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Characterization of decorticated agave americana "marginata" fibres of different leaf levels from Lanet and Tigoni, Kenya

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Abstract
Agave americana "Marginata" plant has commercial and industrial potential ranging from textiles, paper making and composites for the automotive industry. The purpose of this study therefore aimed at characterizing the physical and mechanical properties of decorticated agave americana "Marginata" fibres from three plant leaf levels from Lanet and Tigoni areas. The two areas have distinctive soil and climatic conditions. Tigoni has a cooler climate, with no dry season or warm summer due to its high altitude while Lanet has a dry sub-humid equatorial climate. 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. The research findings revealed that, the fibre properties were influenced by the position of the leaf on the plant, however the locations of plant growth did not have much influence on the fibre properties.

Key words: *Mechanical, Physical and Chemical properties, Agave Americana "Marginata", Leaf levels.*

1. Introduction

Currently, Kenya imports 70% of the vegetable fibres and the future of the industry depends on the availability of raw materials (Bedi, 2011). 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 our clothing, household furnishing, industries and agriculture by man-made fibres such as polyester, acrylic and nylon among others (Hugo, 2009). Manonyane (2006), states that, natural fibres have good possibilities of increasing their market share and importance due to their low price, eco-friendly characteristic and technical properties. Further, with the increasing concern over the environment, researchers are searching for new biodegradable fibres that could be useful for various textile products (Ramkumar & Saravanan, 2021). According to Dunne, Desai & Sadiku (2016) every year synthetic fibres are being replaced with higher utilization of natural fibres. Furthermore, The International Year of natural fibres 2009 (IYNF, 2009) was aimed at raising awareness of the importance of 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. Fibres such as Agave (*Sisalana* and *americana*) have huge potential as a source of textile fibres. The leaves of the Agave plants have been reported to be rich in textile fibres (Verloore, 2005; Udeani and Nkemdilim, 2011). However, there is increased research on agave plants and new species have been discovered. Some of the most common species of the agave plant are *Agave sisalana, Agave americana*, and *Agave anguistifolia*. *Agave americana "Marginata"* is one of the most sought variegated succulent in existence because of its aesthetic appearance (Edward, 1999). According to Msahli et al., (2007), 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).

Though *A. americana* fibres have been used in other countries for industrial and commercial purposes, it has not been utilised in Kenya and neither has any commercialization been done. 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 (Mbugua, 2014).

2. Material and Method

A. americana leaves were harvested from the two locations, Lanet (Nakuru, county) and Tigoni (Kiambu, County). 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. For the purpose of this study three leaf levels from the base of the plant were selected for harvesting. A total of 120 leaves from 10 plants from each location were collected. Twelve leaves were purposively harvested from each plant ensuring that four leaves are harvested from each level of the same plant. Only those plants with six leaf levels were selected for the study in order to obtain leaves of similar age. 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).

Fibre extraction

The leaves were subjected to the decortication process. The fibres were dried and brushed for aligning and this further removed any foreign matters from the fibres. The fibres were packed and labelled according to location and plant levels from which they were extracted. Sample were conditioned in a conditioning chamber to reach the standard testing conditions of relative humidity 65 ± 2% and at a temperature of 20 ± 2°C to ensure accuracy and reliability of results. 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.

3. Results and Discussion

3.1 Physical Properties

3.1.1 Longitudinal View

The morphology of the fibres was studied using a Scanning Electron Microscope. The microscopic analysis of the fibre as shown in plate 1 and 2 is characterised by lengthwise striations on the fibre surface. The fibres from all level in both locations have irregular or rough surfaces since they are covered by extraneous matters on the fibre surfaces. This could have contributed to the effect of fibre coarseness. Kadolph et al. (2009) states that surface contours of the fibre also affect the lustre and texture of the fibre.

