FIBRE EXTRACTION AND CHARACTERIZATION FROM COCONUT HUSKS WASTE FOR INDUSTRIAL APPLICATION

By

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DECLARATION

Declaration by Candidate

I declare that this thesis is my original work and has not been presented for a similar degree in any other University or educational institute. No part of this thesis may be reproduced in any form without the prior written permission of the author and/or Moi University.

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Declaration by the Supervisors

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DEDICATION

This thesis is dedicated to my parents Mr. and Mrs. Joseph Melompuki and siblings. My daughters Tiffany Milanoi, Shirleen Tetei, Arielle Sanayian and son Nathaniel Saruni you really mean a lot to me. The woman in my life, you are simply the best.

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ABSTRACT

Coconut trees are grown in tropical countries along the coastal regions of Asia, Africa, and Latin America. One of the coconut's product whose full potential has not been exploited adequately is the husk, a fibrous part of the coconut fruit which forms the largest component of the fruit. Husks are byproducts of nut extraction after mature fruit harvesting or the cutting of the immature fruit for access to the liquid used as a thirst quencher. This produces husk, a biowaste that is either discarded in the open or burned, posing environmental challenges. Because of the bulkiness of the husk and abundance in the coastal region, there results heap of waste. If this waste could be developed into high-value applications, then the potential of coconut waste could be realized. This study aimed to characterize the products of husk waste extraction from mature and immature coconut fruits for industrial use. The specific objectives were to determine the quantities of coconut husk waste along the Kenyan coastline resulting from immature coconut fruit; to extract fibers from mature and immature coconut husk waste; and to characterize the properties of the decorticated fibers. From a survey carried out, a total of 70 tons coconut husk waste is generated along the Kenya coastal region. For this research work, 384 husk waste samples were collected and sun-dried for six months before fiber extraction, alkali treatment, and characterization. The fiber diameter was measured to be between 123.09μm to 197.44μm. Fiber density was determined to be between 1073.30 kg/m^3 and 2941.38 kg/m^3 a variation due to chemical treatment of the fiber, which altered the diameter, a dimension used in density calculation. Tensile strength ranged from 104.36MPa to 267.10MPa for the fibers. This can be attributed to the non-uniformity of the fiber with intrinsic diameter in which the irregularities increase defects in the fiber. The alkali treatment of fiber extracted from mature and immature coconut husk waste both presented minor changes in Fourier Transform Infra-Red spectra for treated coir fibers. The thermal stability for both types of fibers was improved after the alkali treatment because of the elimination of hemicellulose and lignin. The surface morphology of the untreated coconut fibers revealed a fine and smooth surface whereas that of treated fibers exhibited a rough and fine surface as a result of the removal of impurities. Alkali treatment also decreased fiber diameter and resulted in a rougher surface. Decortication realized coir of various sizes and coco peat. In conclusion, there is significant waste generated from the coconut husk waste which can be extracted by decortication. Evaluation of characterized coir demonstrated usage in industrial application. Optimization of alkalization parameters to explore their influence on fiber properties is recommended.

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ACRONYMS AND ABBREVIATIONS

ADB	Africa Development Bank
ASTM	American Society for Testing and Materials
CDA	Coastal Development Authority
DANIDA	Danish International Development Agency
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
FTIR	Fourier Transform Infrared Spectroscopy
KCDA	Kenya Coconut Development Authority
PSV	Public Service Vehicle
SEM	Scanning Electron Microscope
TGA	Thermal Gravimetric Analysis

CHAPTER 1: INTRODUCTION

1.0 Background Information

Coconut palms are abundantly grown in tropical regions especially along the coastal regions of Asia, Africa and Latin America (Van Dam, 2002)**.** Coconut (Cocos nucifera L.) is a member of the Arecaceae (Palmae) family and the Cocoideae subfamily. The Coconut palm (Cocos nucifera) is native to Southeast Asia (DebMandal & Mandal, 2011).

It is one of the most important crops in the tropics, serving as an income source as well as source of food, drink, fuel, medicine, and building materials (Aljohi et al., 2016). Copra (copra cake), toddy, leaves (brooms, baskets, and mats), oil, dried coconut, coconut cream, Shell (flours, charcoal, activated carbon, charcoal briquettes, coir fiber, coir dust, and fresh coconut juice) are the major coconut byproducts (Gachanja et al., 2007).

The fibrous part of the coconut fruit is known as the husk and is obtained as waste from mature and immature coconut. Traditional coir products account for only a small portion of the potential total world production of coconut husk. Figure 1-1 shows a structure of coconut fruit. Coir is a lignocellulosic material derived from coconut that is widely used in a variety of applications including yarns, ropes, geotextiles, brushes, and a wide range of floor-furnishing materials (Main et al., 2015).

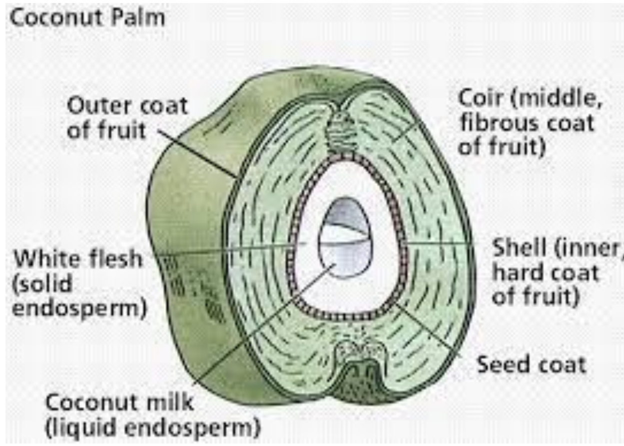

Figure 1-1 Structure of a coconut fruit

(source: Nwankwojike B. N. et al 2012)

In Kenya, coconut trees are grown for the production of fruit that supplies coconut oil, wine and construction materials. According to coconut census conducted by ABD-DANIDA/CDA in 2007, it is estimated that Kenya has 7.4 million coconut trees spread out within coastal region of Kenya. The report further indicates that Kenya produces approximately 62,000 tons of coconut fruit yearly. According to Agriculture and food Authority, Coconut sub-sector is currently made up of 10 million trees, covering 82,921 hectares supporting about 95,000 households (Nuts and oil crops Directorate, 2022).

After maturity of the coconut fruit, the nut is extracted leading to husks generation which are dumped on farmland, take long to degrade naturally hence causing environmental pollution. Figure 1-2 shows husks generated after nut extraction. During the rainy season, the husks accumulate water and with time decompose to release the coir fibers. Chemical compounds release acids, organic and inorganic substances leach into the soil and thus into water masses posing health hazards (Opala et al., 2012).

 

Figure 1-2 Coconut husks dumped after nut extraction

The consumption of coconut tender water in the Kenyan coastal towns is prevalent consequently leading to market growth for the immature nuts. This increases the generation of husk wastes which correspond to roughly 85 percent of the fruit weight according to (Rosa et al., 2010); (Ishizaki et al., 2008). These husks are typically discarded as waste in the open environment, where they take time to degrade leading to generation and accumulation of the husks wastes (Carrijo et al., 2002); (Ferreira et al., 2006); (Corradini et al., 2009).

The large amounts of coconut husk waste produced continue to grow with the increase in coconut farming posing a potential disposal problem. There is need to find a solution to the ever-increasing coconut husks accumulation that poses an environmental problem of pollution. Figure 1-3 is an image of husk waste generated after tender water extraction and/or consumption.


Figure 1-3 Immature coconut fruit and its waste product

1.1 Statement of the Problem

Coir fiber is bio-degradable, environmentally friendly and natural. Coir is unique among natural hard fibers that serve human utilities in that it is the only natural fiber that is associated with the fruit of a tree that is cultivated for the edible values of the fruit. Other competing plant fibers, such as jute and sisal, are grown solely for fiber value. As a result, utilizing the fiber is bound to be more cost effective when compared to the economics of other natural fibers.

Coconut industry is a significantly underutilized source of income for the Kenyan coastline farmers. Despite the fact that the area has a large number of small-scale coconut productions, farmers have limited knowledge of different ways to use the coconut product and the wastes generated from post harvesting processing. According to (Chomchalow, 2011), from the leaflet to the fruit, frond, trunk, and root of the coconut tree, every part of it can be used to increase the farmer's income.

One of the coconut products whose full potential has not been exploited adequately includes the husk. This fibrous part of the coconut fruit forms the largest component of the fruit and is abundant as waste. Husks are by-products of nut extraction after mature fruit harvesting or the cutting of the immature fruit for access of the tender water used as a thirst quencher. The harvesting of mature fruits is anticipated after maturity of the fruit while the harvesting of immature fruits is normally driven by demand of the tender water especially during holidays seasons. The two acts, however, lead to husk generation, a biowaste which is either discarded in the open haphazardly or burnt posing environmental challenges. This necessitates the development of methods for utilizing the husks particularly for value addition.

There have been studies in coconut husk utilization that are focused primarily on the utilization of fibers extracted from matured coconut husk. However, little research has been conducted on various methods of utilizing immature coconut husk waste yet it contributes significant wastes due to heavy consumption of coconut water along the coastal region. As a result, this study will add to the existing research on coconut utilization in Kenya by exploring on the utilization of wastes from both mature and immature coconut husks for industrial application.

1.2 Justification of Study

Consumption of tender coconut water along the Kenyan coastal region is normally high during holidays and festivities when local tourist flocks the coastal towns. The coconut production along the Kenyan coastal for the year 2019 – 2020 was 109,889 metric tons (Danda,2009) which in turn reflects to waste generation. This consumption of tender water results to generation of immature husk wastes. One of the reasons perhaps is the higher economic return compared to cost of matured coconut fruit. The second evident reason is the time for harvesting of immature coconut which is shorter. Matured coconut fruit takes around one year to fully ripen compared to the green nuts which can be harvested from eight months.

Waste management has been a menace in coastal counties and coconut waste is among the contributors. Husks wastes accumulation becomes a habitat and breeding grounds for rodents, snakes, and mosquitoes etc. Heap increases due to its bulkiness and abundance in the region. According to (Main et al., 2015), coir an extract from the coconut husk has a variety of applications including yarns, ropes, geotextiles, brushes, and a wide range of floor-furnishing materials.

If coconut husks could be advanced, both technically and commercially, into high-value applications, then it is possible to tap the potential of coconut waste for socio-economic benefits to the natives of Kenyan coastline. The selection of coconut fiber in this study is aimed to reduce bulk waste from coconut husks through re-use and recycling of this agricultural waste.

1.3 Objectives

1.3.1 Main objective

The main objective of this study was to extract and characterize husks waste fiber from mature and immature coconut fruits for industrial application

1.3.2 Specific objectives

The study had four specific objectives:

1. To determine the quantities of coconut husk waste along the Kenyan coastline resulting from immature coconut fruit
2. To extract fibers from mature and immature coconut husks
3. To characterize the properties of the fiber extracted through decortication
4. To evaluate fiber quality for industrial application

1.4 Scope of Study

The research is limited to the use of coconut husk waste from immature and mature coconut fruit in three counties namely; Mombasa, Kilifi and Kwale in Kenyan coastal region. These counties were selected due to the prevalence consumption of coconut tender water hence inevitable waste generation from husks. The counties are also a representative of the coconut farming in the country a crop mainly cultivated along the coastal region. Fiber extraction was done using a mechanical decorticator. The properties investigated are physical, mechanical, morphology, structural and thermal for comparison in fiber desirability in industrial application.

1.5 Significance of Study

a. This research will add to the existing work on coconut value addition in the country through utilization of the husk wastes.
b. There will be added weight to the pursuit for shift from synthetic to natural fibers and engineering materials arising from eco-concern, renewability and sustainability nature as well the properties of natural fibers

c. The study has potential for capacity building to the local coconut farmers as well as organized groups who may venture into economic activities in wastes generated from coconut husks. This can help in reducing the high rate of unemployment that the country is currently facing.

d. The study provides a method of utilizing of coconut waste in an environmentally friendly manner, as opposed to some of the current methods, which are prone to pollution, such as waste burning.

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

According to (Perera et al., 2016) and (Thampan, 1993), the coconut tree has origin in Asia, although it is a subject of controversy. There is some evidence that the coconut tree originated along Colombia's and Ecuador's Pacific coasts. Except for the Atlantic coasts of America and Africa, the first European explorers discovered coconut in all areas of the tropics. Man appears to have distributed coconuts, but the floating nuts may have been carried to new areas by ocean currents (Gunn et al., 2011) (Thampan, 1993).

(Ward & Brookfield, 1992) speculated that Malaysian sea rovers brought the coconut to Madagascar in the first centuries A.D., and it could have spread from there to the coast of mainland East Africa. The terminology for coconut used in Madagascar can also be found in the Far East and the Pacific, according to(Ahuja et al., 2014; Gunn et al., 2011). However, according to (von Brandis, 2012), the early occurrence of coconuts on deserted islands such as the Seychelles and Mauritius strongly implied spontaneous distribution. As a result, coconuts could have floated to East Africa (Ward & Brookfield, 1992).

