, since the quality of the fibre was not dependent on soil and climatic conditions.

e. Colourfastness to light and rubbing was satisfactory in the case of VD, TD, IRD and DD. This implies that the textile products made from items dyed with these dyes should not be limited to indoor textile products only. However DD and IRD fibres did not meet the minimum requirement for washing.

6.3 Recommendations

Based on the findings the following recommendations are suggested:

i. Due to the immense potential of *A. americana* “Marginata” as a fibre source, the study recommends the Department of Agriculture to consider promoting the growing of *A. americana* “Marginata” plant as a commercial crop. Other than providing fibres the plant would have other benefits such as soil erosion control.
ii. The fibre could effectively be used by textile, cottage, and textile micro enterprises in the manufacture of textiles products (i.e. carpets, mats, and sisal baskets) and post-harvest storage gunny bags.

iii. Textile and cottage industries could use Tami dye and vat dye on A. americana “Marginata” fibres, since they had good overall colour fastness performance.

6.4 Suggestions for Further Studies

1. Research should be focused on suitability of agave americana “Marginata” fibres on technical application in composite materials, geotextiles and post-harvest storage gunny bags.

2. A comparative study focussing on properties of agave americana “Marginata” fibres extracted during two different seasons (dry and wet) should be carried out.

3. A study should be carried out on fibre properties of agave americana “Marginata” at different stages of plant growth.

4. The relationship between the molecular structure of agave americana “Marginata” fibres and their mechanical and physical properties should be carried out.

5. Research should be carried out on other locally available agave species and their quality as textile fibres established.
REFERENCES


APPENDICES

Appendix I: *Agave americana* “Marginata” plant
Appendix II: Research Instruments

a) Desiccator

b) precision balance

c) Spectrophotometer
Appendix III: Research Permit

THIS IS TO CERTIFY THAT:

Prof./Dr./Mr./Mrs./Misa/institution

Gladwell Wanja Mbunga

of (Address) Kenyatta University

P.O.Box 43844-00100, Nairobi

has been permitted to conduct research in

Location

District

Nakuru & Kiambu

Counties

on the topic: Properties of different leaf levels of
decorticated Agave Americana “Majinata” Fibre’s
from Lanet and Tigon, Kenya.

for a period ending 30th June, 2014

Applicant’s Signature

Secretary

National Council for Science & Technology

 Research Permit No. NCST/RGD/8/013/1

Date of issue  21st February, 2013

Fee received KSH. 2,000.
Appendix IV: Kenya Bureau of standards Letter

Our Ref: KEBS/HR/18/2/ Date: 2013-01-30

Chairperson,
Department of Fashion Design and Marketing,
Kenyatta University
P.O. Box 43844-00100
NAIROBI.

RE: INDUSTRIAL ATTACHMENT - GLADWELL MBUGUA

Please refer to your letter seeking industrial attachment in this organization.

I am pleased to inform you that we shall offer the above named student attachment in our Testing Services Department (Textile) from 18th February to 16th March 2013 (Non-renewable). This is subject to her being registered with the Directorate of Industrial Training (DIT). Visit [www.attachmentkenya.org](http://www.attachmentkenya.org) to register on line.

During the attachment period, no Salary/Allowance will be paid to her. She will be expected to make her own arrangements for transport, meals and accommodation. She will also be expected to adhere to all the Rules and Regulations of this organization, failure to which her attachment will be terminated. Upon completion of the attachment, a report will be sent to the college on request.

Please note that we do not charge for this attachment, but to indemnify this organization from any loss or damage arising out of this attachment, she will be expected to fill in the enclosed Indemnity Forms in Duplicate (2) copies and return them the day she will report for attachment. The Institute should endorse the forms.

Yours faithfully,

[Signature]

C. Oluoch (Mrs)
For: AD-HUMAN RESOURCE & ADMINISTRATION
CO/ick

Encs. 2

Please signify your acceptance of the above terms by signing below:

Sign: ________________________________ Date: 18th Feb, 2013.
Appendix V: Map for Lanet
Appendix VI: Map for Tigoni