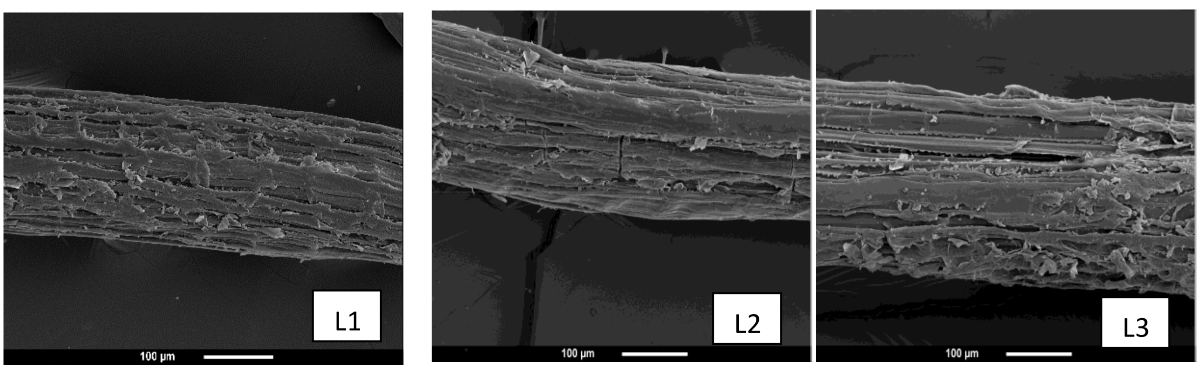

Plate 1: Fibre Longitudinal View from Lanet level 1, 2 and 3 respectively

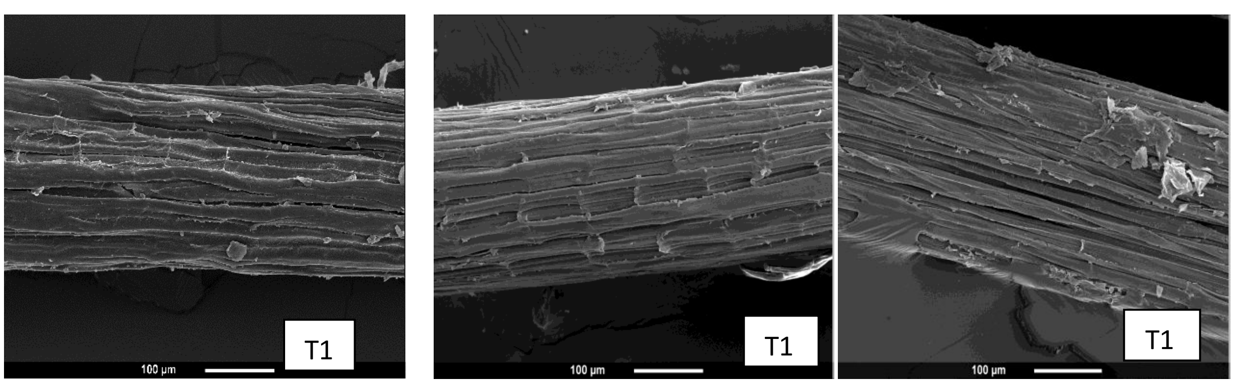

Plate 2: Fibre Longitudinal View from Togoni level 1, 2 and 3 respectively

3.1.2 Cross-sectional View Micrographs of the Fibres

The findings show that fibres exhibited cylindrical shaped appearance Plate 1 and 2. Cross-section view of the fibres also shows lumen regions. The lumen varies in size and shape according to the level of the plant leaf. Based on results from this study, fibres extracted from levels 1 were noted to have smaller lumen than from the other levels in both locations. This implies that the lumen size of the fibre had an influence on the fibre strength since fibres from level1 were found have a higher tenacity than those from the other levels.