The Portuguese introduced coconut cultivation to Kenya in the 16th century, and the coconut palm has since grown to become one of the most important sources of income for many coastal people. The coconut palm (Cocos nucifera) can reach a height of 30 meters and has pinnate leaves that are around 6 meters long. Coconut palms can produce up to 75 fruits per year on fertile terrain. The leaves, fruit, and trunk of the coconut palm have all been traditionally used for a variety of purposes. There aren't many elements of a coconut that aren't utilized. People consume coconut palm products such as food and drink, copra for oil, copra cake/meal, palm wine, building materials such as poles for construction and leaves (makuti) for roofing, as well as timber for furniture; fiber for ropes, mats, brushes, and brooms; and shells for utensils and ornaments. The coconut sub-sector, in general, shows enormous potential to stimulate economic development in the main coastal region. However, this potential has not been fully realized, and coconut growers continue to be among Kenya's poorest.

2.1 Coconut Varieties

According to (Pradeepkumar, 2008) Coconut palms can be divided into two categories: tall and dwarf. From the development in technology of crop production, agriculturalists and scientists have a cross-breed of the two known as the hybrid coconut variety as cited by (Rasam et al., 2016) and (Selvaraj, 2017) .

The Tall, Dwarf, and Hybrid varieties of coconut are farmed worldwide. Figure 4 and 5 shows images of dwarf and East Africa Tall varieties of coconut palm trees respectively. Among each of these primary kinds, however, there are numerous sub-varieties. For example, there are over 11 sub-varieties of the Tall variety in Africa alone, each generally linked with a location, such as the East African Tall (EAT) type found in Eastern Africa. The Dwarf Variety is divided into three sub-varieties: Yellow Dwarf, Orange Dwarf, and Green Dwarf. There are different hybrid variants produced for suitability for diverse goods and agro-ecological adaptability among these kinds (Githende Gachanja et al., 2007). The dwarf is a short variety as shown in Figure 2-1 while the East African Tall variety as the name suggests is distinctive in height as shown in Figure 2-2. The hybrid is a blend species between the first two varieties.

Figure 2-1 Typical tree of dwarf-green coconut

(Source: Esmeraldo et al. 2010)

Gachanja further reports from the baseline survey for coconut sub-sector in Kenya, that there are three principal coconut varieties found along Eastern Africa's coast that is; the East African Tall (EAT), the Dwarf, and the Hybrid. The East Africa Tall is the most prevalent in Kenya, and it produces nuts with good quality copra and toddy, but it lacks immature nuts, i.e. it produces a little amount of coconut tender water, but thick copra and fine wine. The EAT type is the most common among farmers, and it takes 5 to 7 years for the tree to begin producing nuts. It is drought tolerant, produces over 60 nuts each year on average under good husbandry, lives between 60 and 100 years, and grows to a height of 15 meters. A mature coconut tree can yield 50 to 100 fruits each year and reach a height of 30 meters (Chan & Elevitch, 2006).

Figure 2-2 East African Tall coconut palm

(Source: Esmeraldo et al. 2010)

Table 2-1 shows distribution of palm trees varieties in Kenyan coast. The majority of coconut trees are of the East African Tall variety, accounting for slightly more than 87 percent of the trees, with only 12 percent of the trees being of the Dwarf variety. While this pattern holds true across all districts, there are differences in areas with a higher concentration of the Dwarf variety than others, with Kilifi county having a disproportionately higher percentage of this newer variety (Patrick Beja, 2022).

Table 2-1 Geographical distribution of coconut trees by variety in Kenya's coast region

County	Tall Type		Dwarf Type		Total number of palm trees
	Palm tree count	% in Distribution	Palm tree count	% in Distribution	
Kwale	4,075,461	86	638,696	14	4,714,157
Kilifi	3,560,675	85	632,308	15	4,192,983
Lamu	416,956	66	213,552	34	630,508
Mombasa	140,883	67	68,095	33	208,978
Tana River	68,215	84	13,406	16	81,620
Taita Taveta	62,576	79	16,293	21	78,868
Total	8,324,767	84	1,582,349	16	9,907,115

(Source: *KCDA Coconut Tree Survey, June 2013*)

2.2 World's Coconut Production

According to FAO Statistical Database (FAO Stats) 2019 Coconut is grown in 92 countries on approximately 11.8 million hectares of land, with a global production estimate of 62,450,192 tonnes and an average yield of 5.14 tonnes per hectare. Out of the world's 92 coconut producing countries, Indonesia is the largest producer with 18,300,000 tonnes of coconut, while Kenya ranks 29th with 124,382 tonnes of coconut (Factfish, 2019). FAOSTAT, 2019 reports that Africa (3.3 percent), the Americas (8.6 percent), Oceania (4.8 percent), and Asia account for the majority of global coconut production (83.3 percent). According to this statistic, Africa produces the least amount of coconuts in the world as shown in Figure 2-3.

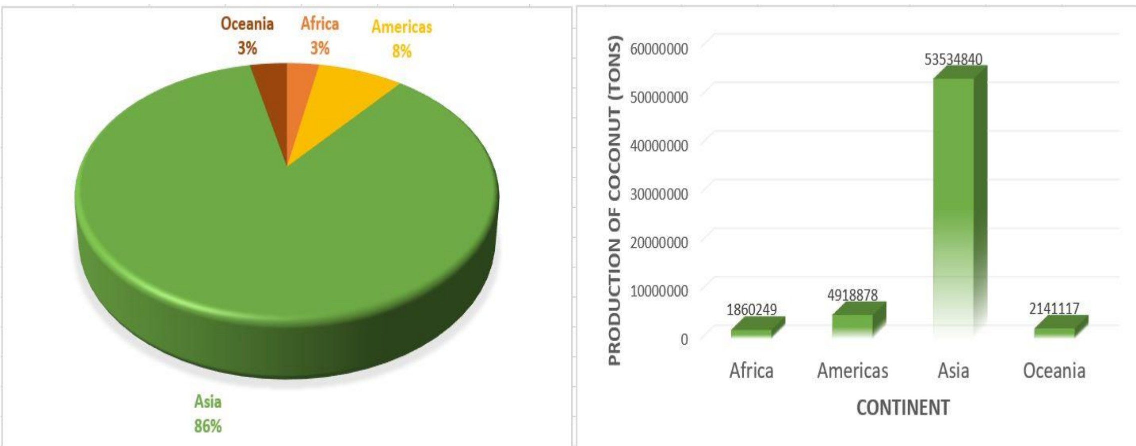

Figure 2-1 Global production of coconut

(Source: Faostat, 2019)

Although it thrives on sandy soils and is highly tolerant to salinity, the coconut tree can adapt to a wide range of soil types. It prefers areas with plenty of sunlight and consistent rainfall (1500 mm to 2500 mm annually). In Kenya, coconut is primarily grown along the coastline although it has since been introduced in other parts of the country namely Tharaka Nthi, Meru, parts of Makueni, Machakos, Busia, Homabay and Siaya. However, majority of its production still originates from the coast region, predominantly Mombasa, Kilifi, Kwale, Taita Taveta and Tana River counties (CS Ministry of Agriculture, 2021).

2.3 Coconut Production in Kenya

According to the Kenya Coconut Development Authority (KCDA) 2013, the main production region of coconut in Coast region has an area of 82,816 Km^2, of which 32,529 Km^2 (39%) is suitable for crop production and the remaining 61 percent is arid and semi-arid land (ASAL) supporting livestock production and wildlife conservation. Kilifi and Kwale counties are the major coconut producing areas in the region. While Tana River County which has the largest agricultural land, produces the least number of mature nuts as shown in Table 2-2

Table 2-2 Area under coconut, production and value 2019-2020

COUNTY	AREA (Ha)		Quantity (MT)		Value (Ksh.) Millions	
	2019	2020	2019	2020	2019	2020
Kilifi	41,432	41,470	52,853	52,913	2,219.8	2,384.0
Kwale	31,358	31,384	46,227	46,240	2,126.4	2,139.0
Lamu	10,713	10,722	6,771	6,792	304.7	322.0
Mombasa	156	158	2,344	2,361	103.1	122.0
Taita Taveta	99	102	873	858	37.5	36.1
Tana River	1,066	1,070	822	849	37.0	35.3
Total	84,824	84,906	109,889	110,013	4,828.5	5,038

Source: AFA-Nuts and Oil Crops Directorate

An increase of coconut growing area of up to 261,241 hectares by 2018, which translate to 143% increase was estimated from 107,507 hectares at the end of 2012 (FAO 2012). This increase is likely to be attributed to sensitization campaigns by Kenya Coconut Development Authority (KCDA) now the Nuts and oil crops directorate (NOCD) and other stakeholders and provision of free coconut seedlings to farmers. According to the report by Kenya Coconut Development Authority 2013, the population of coconut trees in the Coastal region is estimated at 9.9 million, having increased by 33.4% since 2007. Table 2-3 shows the population of trees and the average number of trees farmers own in each of the counties in the region as at 2013.

Table 2-3 Population of Trees and Area under Coconut by 2013

County	Number of coconut trees		Average trees per farmer		Area under coconut in acres in 2013
	2007	2013	2007	2013	
Kwale	2,895,427*	4,714,157	111*	91	227,677
Kilifi	3,818,975	4,192,983	89	128	149,890
Lamu	434,105	630,508	64	128	24,275
Tana River	140,414	81,620	76	46	11,748
Mombasa	136,938	208,978	36	36	15,234
Taita Taveta	NA	78,868	NA	26	7,811
Overall	**7,425,859**	**9,907,114**	**94**	**105**	**436,634**

***Source**: ABD- DANIDA, 2007; KCDA, 2013 NA = Data not available *There might have been some errors in the 2007 estimations of Kwale County tree population and average number of trees per farmer*

According to Agriculture and Food Authority annual market research report (2016), 1760 nuts were recorded as the average production per acre for coconut. (Githende Gachanja et al., 2007) reported that in Kenya, approximately 25% of the potential of the coconut sub-sector is currently being exploited.

There is a reported significant increase in coconut production from 180 million nuts in 2007 to 260 million nuts reported in 2013 to 300 million nuts in 2019 (Gachanja, 2007, UNIDO 2014, Danda 2019). The increment is attributed to farmer sensitization on replanting and use of quality coconut tree seedlings to replace the aged and senile trees in addition to empowerment of the farmers to embrace good agricultural practices as depicted in the table. The improved yield resulted in an overall increased total quantity produced. Figure 2-4 shows production trend for coconut from 2007 to 2019.

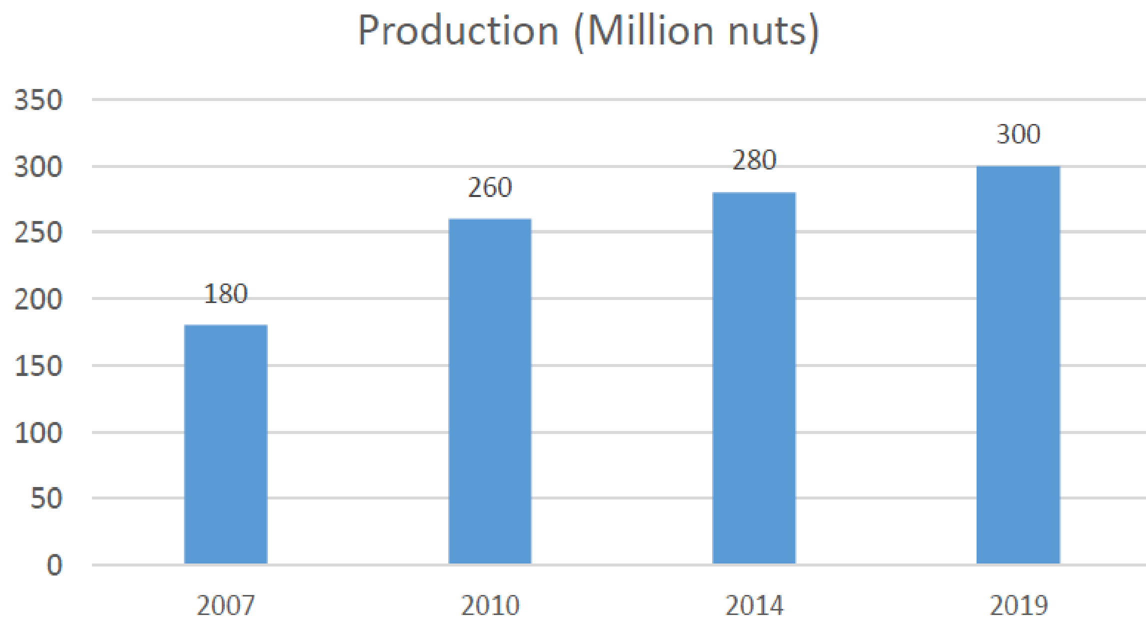

Figure 2-1 Coconut production trends from 2007 to 2019

(Source: Danda, 2019)

Copra, copra cake, toddy, leaves, brooms, baskets, mats, oil, desiccated coconut, coconut cream, coconut shell, shell charcoal, activated carbon, charcoal briquettes, coir fiber, coir dust, and fresh coconut juice are some of the most common coconut products. (ABD DANIDA, 2007). Table 2-4 shows the common products (mostly raw materials) produced in the main coconut producing counties of the coastal region in 2012. It is apparent from this table that most of the nuts and other raw materials are produced in Kilifi and Kwale counties.

Table 2-4 Coconut products in Kenyan Coastal region

County	Mature Nuts (numbers)	Immature Nuts (numbers)	Wine (litres)	Coco-wood (pieces)	Makuti / Thatch (pieces)	Brooms (pieces)
Kilifi	117,053,025	6,578,782	116,109,505	52,167	92,007,182	2,314,663
Kwale	111,538,751	13,693,355	30,370,939	96,893	31,119,969	3,081,018
Mombasa	6,952,922	2,671,404	1,950,788	9,186	1,356,639	201,688
Lamu	6,882,592	1,240,351	567,917	7,061	6,381,715	202,811
Taita Taveta	2,859,092	25,811	4,145,424	1,330	NA	NA
Tana River	1,129,948	545,499	166,804	787	1,061,483	NA

Source: *KCDA, 2013* *NA = data not available*

2.4 Harvesting of Coconut

2.4.1 Immature coconut fruits harvesting (Madafu)

Tender coconut is prized for its sweet water, which is a delightful drink, as well as its tasty gelatinous meat, which is usually around 8 months old (kernel). Tender coconut water, or liquid endosperm, is consumed fresh because it quickly deteriorates when exposed to air and elevated temperatures. Furthermore, sterilizing the water at a high temperature and for a short period of time eliminates part of the nutrients as well as the complete flavor. During maturation, the chemical content and volume of coconut water vary (Jayalekshmy et al., 1988) (S. Azeez & George, 2004).

After 7 months to maturation, the quality and quantity of coconut water, as well as consumer acceptability of tender nut, improve. The bulky nature of tender coconut, as well as its proclivity for biochemical changes and spoilage after harvest, are barriers to the popularization and marketing of tender coconut in natural form in areas where coconut is not grown. Although technologies exist to convert tender coconut water into packaged soft drinks, consumers prefer the natural flavor of tender coconut (Rao et al., 2008).

The growing demand for natural drinks demanded the creation of sensitive coconut water that would neither deteriorate or lose its essential properties. Tender coconut cannot be stored at room temperature for more than one week due to skin shrinkage and discoloration, perianth fall, and fungal attack on the soft perianth region. When a whole nut is wrapped in cling film and stored at 14 - 15°C, the quality of delicate coconut may be maintained for a few weeks, according to a study by (Ranasinghe et al., 2010).

The green coconut (madafu) is the same nut as the coconut matures, but it is picked before it develops and used to make a soft drink. The farmer can either sell the immature nut or wait till the nut matures. However, according to (Gachanja et al., 2007), the decision to sell madafu or wait for the mature nut to be sold may not be a straightforward one for the farmer to make, but rather one imposed by the demand. From a price standpoint, it appears that farmers should sell their nut as madafu, as the price for this product is often higher than that of the dried (mature) nut.

The consumption of coconut tender water along the coastal region of Kenya is prevalent consequently leading to market growth for the immature nuts. This increases the generation of husk wastes which correspond to roughly 85 percent of the fruit weight according to (Rosa et al., 2010); (Ishizaki et al., 2008). These husks are typically discarded as waste in the open environment, where they take time to degrade leading to generation and accumulation of the husks wastes (Carrijo et al., 2002); (Ferreira et al., 2006); (Corradini et al., 2009).

2.4.2 Mature coconut fruits harvesting

It takes around a year for coconuts to fully ripen. The nuts grow together and though may not be ripe at the same time but will in the same season. In addition to the timing of coconut fruit maturity, color is another indicator of ripening, with mature coconuts being brown and immature fruit being bright green. The amount of coconut water diminishes when the meat hardens as the coconut matures. Coconuts that have reached maturity are harvested at the appropriate stages or have fallen to the ground ripe.

Harvested coconuts are sorted, with the ripe coconuts being set to begin the husking process, and the unripe coconuts being spread out on the ground to dry for a month or more to reach the maturity required to husk out. Matured coconut has long been regarded the major product of the coconut tree, and it has been documented as so in Kenyan official papers pertaining to the coconut sub-production sector. After maturity of the coconut fruit, the nut is extracted leading to husks generation which are dumped on farmland, take long to degrade naturally hence causing environmental pollution.

2.5 De-husking of Coconut Fruits

Dehusking refers to the process of removing the nut from the husk. It is a crucial post-harvest process that is required in order to prepare the coconut for further use. It also produces husk, which is a vital component of the coir processing industry. Husking is traditionally done with conventional tools like as a hoe, blade, or spear. An operator must use strength and skill to bring the coconut sharply down into the blade, twist the coconut to one side, remove the husk, and detach the fiber from the shell in the manual husking process. This process is repeated until the fiber is completely freed from the shell. This technique is not only demanding and dangerous, but it also necessitates a high level of skill and physical strength.

There are lots of machines developed around the world to automate dehusking. Furthermore, (Nwankwojike et al., 2012) developed a dehusking machine which is able to automatically open the husk of a coconut with two blades. (Venkataramanan et al., 2014) designed a machine for stripping and removing coconut crowns from coconuts. Program Logic Control was used in a study to build an automatic coconut peeling machine (Shansen et al., 2017). With the numerous designs to automate dehusking it is apparent that the technology is a challenge to coconut's small-scale farmers, firstly, with the cost of acquisition and secondly the cost of maintenance.

2.6 Coconut Waste Utilization

Coconut has no single part that can be considered as unimportant since even its waste by-products might help farmers supplement their income. According to (Eyzaguirre, 1996), Coconut husk waste has been put to good use and has even become a money-making industry. Coir fiber pith, also known as coir dust or coco peat, is a major by-product of coir production that is now being sought to help save the environment. It is being used as a plant potting media to replace peat. In nations with high coconut output, such as Sri Lanka, the peat or dust is now being exported and is becoming a key foreign cash earner. Coconut waste is a by-product of the harvesting and processing of coconuts.

(Madakson et al., 2012) reported that Coconut shell, a type of agricultural waste, is widely available in most tropical nations around the world. The husk and shell, which are byproducts of the coconut oil and tender water businesses, are often thrown or burned. A fresh source of energy is provided by the shell. Coconut shells were previously burned as a solid waste disposal method, contributing significantly to carbon dioxide. However, since the cost of petroleum, natural gas, and electricity has risen, coconut shell has considered as an alternative fuel source rather than waste (Cimons, 2014).

Basak et al., 2014 reported that coir is a natural fiber made from the husks of mature coconuts. Green husks, an agro-waste, are, however, widely available, and recent research have shown that high-quality coir fiber can be recovered from them. In light of today's environmental and economic concerns, coconut husk, has become a very useful product.

2.7 Coconut Fiber Extraction

2.7.1 Retting

This is the process of separating the coir fiber from the husk pulp by natural and chemical means. The husk is partially destroyed during this process, making it easier to separate the coconut coir fiber from the coconut Coir pith. For optimal retting of coconut husks, completely mature coconut husks are immersed in normal freshwater for six months, allowing the bacteria to react and ease the retting process.

According to (Mishra & Basu, 2020), the traditional method of coconut fiber extraction involves dipping the husk in a water lagoon for 6–12 months to obtain whiter, softer, and spinnable retted fibers. However, retting is rapidly becoming extinct as a result of various technological and societal concerns.

According to FAO (2013) and FAO (2015), the main challenge of conventional water retting is pollution of open water bodies and the surrounding air. Traditional extraction (retting) causes occupational diseases, particularly among women in the profession.

According to the report, the subsequent manual yarn manufacturing is the source of enormous human drudgery, and as a result, production has been steadily declining.

There are modern methods for retting that use a machine for decortication and reduce months of retting to days. Mature husks are crushed in a decorticator after only 7 to 10 days retting to begin the fiber separation process, whereas green husks are crushed and dampened with water for one to two days before being sent to de-fibering (Sisti et al 2018). Figure 2-5 shows traditional fiber extraction done after retting.

Figure 2-1 Manual defibering of retted husk.

(Source: *Leena Mishra, Gautam Basu 2020)*

This type of traditional practice produces the highest quality (white) fiber for spinning and weaving. The most suited fibers for dyeing and bleaching are retted fibers from green husks. Shorter retting durations can be used to produce coarser brown yarns. These are increasingly being used in geotextile applications.

2.7.2 Mechanical extraction

After only five days of immersion in water tanks, the husks are processed mechanically using either de-fibering or decorticating equipment. The fibers are opened by crushing the husk in a breaker. The long fibers are separated from the short woody components and the pith using revolving drums. The stronger fibers are washed, cleansed, dried, hackled, and combed after they have been washed, cleaned, and dried.

2.8 Coconut Fiber

Coconut fiber is produced from the husk of the coconut fruit and is one of the natural fibers plentiful in tropical climates. Coconut fibers can reach a length of 35 cm (13.8 inches) and a diameter of 12-25 microns. Coconut fibers are divided into two types: brown fibers recovered from mature coconut husks and finer white fibers derived from immature coconuts husks.

Brown fibers are thick, robust, and resistant to abrasion. White fibers are finer and smoother, but they are also weaker. Coconut fibers are sold in three different types: bristle (long fibers), mattress (short fibers), and decorticated (mixed fibers). Depending on the application, these various types of fibers can be used in a variety of ways. Brown Fibers are commonly utilized in engineering particularly in civil engineering as a construction material (Ali, 2010).

Cellulose, hemicellulose, and lignin are the main constituents of fiber cell walls, with pectin serving as the primary binder. Cellulose is a glucose-containing polymer. It's a strong, crystalline (linear) molecule with no branches. Although cellulose is resistant to hydrolysis, it will be degraded to some amount by chemical and solution treatments (Heinze T & Fischer K, 2005).

Hemicellulose is a polysaccharide polymer made up of glucose, mannose, glucuronic acid, arabinose, and xylose copolymers with a low molecular weight. Furthermore, it appears as a random, amorphous structure. The hemicellulose is hydrolyzed by a weak acid or base and opens the bonded structure of cellulosic materials (Summerscales et al., 2010). Figures 2-6 and Figure 2-7 shows mature and immature coconut husks and fibers extracted from each.

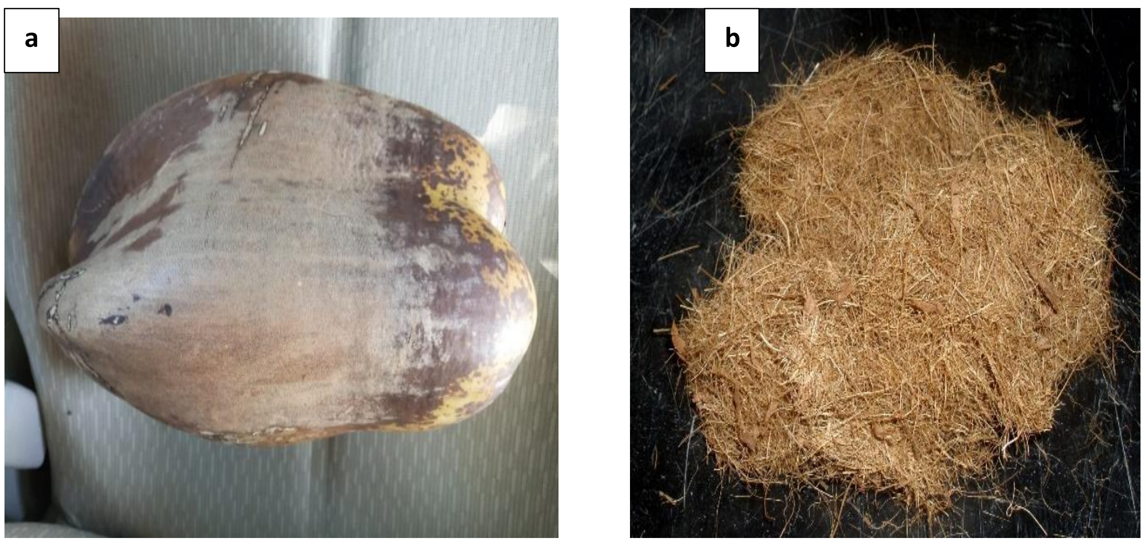

Figure 2-1 (a) matured coconut fruit and (b) fibers from matured coconut fruit

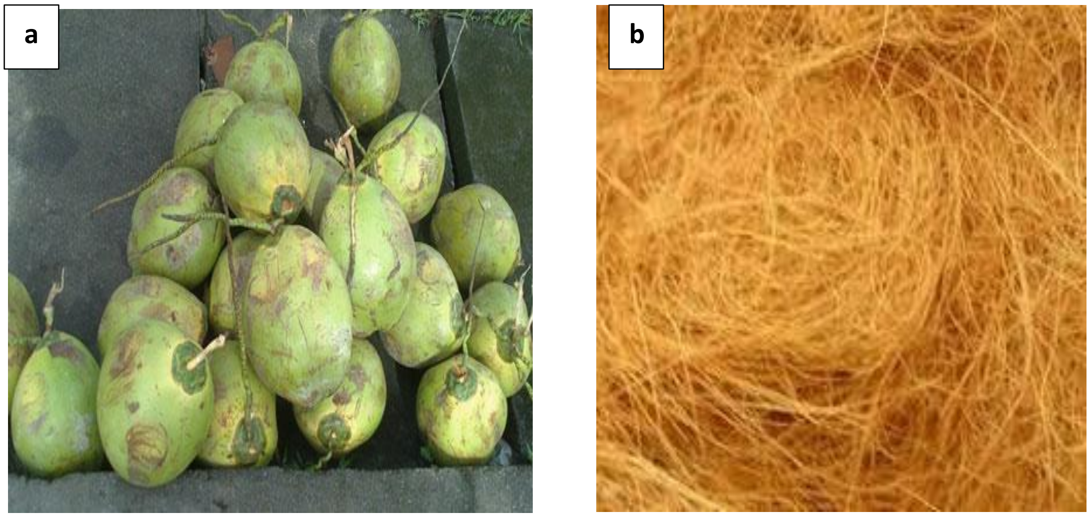

Figure 2-2 (a) Immature coconut fruits and (b) fibers from immature coconut

2.9 Fiber Treatment and Modification

Researchers have focused on the application of natural fibers to meet the demand for environmental consciousness. Natural fibers outperform synthetic fibers in terms of cost, availability, biodegradability, and recyclability (Nurazzi et al., 2021). Apart from these benefits, natural fibers have some hindrances in their application such as high moisture absorption and incompatibility with the matrix in the manufacture of polymer composites. (Amiandamhen et al., 2020) reported that natural fibers' reactive functional groups were covered by waxes and pectin in their cell walls, preventing them from interacting with the matrix. Because fibers are inaccessible to the matrix, they have low adhesion across the phase boundary, weak force dispersion, and poor strength qualities. He further alluded that natural fiber's structural composition, which includes cellulose, hemicellulose, lignin, pectin, and wax components, provides for moisture instability and weak adhesion with the polymer matrix and therefore modification is needed to overcome the insufficiencies associated with natural fibers.