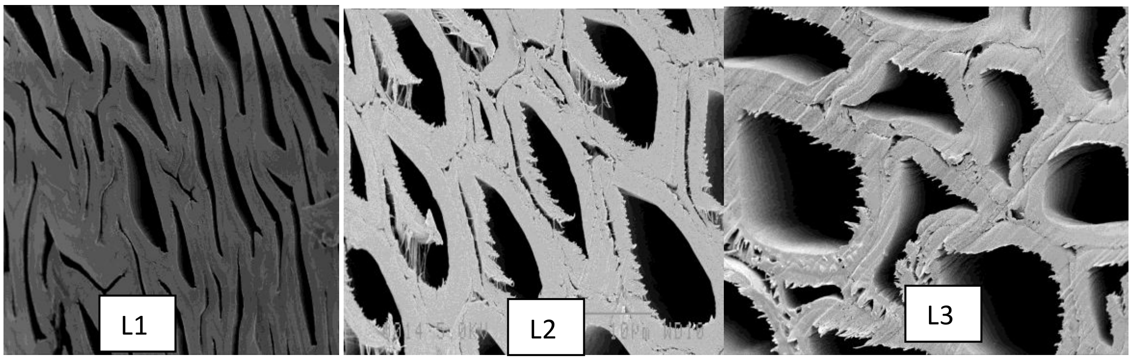

Plate 3: Cross-sectional View Lanet level 1, 2 and 3 respectively

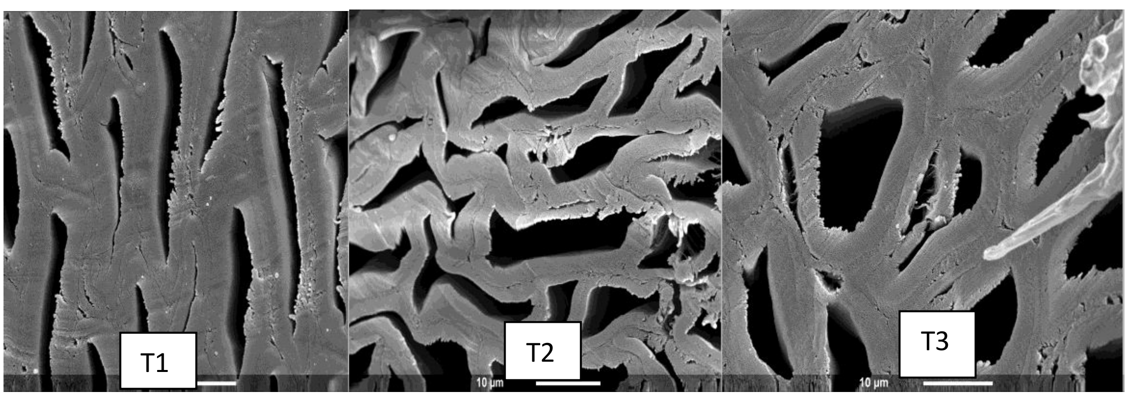

Plate 4: Cross-sectional View Tigoni level 1, 2 and 3 respectively

3.2 Mechanical properties

3.2.1 Linear density

The linear density was measured using the gravimetric method (ISO: 1973:1995). The results revealed that the mean linear density for all leaf levels in both locations ranged between 20.257 - 26.808tex and 21.67 - 26.341tex from Lanet and Tigoni respectively from three leaf levels. This is comparable to linear density of *A. americana* fibres from other studies. Msahli et al., (2006) noted that *A. americana L* from Tunisia has an average linear density of 24 tex. However, fibres from leaves extracted the base of the plants from both locations exhibited the lowest linear density compared to the other levels. The results therefore, differ from Boguslavsky (2009), who states that linear density increases with leaf age. Statistically the study revealed no significant difference in linear density between fibres from the different leaf levels from Lanet location ($p>0.05$, $p=0.0945$). The results also show significant difference in linear density between fibres from the different leaf level from Tigoni location ($p<0.05$, $p=0.0073$). However, the results also indicated that there was no significant difference in linear density between fibres from the two locations at $p>0.05$, $p=0.8221$. It was concluded that the location of fibre growth did not influence the linear density of the fibre. This could be as a result of little or no difference in soil and climate conditions in the two locations.

Table 3.1: Mean Linear Density of Raw A. americana "Marginata" Fibres from Different Leaf Levels and Locations in Tex

Locations	**Tigoni**			**Lanet**		
Levels	**T1**	**T2**	**T3**	**L1**	**L2**	**L3**
Linear density (Tex)	21.67a	26.341b	25.172c	20.257d	26.808d	25.017d

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

Table 3.2: ANOVA Summary of Differences in Linear Density between L1, L2 and L3

Source of Variance	**Sum of Square**	**Df**	**Mean square**	**F**	**P-value**	**F critical**
Between groups	321.184	2	160.592	2.4588	0.0945***	3.15884
Within groups	3722.744	57	65.3113			
Total	4043.929	59				

Note. *** = $p > 0.05$

Table 3.3: ANOVA Summary of Differences in Linear Density between T1, T2 and T3

Source of Variance	**Sum of Square**	**df**	**Mean square**	**F**	**P-value**	**F critical**
Between groups	546.5191	2	273.259	5.3636	0.0073***	3.15884
Within groups	2903.946	57	50.9464			
Total	3450.465	59				

Note. *** = $p < 0.05$

Table 3.4: ANOVA Summary of Differences in Linear Density between the Two Locations

Source of Variance	**Sum of Square**	**df**	**Mean square**	**F**	**P-value**	**F critical**
Between groups	0.595207	1	0.59520	0.0576	0.8221***	7.70864
Within groups	41.33183	4	10.3304			
Total	41.91703	5				

Note. *** = $p > 0.05$

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. Therefore, the resistance of a fibre to bending increased 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.