The surface of a natural fiber can be modified using physical and chemical methods. Stretching, calendaring, cold plasma treatment, and the electric discharge method are all physical methods (Kabir et al., 2012). (Ramadevi et al., 2012) cited that alkalization (mercerization), acetylation, benzoylation, bleaching (baking soda), and silane treatment are common chemical methods for surface modification of fibers. Natural fibers are immersed in a concentrated sodium hydroxide solution during the mercerization process. Table 2-5 shows various alkalization parameters used by some researchers for surface modification.

Table 2-5 Alkalization parameters for coir fiber treatment

Alkali used	Concentration (wt%)	Immersion time (hrs)	Temperature (°C)	Reference
NaOH	5	4	Room temp	Debasmita P. and Punyapriya M. 2019
NaOH	5	2	100	Bakri et al 2018
NaOH	2, 4 and 6	0.5	-	Thirumurugan et al 2021
chromium sulfate $CrSO_4$ + $NaHCO_3$	4 4 CrSO4 0.02% NaHCO3	3 2	-	Samia et al 2011
hydrogen peroxide (H_2O_2)	5	1	90	Vandan J.E.G 2002
NaOH	5, 10, 15 and 20	3	-	Muhammad, A. H. 2017.
NaOH	3 and 7	72	Room temp	Nam et al 2011
NaOH	5 - 30	24	Room temperature	Monnisha G. and Gobi N. (2021)

The alkali reacts with the hydroxyl groups of natural fibers, removing the hemicellulose, lignin, wax, and oils that surround the external surface of the fiber, resulting in an increase in the surface roughness aspect ratio and a decrease in fiber diameter, and producing a mercerized cellulose structure that improves interfacial bonding between hydrophilic fibers and hydrophobic polymer matrices (Vasquez et al., 2016). Untreated natural fibers appear to be encased in cementing components such as lignin and hemicellulose, as well as other impurities such as wax and oils (Zhu et al., 2013). Figure 2-8 shows structure of an untreated and alkali treated cellulose fiber. Due to the partial removal of lignin, hemicellulose, and other impurities, alkali-treated natural fibers are found to be clean and rough (Guduri et al., 2009).

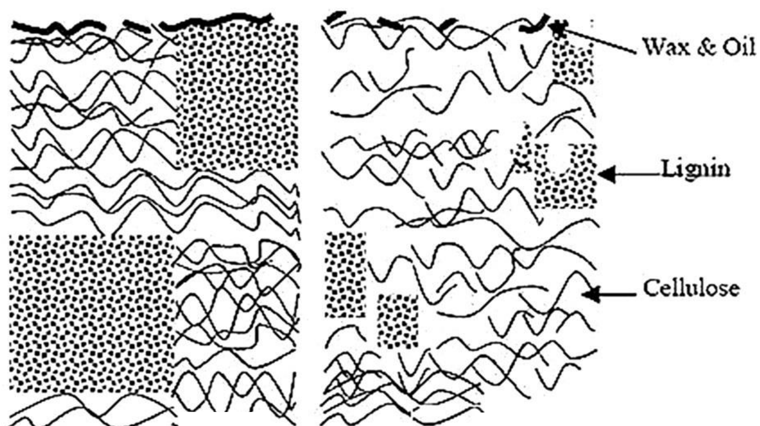

Figure 2-1 Typical structure of (i) untreated and (ii) alkali-treated cellulose fibers (Source: Kabir et al., 2012)

2.10 Fiber Characterization

2.10.1 Fiber diameter

Fiber structural properties such as fiber orientation, fiber diameter, pore size, homogeneity, and fiber crimp, among others, influence the physical and mechanical performance of natural fibers in water structure (Stanger et al., 2014); (Ganjkhanlou et al., 2014); (Huang et al., 2003) .

For a single natural fiber bundle, precise diameter measurement is a significant challenge. Natural fibers, as opposed to synthetic fibers, have irregular shapes and textures, as well as non-uniform lengths and thicknesses (Kabir et al., 2013).

Natural fibers, like all other materials, have defects (Hu et al., 2010). Furthermore, a single fiber bundle is made up of a large number of elemental fibers that are held together by a lignin and hemicellulose matrix. As a result, the cross-sectional geometry of a single fiber bundle is not circular in general. It should therefore be noted that the assumption of circular cross-sections in natural fibers will almost certainly result in measured tensile properties that differ slightly from true values. (Munawar et al., 2007) reported that on the cross-section, coconut fiber has an almost circular shape, whereas the cross-sectional shape of other fibers varies greatly.

In textile fibrous systems, fiber diameter is one of the most essential structural parameters. Fiber diameter is frequently measured manually, which is a time-consuming process that is subject to analyst bias. (Baheti & Tunak, 2017), reported that for online and real time quality control during high-speed nanofiber production, manual methods are ineffective. He went on to say that measuring fiber diameter by hand is time-consuming, labor-intensive, operator-dependent, and requires a limited number of measurements.

Various researchers have reported the coconut fiber diameter as shown in Table 2-6

Table 2-6 Reported fiber diameter by researchers

Type of fiber	Fiber Diameter	Reference
Green coconut fiber	110 µm to 460 µm	Mathura et al. 2014
Brown coir	600 µm	Reddy 2013
Brown coir	170 µm to 240 µm	Hasan et al. 2012
Brown coir	200 µm	Leite et al. 2010
Brown coir	69 µm to 495 µm	Brígida et al. 2010
Brown coir	55.6 µm to 197.6 µm	Rahman and Khan 2007

To curb the challenges in manual fiber diameter measurement variations, there are various automated methods developed. The automated methods generate results that are free of researcher bias, more consistent, and have fewer inaccurate measurements. Table 2-7 gives a summary of approaches used in fiber diameter measurement to curb the numerous short falls evinced in manual methods.

Table 2-7 Approaches used to determine fiber diameter

Method/ Approach	**Tool used**	**Reference**
Optical microscopy	SEM	Rajeshkumar et al 2021
Optical micrographs	SEM	Madueke et al 2021
Optical microscopy	SEM	Mumthas et al 2019
Hierarchical scale	Diameter J	Deubler et al 2015
Computerized Image evaluation	Diameter J	Hotaling et al 2015
Ziabari	Web simulation	Ziabari et al 2005
Optical	SEM	Eichhorn et al 2004

2.10.2 Fiber density

Fiber density can be utilized as a distinguishing feature for fiber identification because it is a physical attribute. Density is generally determined indirectly by measuring the volume and weight of a representative fiber sample and then combining these quantities to compute density.

The denier, the traditional unit for which the weight of the fiber, in grams, is normalized to a length of 9000 m; the tex, the internationally recognized unit normalized to a length of 1000 m; and the decitex, normalized to 10,000 m are the most prevalent units. The denier and the decitex are frequently used in the clothing industry and can easily be converted from one to the other.

Various researchers have reported the coir fiber density as investigated and some of the typical values include 0.67-10 g/cm^3 (Bai et al, 2019), 1.2 g/cm^3 (Ticoalu et al, 2010), 1.1-1.5 g/cm^3 (Adeniyi et al 2019) and 0.9-1.3 g/cm^3 (Bui et al, 2020).

A good analytical balance is the easiest way to get the weight measurement. However, there are various different methods for determining volume. (Truong et al., 2009) highlighted and compared the following methods that can be used for determination of density for natural fiber. Table 2-8 shows the various methods that has been used in measurement of linear density of natural fibers.

Table 2-8 Methods for measurement of natural fiber density

Method for fiber density measurement	**Reference**
linear density and diameter calculation	Soykeabkaew et al., 2004)
Archimedes (buoyancy)	ASTM-D3800–99, 2005
helium pycnometry	Rude et al., 2000
gradient column	ASTM-1505–03, 2005
liquid pycnometry	Rude et al., 2000

2.10.3 Fiber moisture content

This is the mass of water contained in whatever form in the textile as a percentage of the oven-dry mass of the material, as determined by the standard procedure. The atmospheric conditions affect different fibers in different ways. Some fibers are hygroscopic, meaning they take water from the air or release it in a dry environment. The reported coir fiber moisture content in percentage is 13.85% (Gil et al 2019), 10.2% (Barbosa et al 2010) and 9.8% (Abraham et al, 2013).

2.10.4 Tensile strength of the fiber

Tensile strength, also known as ultimate tensile strength, is computed by dividing the sample's peak tension force by its cross-sectional area. Tensile strength is measured with a tensile tester. To measure tensile force, the tensile tester is equipped with a load cell. The tensile strength of single fibers is pivotal to the reliability with which fibers are processed into products, as well as the standard grading of these products.

The tensile properties of natural fibers are largely dependent on test conditions, fiber extracted species, and dimensions of the fiber (Bezazi et al., 2014). Reported tensile strength for coconut fiber is 175 MPa (Naveen et al, 2013), 405 MPa (Amadi et al, 2013), 176 MPa (Ramli et al, 2012) and 15-327 MPa (Ramakrisha et al 2004).

2.10.5 Surface morphology analysis

The scanning electron microscope (SEM) is one of the most widely used techniques for analyzing nanomaterials and nanostructures. The technique examines the surfaces of materials, particles, and fibers in order to measure and assess fine details using image analysis. The signals produced by electron-sample interactions reveal information about the sample such as surface morphology changes such as pore size, texture, and shape, among other things, as well as the chemical composition of the sample.

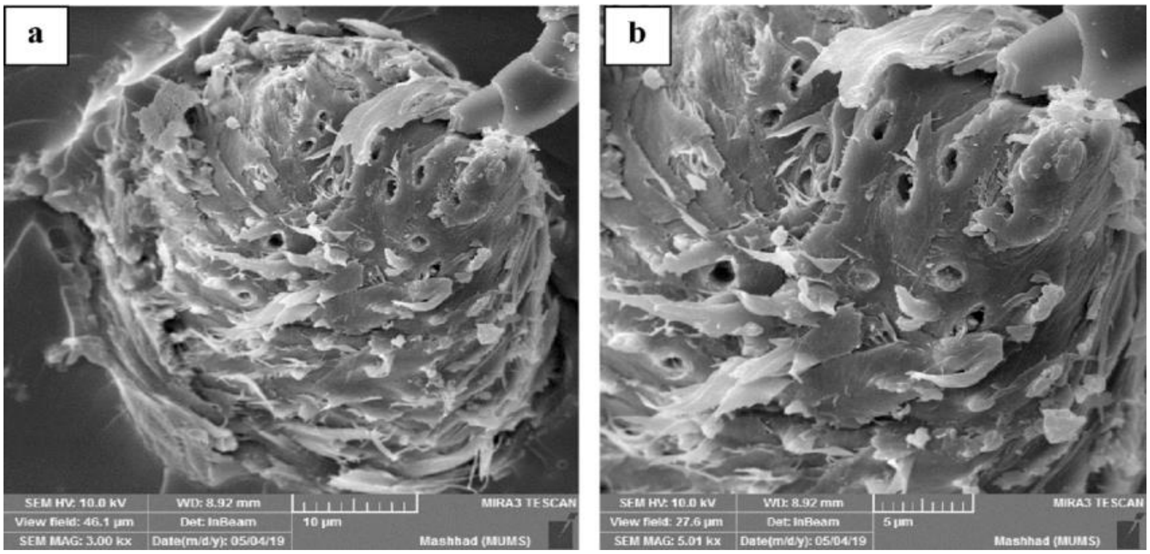

Figure 2-1 SEM image (a-b) of the morphology of coir fiber cross section

(Source: Sadeq et al, 2020)

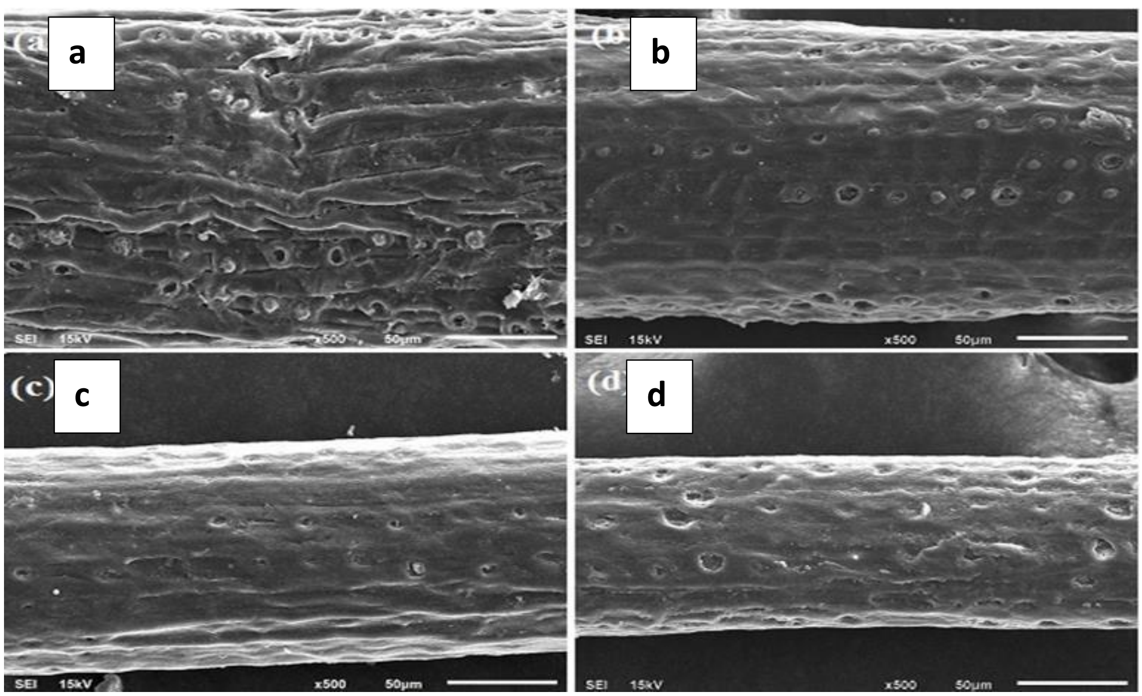

Figure 2-2 SEM images of (a) raw coir fibre and; solution treated coir fibre at (b) 8 % and; (c) 10 %, (d) 12 % $NaHCO_3$ after soaking for 24 hours.