3.2.2 Fibre Tenacity and Elongation of dry and wet Raw fibres

The test was performed in compliance with the Kenya standard, KS 08-630, (1987) Part 2. The tenacity of dry *A. americana "Marginata"* in this study showed that they had varied tenacity as shown in Table 3.5. This could have been caused by the difference in leaf levels and influence of soil and climate conditions of the two locations. Kadolph et al., state that natural fibres are subject to growth irregularities which further affect uniformity and size of fibre even from same plant. The tenacity of dry fibres from Tigoni and Lanet varied from 22.49cN/tex to 26.53cN/tex and 19.78cN/tex to 27.33cN/tex respectively (Table 3.5)

The fibre tenacity of the current study is also consistent with a study conducted by Msahli et al., on *A. americana L*, who noted mean tenacity of 28.29cN/tex. It can be concluded that the fibres are quite strong and therefore can withstand the fibre spinning processing. Kadolph et al., states that fibre tenacity influences durability of fabrics. Therefore, the *A. americana "Marginata"* fibres could therefore produce strong and long lasting textile products.

Table 3.5: Mean Tenacity (cN/tex) and Elongation (El) of Dry and Wet A. americana "Marginata" Fibres

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

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

Statistically Tigoni fibres from the three levels had a significant difference in tenacity ($p < 0.05$, $p=0.0177$). Similarly, it was established that there was significant difference in tenacity between fibres harvested from the three plant leaf levels of Lanet ($p<0.05$, $p= 0.0003$). Fibre tenacity for the same levels from both locations was not significantly different. This indicates that the position of plant leaf levels influenced fibre tenacity. The results indicate that moisture application increased the elongation and decreased the tenacity of the *A. americana "Marginata"* fibres across the levels for both locations.

3.2.3 Force at break and Elongation of Raw dry and wet fibres

The force at break of *A. amerinana "Marginata"* fibres from Lanet varies from 5.305 - 5.916(N) whereas that from Tigoni was higher varying from 5.748 - 6.975(N) (Table 3.6). This meant that more force (work load) was required to rupture Tigoni fibres. However even with the higher force at break the fibres from Tigoni had slightly lower tenacity in some levels compared to fibres from Lanet. This could have been attributed to the effect of high linear density that some fibres had. However, *A. americana "Marginata"* fibres have a high breaking load, a property that can be used in evaluating the quality of the fibre since fibres with high tenacity will withstand fibre processing. The 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).

Table 3.6: Force at Break (N) and Elongation (mm) of Dry and Wet A. americana "Marginata" Fibres

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

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

Tigoni exhibited a different trend from Lanet as it was observed that there was a significant difference in fibre force at break property across the three different leaf levels. There was also no significant difference in force at break between fibres from two the locations. The elongation of dry fibres showed that there was no significant difference between the two locations.

3.3 Chemical properties

3.3.1 Moisture Content and Regain of Raw fibres

The findings from this study showed that moisture content and regain of *A. americana "Marginata"* fibres is comparable to other cellulosic fibres. Fibres from Tigoni recorded moisture content ranging from 6.89 - 6.93% while the moisture regain was between 7.42 - 7.44% (Table 3.7). On the other hand, fibres from Tigoni and 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 to other cellulosic fibres.

Table 3.7: Moisture Content and Regain percentages for each level and location

	Tigoni			Lanet		
Parameters	**(T1)**	**(T2)**	**(T3)**	**(L1)**	**(L2)**	**(L3)**
Moisture Content %	6.92	6.89	6.93	7.04	6.9	7.08
Moisture Regain %	7.43	7.42	7.44	7.51	7.43	7.61

In comparison to other research from the same family of the 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. 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. This means that articles made from the *A. americana "Marginata"* fibre will be comfortable to wear and that they will accept dyes readily.

3.3.2. Chemical Composition

3.3.2.1 Hemicellulose, Pectin and Lignin content

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 hemicelluloses from Tigoni and Lanet ranged from 15.2 - 22.4% and 20.4 - 26.5% respectively Fig 3.2. The study also recorded a lignin percentage content ranging between 11.5 - 14.1% and 11.9 - 12.8% from Tigoni and Lanet respectively (Fig 3.3). 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 Fig 3.4. This finding is in line with related studies on agave fibre and other cellulosic fibres. Mylasamy and Rajendran (2010) noted that *A. americana L* fibres revealed hemicelluloses content of 15.7% and a lignin content of 4.9%.