(Source: Bakri et al 2018)

2.10.6 Infra-red spectroscopy analysis

The Fourier transform infrared spectroscopy (FTIR) technique identifies the presence of functional groups in an organic molecule. The vibration frequencies of the functional groups are characteristic of that functional group and fall within the infrared frequency range. When an infrared signal passes through an organic compound, it is absorbed or emitted at these specific frequencies, which can be converted into a distinct spectrum. (Chai et al., 2020); (Griffiths, 1983). The presence of new groups can be visualized in infrared analysis, allowing one to determine whether the chemical modifications were successful (Chen et al., 2015).

(Troedec et al, 2008), (Sgriccia et al,2008) and (Rout et al 2000) reported an FTIR spectroscopy that shows the peak at 1736 cm^{-1} (C=O stretching of the acetyl groups of hemicelluloses) and disappears after treatment with NaOH. (Arrakhiz et al., 2012; Pereira et al., 2019) associated the intensity of the absorption peak at 1248 cm^{-1} to the C-O-C stretching in lignin, indicating that most of the lignin is removed. (Ru et al., 2022) summarizes the functional groups to corresponding peak in the analysis of coir fiber as is given in Table 2-9

Table 2-9 Peak value of change in FTIR spectrum

Intensity (wavenumber cm^{-1})	Functional group
1737	C=O
1608	C=C
1376	C-H
1248	C-O-C
897	C-H

2.10.7 Thermogravimetric analysis

Thermogravimetric Analysis (TGA) is a thermal analysis technique that has been used to quantify reactions involving gaseous emissions by measuring changes in the weight loss (mass) of a sample that has been subjected to a constant increase in temperature (Villain et al., 2007); (Reis et al., 2007). The method entails heating a material at a regulated rate up to and past its thermal degradation temperature while monitoring mass loss during the process. This method gives researchers a comparative assessment of heat flow, allowing them to learn more about molecular motion. The sample is subjected to a temperature-controlled program in this scenario, which results in a mass change as the temperature rises (Agrawal et al., 2019).

(Ru et al., 2022) reported that the thermal decomposition of natural fibers is in three phases. The first phase is the evaporation of water, the second is the decomposition of hemicellulose, pectin and part of cellulose, and the third is the decomposition of cellulose. Lignin is usually very stable and difficult to decompose and its decomposition is taken to be the whole process. The final residue in thermal test is ash, and the ash residue of coir fiber after alkali treatment increases from 25.54% to37.41% at 500 °C.

2.11 Properties of Coconut Fiber

2.11.1 Mechanical and physical properties

Natural fibers have a wide range of qualities. Coconut fibers, for example, have almost equal diameters but wildly varied tensile strength magnitudes (Ramakrishna & Sundararajan, 2005a); (Toledo et al., 2005). Coconut fibers have a wide range of characteristics, which makes them difficult to regularly use in engineering applications. The goal of compiling data on fiber qualities is to create a guideline, but the results show a wide range of results. This necessitates the establishment of certain guidelines for such deviations. Table 2-10 shows some physical and mechanical properties of coir fibers as reported by different authors.

Table 2-10 Coconut fibers' physical and mechanical qualities

Diameter (mm)	Length (mm)	Tensile strength (Mpa)	Elongation (%)	Moisture content (%)	Water absorption saturation (%)	Elastic Modulus (GPa)	Density (Kg/m^3)	Reference
0.4 - 0.10	60 - 250	15 - 327	75	-	-	-	-	Ramakrishna et at 2005a
0.21	-	107	37.7	-	93.8 - 161.0	2.8	1104 - 1370	Agopyan et al 2005
0.3	-	69.3	-	-	-	2	1140	Paramasivam et al 1984
-	-	50.9	17.6	-	180	-	1000	Ramakrishna et at 2005b
0.27 ±0.073	50 ±10	142±36	24 ±10	10	24	2.0 ±0.3	-	Li et al 2007
0.11 - 0.53	-	108 - 252	13.7 - 41	-	85 - 135.0	2.50 - 4.50	670 - 1000	Toledo et al 2005
0.12 ±0.005	-	137 ±11	-	-	-	-	870	Munawar et al 2007

(Source Majid Ali 2010)

2.11.2 Chemical properties of coconut fibers

The primary components of coconut fibers are cellulose, hemicellulose, and lignin. The characteristics of coconut fibers are affected by these mixtures. Pre-treating fibers alters their composition and, as a result, their properties, as well as the qualities of composites. It occasionally enhances fiber behavior, but it can sometimes have a negative impact.

The chemical composition and tensile strength of four natural fibers (coconut, sisal, jute, and kenaf fibers) were studied after they were subjected to alternate wetting and drying, as well as continuous immersion in three mediums for 60 days. (water, saturated lime, and sodium hydroxide) (Ramakrishna & Sundararajan, 2005b). For all of the examined conditions (continuous immersion was shown to be crucial), the chemical makeup of all fibers altered, and the fibers lost their strength. The impact of pre-treating coconut fibers was studied by (Asasutjarit et al., 2007) for lightweight cement boards. Table 2-11 shows the chemical composition of coir fiber.

Table 2-11 Chemical composition of coir fiber

Fiber	Hemicellulose (%)	Cellulose (%)	Lignin (%)	References
Coir	31.1	33.2	20.5	Ramakrishna et at 2005a
	15 – 28	35 – 60	20 – 48	Agopyan et al 2005
	16.8	68.9	32.1	Asasutjarit 2007
	-	43	45	Satyanarayana et al 1990
	0.15 – 0.25	36 - 43	41 - 45	Corradini et al 2006

(Source: Ali, 2010)

2.12 Summary of Literature and Research Gaps

From the reviewed literature, coconut value addition particularly in the waste generated during production is economically significant to the Kenya's national GDP. Further, its contribution to economic opportunities in the regional market cannot be emphasized. However, quality and yield of the fiber produced is of great significance particularly for industrial and commercial perspective. There exists scanty information on the immature coconut husk fiber extraction, characterization and utilization in Kenya. According to (Ali, 2010) Coconut fiber dimensions vary, and are claimed to be influenced by the type of coconut plant, its location, and its maturity. Several studies have been undertaken in developed countries in diverse regions where the geography and climatic conditions in which coconut palms are produced may differ from the Kenyan coastline where this study was conducted.

The prevailing localized challenges affecting the regional coconut farming are also different. (Gachanja et al., 2007) reports that Since 1990, there has been no coconut research in Kenya save for the preservation of germ plasm, owing to national research priorities that have given coconut a poor rating, insufficient manpower, and a lack of finances. This study will therefore address the evincing research gap through a comparative analysis of brown and green fiber extraction and characterization for mechanical, physical and chemical properties.

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

This chapter describes the experimental set ups for husk waste collection, fiber extraction and testing for mechanical, physical, surface morphology, structural and thermal properties. Collection of husk waste was done in three counties along the Kenyan coastal region namely; Mombasa, Kilifi and Kwale. These counties were selected due to the prevalence consumption of coconut tender water hence inevitable waste generation from husks.

The counties are also a representative of the coconut farming in the country which mainly done in the coastal region. The tests were carried out in order to assess the properties of green coir fibers extracted from coconut husk waste resulting from consumption of the coconut tender water. The samples were scientifically selected and classified into three categories according to length giving small, medium and large size samples, where it directly reflects to the fibers extracted. In addition, a survey was conducted on the availability and quality of coconuts. Husks of each category were taken to the husk decorticator for fiber extraction and separation.

Experiments were undertaken to establish coconut fiber properties and quality, as well as suitability of industrial applications. Research Method for this study is largely quantitative and experimental. However, the participatory approach was used to gather information where the immature nuts vendors were engaged for the purposes of profiling the population of the fruit in the research sites. Questionnaires were issued to vendors selling coconut tender water to determine the source of the immature coconut, the amount of coconut green husk waste produced and waste management in the study's target locations.

Figure 3-1 is an illustration of conceptual framework for this research;

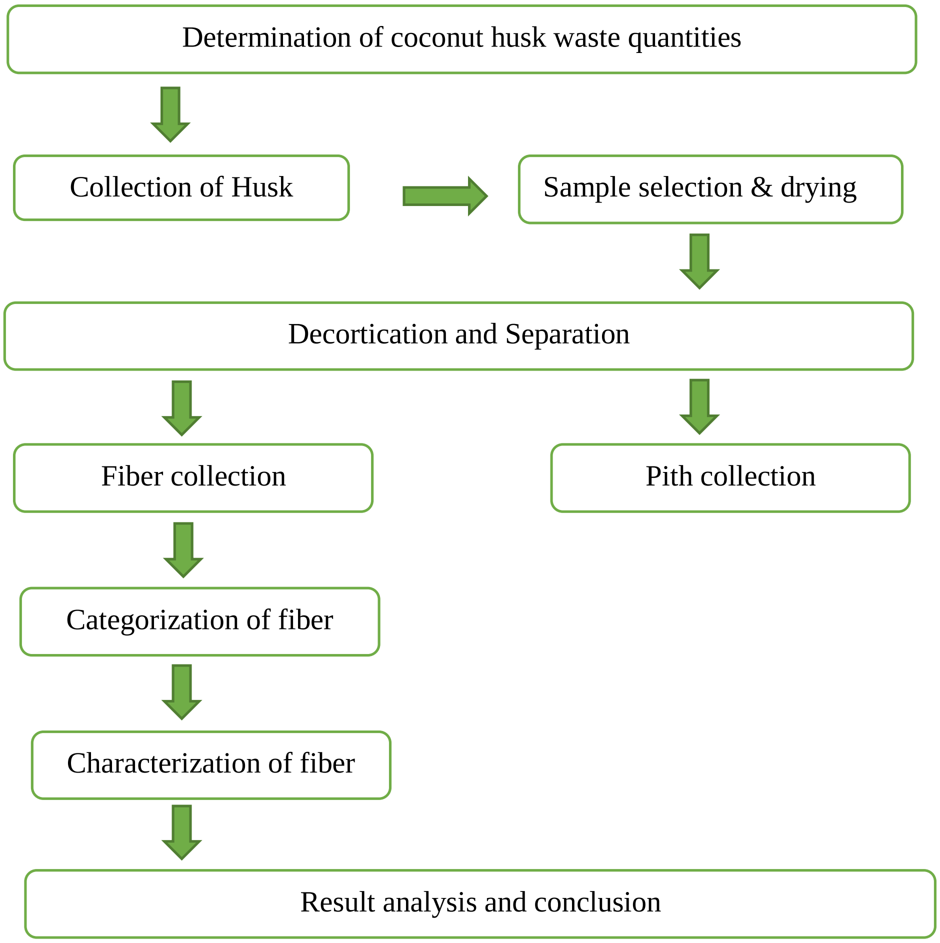

Figure 3-1 Conceptual framework

3.2 Quantification of Generated Coconut Husks Waste

Husk waste quantity is of significance for sustainability of coconut fiber applications. Mapping was done to determine the common locations in which coconut tender water is sold for the fixed location vendors as well as the areas where vendors with no fixed point of sale are likely to be found. The information regarding the exact number of coconut tender water vendors along coastal tourist town of Mombasa is unavailable either within the business licensing authorities or publication. However, during the face validity of the questionnaire developed the number of vendors was factor out in the pilot survey. It was determined that 45 vendors operate within Mombasa CBD a number that was targeted for data collection.

Questionnaires (see appendix A) were issued to vendors selling coconut tender water to determine the source of the immature coconut, varieties, location of sale, the quantity of waste generated from coconut green husk and waste management in the areas targeted by the research.

Simple random sampling method was used where respondents were randomly selected from the perceived population of coconut tender water vendors. The vendors had equal chance of being selected, however high potential commercial areas and vantage points for coconut tender water sellers were taken into consideration.

The data was collected using both open ended and close ended questionnaires and entered on excel. Target respondents were 45 and only 32 were accessible which gives a 71% response rate. The analysis of research data collected through questionnaire was done using SPSS version 20 and Microsoft excel 2016. Simple descriptive statistics and analytical methods were used where frequency tables, percentages, bar charts, histograms and pie charts were generated.

3.3 Collection and Classification of Coconut Husks Waste

Immature coconut husks were collected from Mama Ngina drive, Mombasa town CBD, Mtwapa and Kwale which are proximally located. The three locations were selected first, because they are a representative of the four counties in the Kenyan coastal region with significant coconut farming according to the Agriculture and Food Authority (AFA) report of 2016. Secondly, Mombasa town is a converging zone for coconut tender water vendors, consumers as well as the suppliers from North and South coast regions.

This leads to a challenge in significantly categorizing the husk wastes in terms of the exact locational origin as well as the variety. From Literature however, it is apparent that the East African Tall variety is predominant. However, the other varieties cannot be wished away particularly with the attention coconut farming has currently attracted where increase in production levels and value addition is targeted.

Mapping was done to determine the common locations in which coconut tender water is sold for the fixed location vendors as well as the areas where vendors with no fixed points of sale are likely to be found. Questionnaires were issued to vendors selling coconut tender water to determine the source of the immature coconut, varieties, location of sale, the amount of coconut green husk waste produced and waste management in the study's target locations. The sample size was collected according to Scott Smith formula for determination of sample size for large and/or unknown population.

According to Scott Smith Equation 1 can be used to determine sample size for large populations or unknown population

$$n = \frac{z^2 * \sigma(1-\sigma)}{E^2} \qquad \text{Equation 1}$$

Where n - sample size

Z - score corresponds to a chosen confidence level

σ - standard deviation

E - Margin of Error

He further recommends that for large or unknown populations the preferred confidence level of 95% with a standard deviation of 0.5 and a confidence interval of ±5%. Therefore, the sample size was determined as follows using Equation 2;

$$n = \frac{1.96^2 * 0.5(1 - .05)}{0.05^2} \qquad \text{Equation 2}$$

$n = 384$

Fibers from mature coconut husk were bought from a local husk processing company that deals exclusively with extraction of immature fibers.

3.4 Extraction of Coconut Fibers

The fibers were extracted using a mechanical decorticator. A Coconut husk decorticator is a machine that uses impact and/or thumping action to crush dried coconut husk and remove coir fiber and dust from the husk. The principle of operation involved crushing the dried coconut husks consequently resulting to fibers and coco peat.

Dried coconut husks were fed manually to the feeding hopper of the decorticator machine a piece at a time after been passed through a coconut beater to soften the husk. The husks are further beaten by blades, which are strategically welded axially to a rotating cylindrical drum run by a three phase 8.5 hp motor. Multiple blades welded strategically to the spinning shaft assembly drag coconut husks to a series of counter blades located horizontally in the center of the housing cylinder, causing quick separation of coir fiber and dust.

Separation of the coir and peat occurs simultaneously during the extraction process, with coir dust passing through the sieve bars located beneath the housing cylinder and falling by gravity to the collection tray beneath, while the coir is discharged in the fiber discharge outlet on the machine's left-hand side. The coir dust that falls beneath the machine and the coir discharged at the fiber outlet are taken separately for characterization. Figure 3-2 shows a mechanical decorticator that was used for fiber extraction.


Figure 3-2 Decorticator and fiber screener used for fiber extraction

3.5 Fiber Treatment

Coir used in this study were extracted from immature coconut husk wastes and matured coconut husk wastes. The fibers were soaked into NaOH solution with a 20% concentration for 3 hours in a fiber-to-solution ratio was set to 1:20 so as to ensure the fibers were fully submerged in the alkali solution and soaked. After the treatment, the fibers were thoroughly rinsed with distilled water to eliminate any NaOH residue on the fiber strands, until no change in color was observed in the drained water. The fibers were then dried in an oven at a temperature of 90^{o}C for 5 hours and then was cooled to room temperature. There were four categories of samples with the following notations as shown in Table 3-1;

Table 3-1 Notation of coconut fiber

Notation	Description
IM_Untreated	untreated immature coconut fibers
IM_Treated	Treated immature coconut fibers
M_Untreated	untreated mature coconut fibers
M_Treated	Treated matured coconut fibers

3.6 Coir Characterization

3.6.1 Fiber diameter

The diameter of coir fibers was measured using SEM images obtained from TESCAN VEGA 3 Scanning Electron Microscopy. The microscope has a resolution of 2nm and operate at 30keV with a magnification of 1x up to 1000000x. Tests were performed at room temperature on single coir fiber bundles.

Determination of fiber diameter is crucial for fiber quality evaluation. The fiber diameter was determined by manually measuring the diameters of randomly selected fibers on scanning electron microscope (SEM) images as shown in figure 3-2. Four samples were measured for each of the four notations where each sample had 10 randomly measured fiver diameter then the average diameter for the fiber was determined. A voltage of 10.0 kV was used alongside the width difference (WD) of 15.00 mm and a magnification of 776x. The software for fiber measurement was an inbuilt that is integrated with TESCAN VEGA 3 Scanning Electron Microscope. There was no coating done to the fiber.

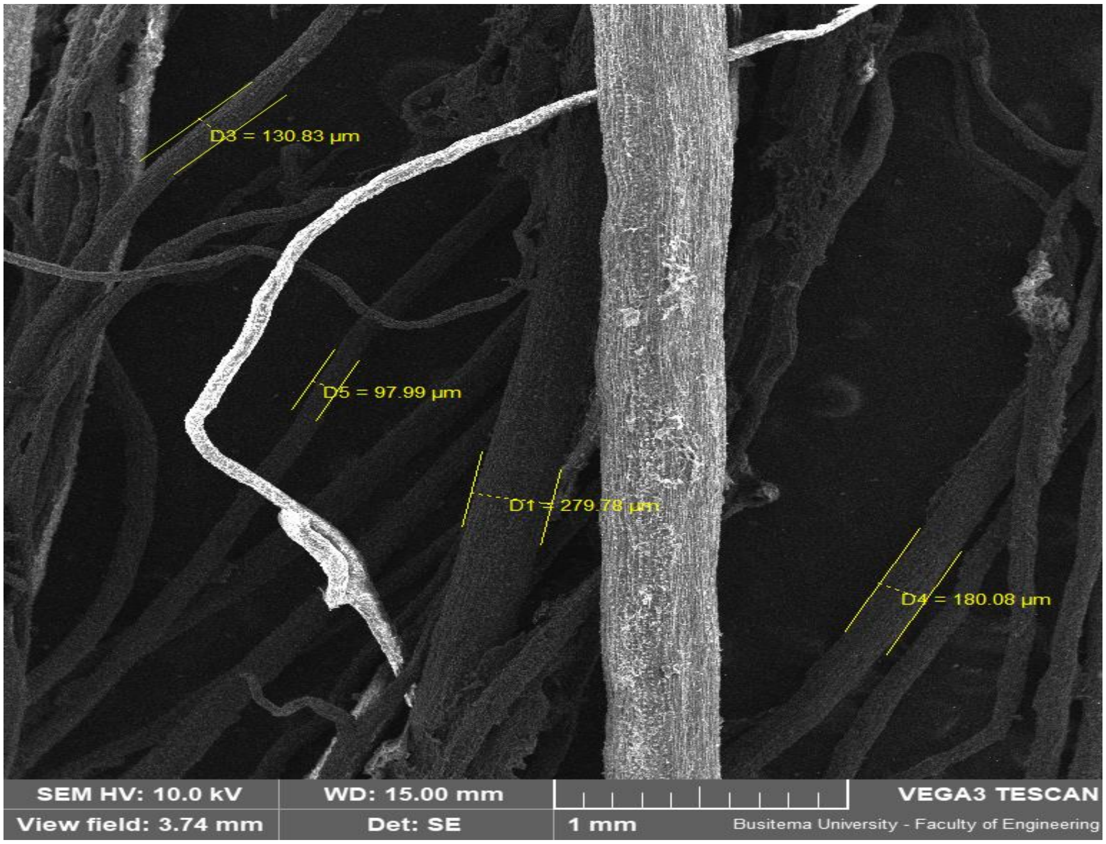

Figure 3-1 Fiber diameter measurement

3.6.2 Linear density

Coir fiber linear density was determined from the measurement of fiber mass per unit length in accordance with ASTM D1577 standards. A precision balance with a tolerance of 0.0001g was used to weigh the mass of fiber bundles within the relative humidity of 65% and temperature of 21°C. Ten samples of fibers from both mature and immature were weighed and their length was measured using a stainless-steel ruler.

The linear density of each fiber was calculated using Equation 3:

$$Linear\ density = 9000\ x\ \frac{W}{L\ x\ N}\quad \text{tex} \qquad \text{Equation 3}$$

Where W- mass of bundle specimen, mg

L - length of bundle specimen, mm, and

N - number of fibers in the bundle specimen

3.6.3 Fiber density

The density of coir fibers was determined by measuring the mass and volume of a bunch of coir fibers according to ASTM D861-01a standards. A precision balance with a tolerance of 0.0001mg was used to weigh the mass of fiber bundles within the relative humidity of 65% and temperature of 21°C. Ten samples of fibers from both mature and immature were weighed and their length was measured using a stainless-steel ruler. The diameter of coir fibers was measured using SEM images obtained from TESCAN VEGA 3 Scanning Electron Microscopy. The density of each fiber was calculated using Equation 4:

$$\rho = \frac{M}{V} \qquad \text{Equation 4}$$

Where ρ – Density (g/m^3)

M - Mass (g)

V – Volume (m^3)

Volume of the fiber was obtained by multiplying the length and cross section area of the samples.

3.6.4 Fiber moisture content

The amount of water absorbed by the textile fiber depends on the properties of the fiber in terms of chemical and physical structure. Temperature and humidity of surroundings also affect moisture regain of fiber. Moisture content of the fibers was determined using a dry oven and a digital scale in accordance with ASTM D2654 standards.

A sample of coir fibers were conditioned under standard atmospheric conditions for 24 hours and then weighed on an analytical scale. The fibers were then put in an oven at temp of 105°C for 2 hours. The oven dry weight was measured thereafter at 15 minutes intervals to ensure that the oven dry weight is constant. The fibers were then weighed and mass noted. The moisture content was calculated using equation 5 below:

$$MC = \frac{loss\ in\ moisture}{initial\ weight\ of\ sample}\ x\ 100 \qquad \text{Equation 5}$$

Where MC = Moisture content in percentage

Loss in moisture = initial weight (g) - final weight (g)

Initial weight = weight of conditioned sample before drying (g)

Final weight = weight of sample after drying (g)

The weight of water in the fiber was determined by subtracting the mass of oven dried fibers from the mass of conditioned fibers before drying.

3.6.5 Tensile strength

Tensile strength testing for treated and raw coconut fiber from immature and mature husk wastes was determined from the breaking load and elongation at break of single fiber performed using Electronic single fiber strength tester Model YG003E, Figure 3-3. The test on tensile strength was done in accordance with ASTM D3822 standards for testing single fiber tensile strength. The fibers were clamped on the holding jaws in conformity to a good gripping and straight direction to the test clamps as shown in figure 3-3b. The pulling force, speed and gauge used were set at 100 cN, 200 mm/min and 100 mm respectively.

Tensile test is the measurement of the fiber to the extent in which it can bare the applied loads. The breaking strength upon applied force for both raw and treated fibers was conducted and automatically recorded by the machine. Three specimens of 10 cm from both raw and treated fibers were taken and average breaking strength was determined.

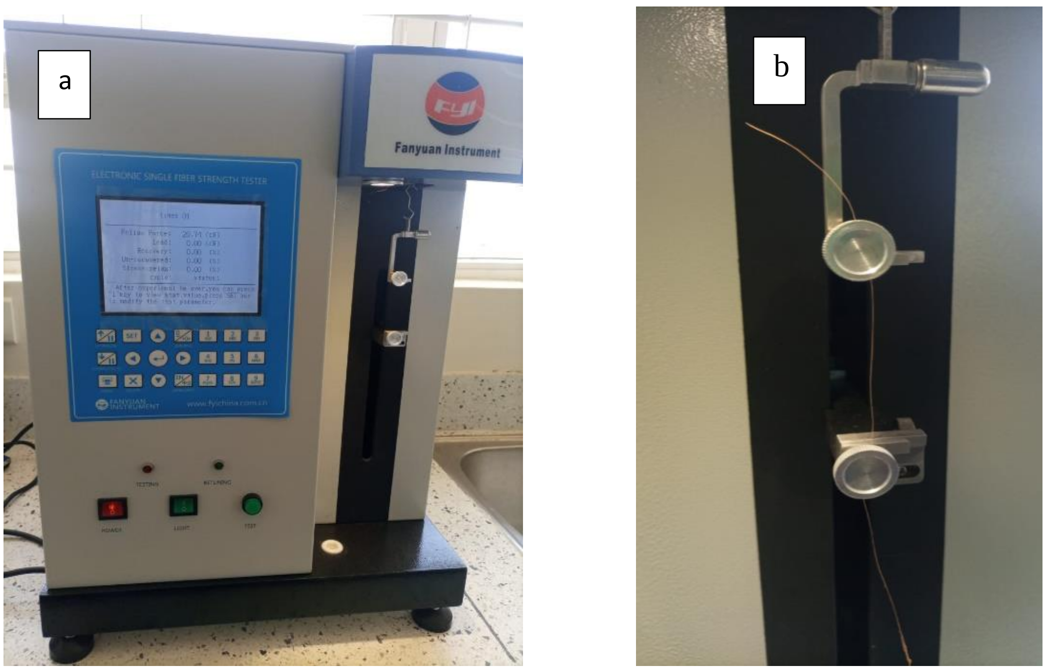

Figure 3-2 Single fiber Tensile strength testing (a) the screen and (b) clamping of the fiber

Using Equation 6, the tensile strength was calculated by dividing the applied load by the average cross-sectional area of the fiber.

$$\sigma = \frac{F_{max}}{A} \qquad \text{Equation 6}$$

Where σ – Tensile strength
F_{max} – maximum breaking force
A – fiber average cross-sectional area

The cross-sectional area of each fiber was determined by using Equation 7

$$A = \pi \left(\frac{d}{2}\right)^2 \qquad \text{Equation 7}$$

Where d - is the average diameter of fiber

The shape of single fiber bundles was considered to be cylindrical in the calculation of fiber cross sectional area. Similar assumption has been made by several studies as stated by (Rosa et al., 2010).