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. Therefore, from the current study fibres from T1 and L1 levels are stronger and more aligned than fibres from T3 and L3 levels. Since high lignin content causes fibres to have a hard touch, the results imply that *A. americana* fibres from Lanet would feel coarser than those from Tigoni, since they have more lignin content compared to those from Tigoni.

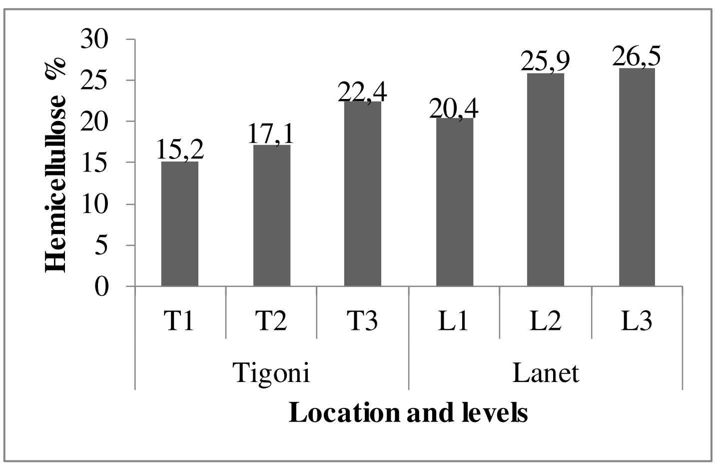

Figure 3.1: Hemicellulose percentages for each level and Location

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 (Fig 3.1).

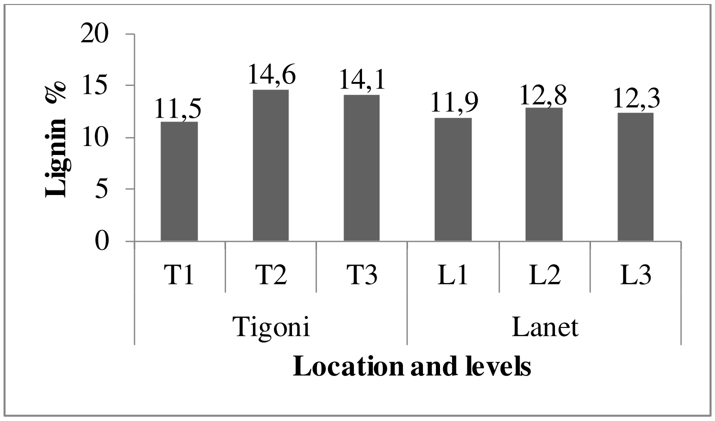

Figure 3.2: Lignin percentages for each level and Location

From the 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 Fig 3.2.

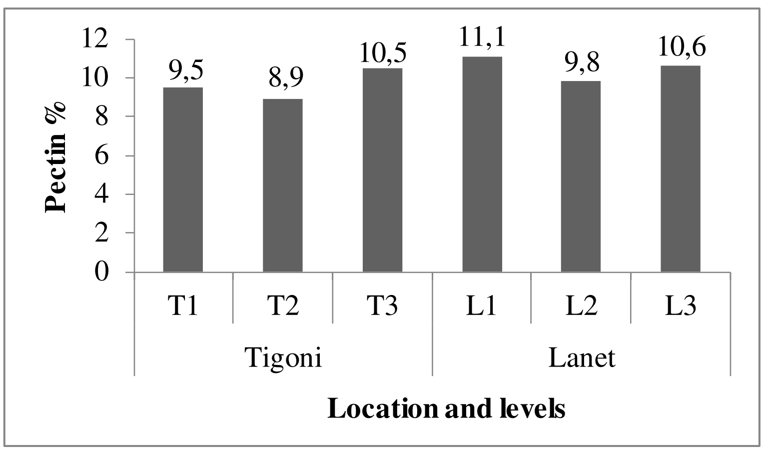

Figure 3.3: Pectin percentages for each level and location

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, fibres from the two locations were not significantly different in pectin percentage Fig 3.3.

4. Conclusions

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

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.

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 different areas with different soils and climates, since the quality of the fibre was not dependent on soil and climatic conditions.

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