3.6.6 Scanning Electron Microscopy

Raw and treated fibers were both analyzed morphologically using TESCAN VEGA 3 scanning electron microscopy shown in Figure 3-4. The instrument has a resolution of 2nm and operates at 30keV with a magnification of 1x up to 1000000x. This makes the instrument a versatile multifunctional tool in which images of sample surface structure and morphology with high resolution are obtained.

Figure 3-3 Tescan Vega 3 SEM

Coconut fibers for the four notations were cut into small pieces so as to fit the specimen holder then inserted into the specimen chamber as shown in Figure 3-5. Images were acquired and analyzed using an inbuilt integrated software and displayed on the computer screen. A width difference of 15.00 mm, voltage of 10.0 kV and a magnification of 1.0x to 10kx depending on the image was used.

Figure 3-4 Fiber sample placement in the microscope

3.6.7 Infrared spectroscopy

Raw and treated samples from both immature and matured coconut fibers were analyzed by infrared spectroscopy (FTIR) using JASCO FT/IR-6600 type A Spectrometer serial number A027761790 as shown in figure 13. The spectrometer has a wavelength range of 7,800 cm^{-1} to 350 cm^{-1}. Both raw and treated samples for matured and immature coconut fibers were analyzed. The fibers were cut into small pieces and weighed to 1mg and placed in sample holder then inserted into the sample compartment. The parameters were set and then a spectrum measurement started by running the program which was displayed on the screen of a computer. The equipment had an integrated measurement and analysis program. Figure 3-6 and Figure 3-7 show infrared spectroscopy of coconut fibers using Jasco FTIR.

Figure 3-5 Jasco FTIR

Figure 3-6 Infrared spectroscopy of coconut fibers using Jasco FTIR

3.6.8 Thermogravimetric Analysis (TGA) characterization

TGA was performed using a PerkinElmer STA 6000 thermogravimetric analysis instrument, in a Nitrogen atmosphere, at a heating rate of 20 °C/min from 25 °C to 700 °C to obtain derivative curves for the fibers. All samples were analyzed in powdered form, previously segregated in a mesh sieve. The sample weight of 28mg was used which was placed on a ceramic sample holder pan kit. The cycle took one hour and 20 mins both for heating and cooling. Figure 17 shows a thermal analyzer that was used for TGA testing of coir fiber.

Figure 3-7 PerkinElmer simultaneous thermal analyzer

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

Immature coconut husk wastes were collected along the Kenyan coastal region and fibers extracted from the husks. Fibers from mature coconut husk wastes were bought from a local coir processing company. The physical and mechanical properties of husk waste fibers were determined and analyzed. The characterization included fiber diameter, linear density, fiber density, coir moisture content, tensile strength, SEM, FTIR, and TGA.

4.2 Quantification of Coconut Husk Waste Generation

Coconut husk waste generation is paramount in determining sustainability in utilization of the waste for value addition. Mapping was done to determine the common locations in which coconut tender water is sold for the fixed location vendors as well as the areas where vendors with no fixed point of sale are likely to be found.

The data was collected using both open ended and close ended questionnaires and entered on excel. Target respondents were 45 and only 32 were willing to participate in the survey giving a 71% response rate. The analysis of research data collected through questionnaire was done using SPSS version 20 and Microsoft excel 2016. Simple descriptive statistics and analytical methods were used where frequency tables, percentages, bar charts, histograms and pie charts were generated.

Questionnaires were issued to vendors selling coconut tender water to determine the source of the immature coconut, varieties, location of sale, the amount of coconut immature husk waste produced and waste management in the study's target locations. Secondary data was also used to estimate the quantities of coconut fruit production in the Kenyan coastline as shown in Table 4-1

Table 4-1 Coconut production in Kenyan coast region

Reference	**Data collection method used**	**Coconut Acreage (Ha)**	**Coconut tree population (Million)**	**Nut production**
NOCD annual market research report 2016	Interviews and survey	-	-	1760 nuts/acre
AFFA year Book of statistics 2014	survey	176669	-	246 million
National coconut survey 2013	survey	176,699 (436634 acre)	9.9	-
Coconut mapping guidelines for cultivation of coconut in the coast region of Kenya 2013	questionnaires	-	-	50-200 nuts/tree/year
ABD – DANIDA/CDA coconut survey 2007	survey	-	7.4	-

It is apparent from the Table 4-1 that coconut palm tree population along the coast has gradually increased with 9.9 million trees in 2013 up from 7.4 million trees in 2007. This increase result to more nut production and consequently an increase in husk waste from both immature and matured nuts. The ratio of mature to immature waste is high since there is a chain of utilization of the brown coconut and its byproducts.

Table 4-2 Comparison of mature and immature coconut fruit

Type of fruit	**Harvesting age**	**Price/nut (KES)**	**Predominant usage**	**Data collection method used**
Matured nut	12 months	30-60	Copra, fiber, oil, shell,	Interviews and Survey
Immature nut	6 - 8 months	100-150	Tender water	Interviews and Survey

Immature coconut fruit is gradually getting preference due to the high economic value compared to the matured nut. From the market analysis, an Immature coconut for tender water costs a minimum of 100 Kenya Shillings while the matured one cost as low as 30 Kenya Shillings for the small size. The age for harvesting an immature nut is eight months while for matured takes a year. Once the industry realizes significant quantities of immature fibers there could be diversity in terms of coconut fibers application. Table 4-2 shows a price comparison for immature and mature coconut fruit along the Kenyan coast region.

The prices for immature coconut get higher during festive seasons when the coast registers high number of visitors both local and international. The sale of nuts for tender water is common along the public beaches, Mama Ngina drive and at the Mombasa central business district. The mature nuts as well get considerably a lower market and the pricing depends on the size of the nut. It is commonly sold at the central business district particularly the bus stations where the local tourist board back to the upcountry. A bunch of between 4 - 6 nuts go for a maximum of two hundred Kenyan shillings. Husks waste from immature nuts are therefore attributed by economic reasons where the price of an immature fruit attracts high returns than for mature nut.

4.2.1 Respondents demographic characteristics

The respondent's socio-demographic characteristics of respondents revealed a male dominance in tender water business. Probably this is attributed to the challenging nature of business particularly the opening up the fruit for the client to access the water. From the analysis, majority of the respondents were between 30-39 years which translated to 46.9% of the total responses as shown in Table 4-3. This means that majority of vendors are youth who are more aggressive and energetic which translate to high volume of sales of tender water and consequently higher waste generation.

Table 4-3 Respondents age distribution

Age	20-29	30-39	40-49	50-59	Total
Frequency	2	15	12	3	32
Percentage	6.3	46.9	37.5	9.4	100
Cumulative Percentage	6.3	53.1	90.6	100	

There were three categories on Education Level of the respondents. Primary level, post primary and those who never received any form of education. 50% of the respondents attained primary education as their highest level of education while 6.25% received post-primary education. Majority of the respondents have no formal education as shown in Figure 4-1. This implies that the greater number of vendors in coconut tender water business get involved in this venture due to lack of funds to continue further their studies. Since they lack qualification for formal employment, there are higher chance that they will be longer in this business to sustain their livelihood hence gradual waste generation. Out of the 32 respondents, 42.75% lived in Mombasa, 37.54% in Kwale and 18.75% lives in Kilifi as shown in the Figure 4-2.

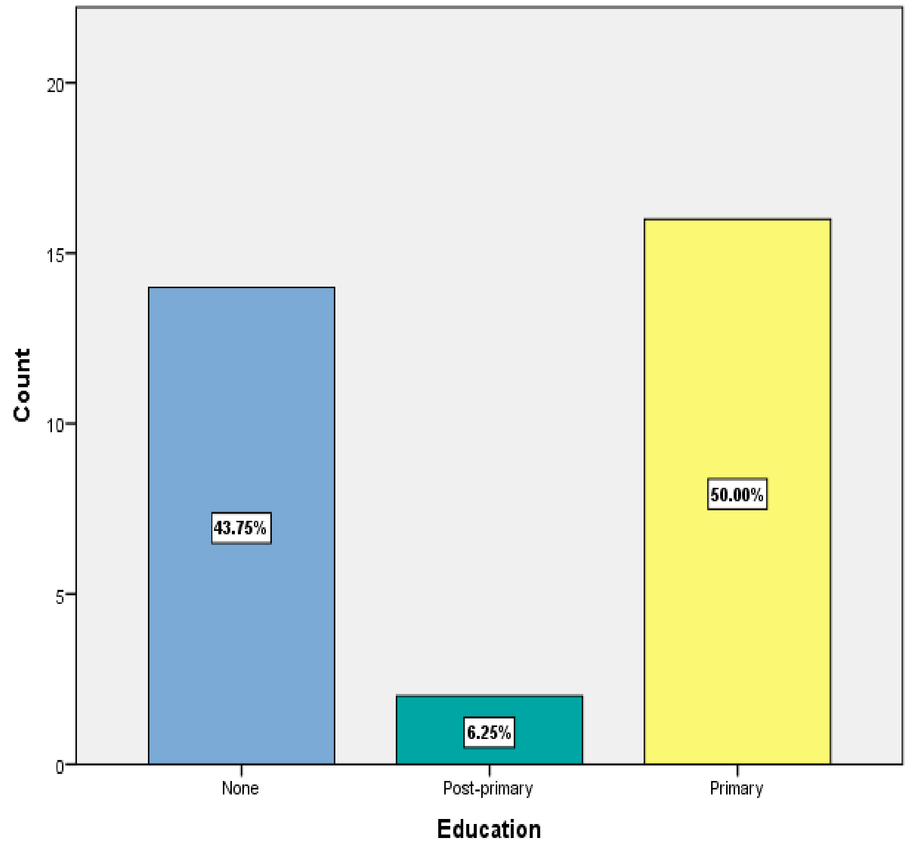

Figure 4-1 Respondents level of education

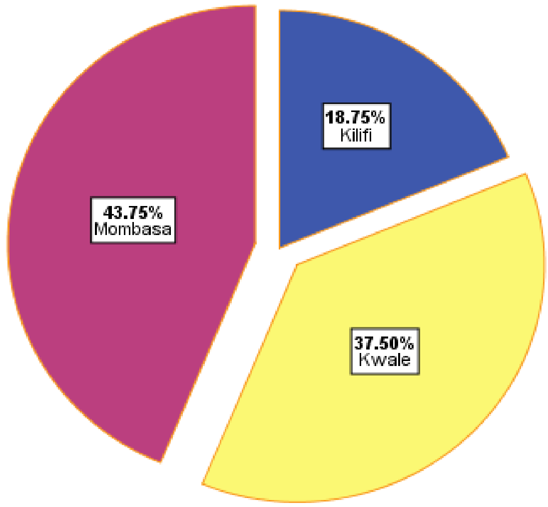

Figure 4-2 Respondents county of residence

Majority of the traders are located in Mama Ngina which translates to 15.6% of the respondents. Likoni and Mtwapa recorded 3.1% while Bamburi, Diani and Digo Road in Mombasa recorded 18.9% (6.3% each). Ukunda and Kenyatta Public beach recorded 12.5% each. Table 4-4 below shows the detailed summary.

Table 4-4 Coconut tender water business location

Location	**Frequency**	**Percentage**	**Cumulative Percentage**
Likoni	1	3.1	3.1
Mtwapa	1	3.1	6.3
Bamburi	2	6.3	12.5
Diani	2	6.3	18.8
Mombasa town cbd	2	6.3	25
Likoni	3	9.4	34.4
Mama ngina drive	5	15.6	50
Marikiti	2	6.3	56.3
Mtwapa	3	9.4	65.6
Mwembe tayari	3	9.4	75
Public beach	4	12.5	87.5
Ukunda	4	12.5	100
Total	**32**	**100**	

4.2.2 Coconut waste generation

From the survey, majority of immature coconut fruits are sourced from Kwale which is represented by over 56.3% of the responses. However, 12.5% of the respondents' source immature coconut fruits from both Kwale and Kilifi. 31.3% source entirely from Kilifi as shown in Table 4-5.

Table 4-5 Source of immature coconut fruits

Region	Kilifi	Kwale	Kwale and Kilifi	Total
Frequency	10	18	4	32
Percentage	31.2	56.3	12.5	100
Cumulative Percentage	31.2	87.5	100	

Apparently, majority of the respondents don't know the variety of the coconut they are selling with a paltry 3.13% who could describe the palm tree which was classified as the East African Tall as indicated in Figure 4-3

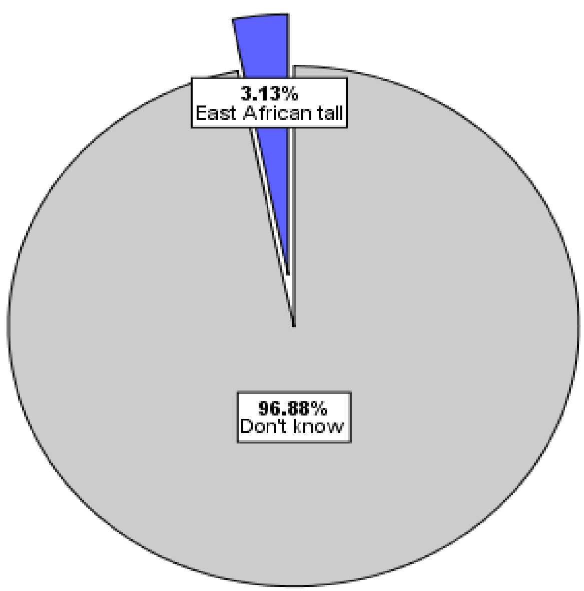

Figure 4-3 Identification of fruit variety by traders

The means of transport of immature coconut fruits from the source to the market is either by tri-cycle bike (tuktuk) or a public serving vehicle (PSV) locally referred to as matatu which correspondents to 56% and 44% respectively. The vendors with no fixed location for sale of the fruits use a handcart to transport the fruit during sales. However, the mode of transport of choice from the source to the various sales points within the central business district was either tri-cycle bike or a public serving vehicle as shown in Table 4-6. Because of the bulky nature of the coconut business, the majority of respondents prefer to sell at a fixed location.

Table 4-6 Mode of transporting coconut fruit to market

Transport mode	Frequency	Percentage	Cumulative Percentage
PSV	14	43.8	43.8
Tri-cycle	18	56.3	100.0
Total	32	100.0	

According to respondents, business in immature coconut fruit sale differs from seasons to season, reaching its peak of sales during festivities and holidays when the coast region registers high number of tourists both local and international. The sale of nuts for tender water is common along the public beaches, Mama Ngina drive and at the Mombasa central business district. The months of April, August and December were reported to register high sales as shown in Figure 4-4. Majority of respondents which constitute 59.4% have been in coconut business between 5 to 7 years as shown in Table 4-7.

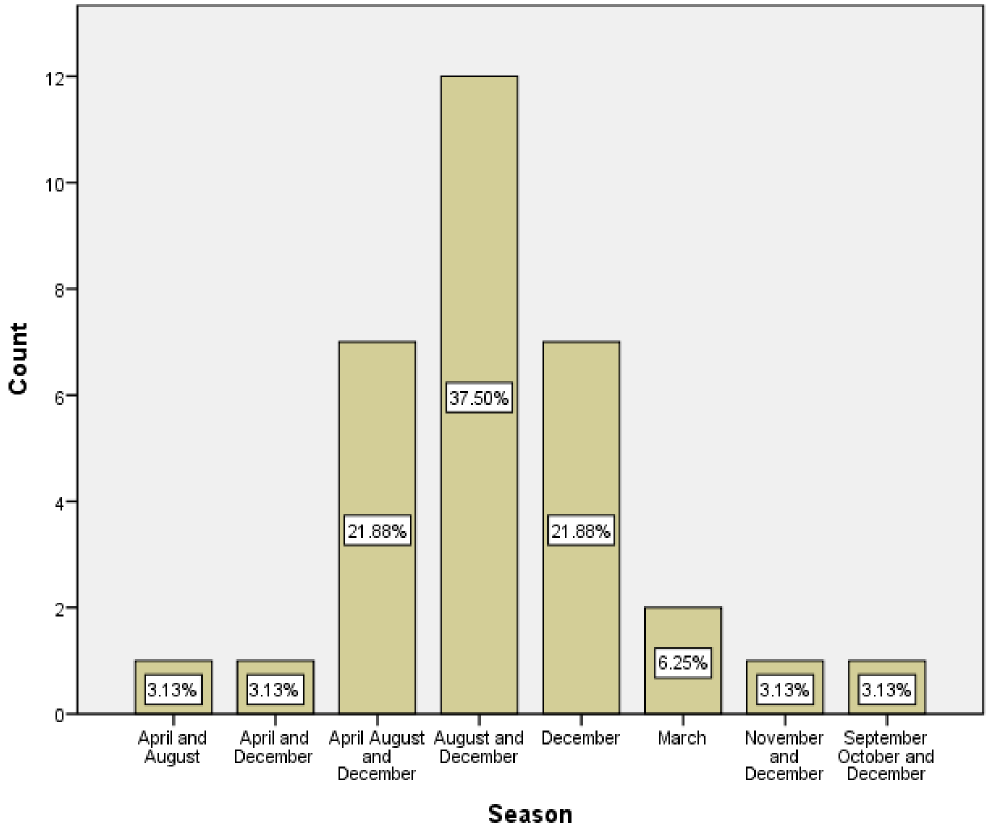

Figure 4-4 Coconut fruit high sale months in Kenya coast region

Table 4-7 Respondent duration in immature coconut business

Age	Frequency	Percent	Cumulative Percent
2-4 years	11	34.4	34.4
5-7 years	19	59.4	93.8
8-10 years	2	6.3	100.0
Total	32	100.0	

Table 4-8 Quantity of immature coconut sales per day

Type of coconut	N	Minimum	Maximum	Mean	Std. Deviation
Immature	32	30	120	75.94	24.998

From the analysis the average sale of coconut immature fruit was 75 pieces per day per vendor during the high seasons as shown in Table 4-8. A daily estimate of waste by the number of vendors who responded is husk waste 2400 and 7200 monthly. Taking average weight of 0.973269 kg from the sample of 384 husk waste, the estimated husk generated is 70 tonnes per month.

Of the waste generated, 43% dump the wastes haphazardly in the open environment, 37% store for collection by waste handling agencies and 20% sell the waste. The collection is majorly done by the county government which attracts a fee for disposal which is incorporated during acquisition of business permit. All the correspondents were aware of at least one use of husk waste generated where majority mentions fuel and ornamental use.

It is evident that there is significant waste generated from the coconut husk waste resulting from coconut tender water consumption. The waste generated was not properly managed where the majority of the vendors dump the husk waste in the open environment in undesignated dumping location.

4.3 Collection of Husk Wastes

A total number of 384 green coconut husk wastes were collected from three locations within coast region namely Mombasa, Kwale and Kilifi counties. Figure 4-5 shows images of coconut husk waste under sun drying. The husk wastes were dried for six months on the sun and the weight taken before drying and during drying at an interval of four weeks for the six months.

The average weight for the 384 husks waste before drying was 973.37 ±15.3 g with a maximum and minimum weight recorded of 2136g and 323g respectively. It is desirable to have a classification of the husk wastes in terms of small, medium and large. However, the exact range and threshold for each category was a challenge hence the general classification.

The mean weight after drying for the 384 dried husks waste was 223.75 ±8.5g with a maximum and minimum weight recorded of 578g and 84g respectively. Figure 4-6 shows weight measurement of coconut husk waste.


Figure 4-1 Drying of immature coconut husk waste

Figure 4-2 Weight measurement of coconut husk waste

4.4 Extraction of coconut fibers

Figure 4-7 and 4-8 shows images of fiber screener used for fiber separation after extraction.

Figure 4-1 Extracted immature coconut husk fibers

Figure 4-2 Collection of cocopeat

4.5 Fiber Characterization

4.5.1 Fiber diameter

Natural fibers are characteristically non-uniform with large fiber to fiber variation. These variations are brought about by a number of factors which can be categorized into agricultural practices, physical factors and processing factors. The three main factors are a justification for the variability of all-natural fibers (Duval et al., 2011); (Malkapuram et al., 2009). The average and standard deviation of four diameter values from immature to mature were calculated over a gauge length of 100 mm for each strand as shown in Table 4-9 and it is consistent to the range of coir fiber diameter given by various researchers as Table 2-6 in the Literature review.

Table 4-1 Fiber diameter for treated and untreated mature and immature fibers in μm

Fiber type	Sample 1	Sample 2	Sample 3	Sample 4	Average
Immature untreated	244.53	138.63	216.27	190.32	197.44 ±45.02
Immature treated	153.44	166.97	155.81	150.38	156.65 ±7.23
Mature untreated	116.18	106.38	123.36	146.43	123.09 ±17.05
Mature treated	279.78	130.83	180.08	97.99	172.17 ±79.28

4.5.2 Linear density measurement

Coir linear density for the different coir samples was determined in accordance with ASTM D1577. The calculated linear densities were 540 denier and 855 deniers for immature and mature fiber respectively. The mass per unit length for mature coconut fibers is higher than that for immature coconut fibers. This can be attributed to the difference in maturity of the fibers. Immature coconut fiber is extracted from coconuts before they ripen. The fibers are white or light brown in color, smoother and finer in texture, but also weaker. Mature coconut fibers are extracted from fully matured coconuts.

4.5.3 Fiber density

The density of the coir fibers was measured by obtaining the mass of a bundle of 10 fibers from the raw and treated fibers of immature and mature coconut fibers. The length of the fibers was also determined for calculation of fiber volume. The volume obtained and the mass of the fibers were used to calculate density of fibers. The determined density for fibers was 1306.51 kg/m^3 for immature untreated, 1556.58 kg/m^3 for immature treated, 2941.38 kg/m^3 for mature untreated and 1073.30 kg/m^3 for mature treated respectively. These values are within the values reported by other researchers (Bai et al, 2019; Ticoalu et al, 2010; Adeniyi et al 2019; Bui et al, 2020).)

The density of mature untreated fibers was found to be relatively high when compared to the determined densities for mature treated, immature raw and treated fibers. This variation can be attributed to the chemical treatment of the fiber which altered the diameter, a dimension used in the calculation of density. According to (Madueke et al., 2021), the presence of debris or residual components on the fiber, fiber species, and the level of maturity of the fiber all influence fiber density.

4.5.4 Moisture content

The coir fiber moisture content was determined by oven drying method. The moisture content of raw and treated coconut fiber was determined by calculating the loss in weight using air oven drying method at 105 °C for 2 hours then at an interval of 20 minutes up to constant weight loss. The percentage of moisture content calculated for coir fibers was 9.08% for immature raw, 7.91% for immature treated, 11.04% for mature raw and 8.62% for mature treated fibers respectively.

The results show that alkali treated coir fibers had lower moisture content than untreated fibers. This is so due to the reduction of the free –OH groups from surface of fibers attributed to treatment of coir fibers which consequently minimize moisture absorptions

(Adeniyi et al., 2019). Absorption of moisture from the surrounding atmosphere is function of –OH group present in the polymeric structure of coir fiber (Pérez-Fonseca et al., 2016).

4.5.5 Tensile strength

Three specimens of 10 cm from both raw and treated fibers were taken and the average breaking load was determined as shown in table 4-10;

Table 4-2 Breaking load for treated and untreated mature and immature fibers

Fiber type	**Sample 1 (cN)**	**Sample 2 (cN)**	**Sample 3 (cN)**	**Average (cN)**
Immature untreated	318.20	318.57	321.77	319.51 ±1.96
Immature treated	340.65	340.65	340.14	340.48 ±0.29
Mature untreated	318.09	317.86	317.53	317.83 ±0.28
Mature treated	343.36	340.65	332.91	338.97 ±5.42

An electronic Single Fiber Strength Tester was used to determine the breaking force of coconut fibers. The breaking force was used to calculate the strength of the fiber.

The breaking force was recorded automatically by the Electronic single fiber strength tester. The average breaking load for each fiber category was used to calculate the tensile strength. The determined tensile strength for the coir fibers is shown in Table 4-11.

Table 4-3 Tensile strength for coir fiber

Fiber Type	Tensile strength (MPa)
Immature untreated	104.36 ±1.96
Immature treated	176.66 ±0.29
Mature untreated	267.10 ±0.28
Mature treated	145.60 ±5.42

Fiber tensile strength is the measurement of the extent of fiber to bear the applied loads. The tensile strength of single fibers is pivotal to the reliability with which fibers are processed into products, as well as the standard grading of these products. The tensile properties of natural fibers are largely dependent on test conditions, fiber extracted species, and dimensions of the fiber (Bezazi et al., 2014).

Table 4-11 shows the fiber breaking load before and after alkali treatment for both immature and mature fibers. The fiber treated with alkali treatment appeared to slightly enhance the strength of the fibers in comparison with the untreated fibers in the case of immature coconut fibers. The case is different with mature fibers where raw fibers show high strength compared to treated fibers. This can be attributed to the non-uniformity of the fiber with intrinsic diameter in that irregularities in the fiber increase defects in the fiber and vice versa. The alkali treatment also significantly increased the tensile strength of immature fibers. This resulted in the elimination of wax and other impurities thus exposing the amorphous cellulose.

Studies by Mohanty et al 2011 reveal that NaOH treatment at high temperatures can remove lignin and depolymerize the native cellulose, which results in reduced fiber strength. Lignin removal results in higher fiber strength because lignin is stiff and brittle hence breaking off easily. The lower the lignin percentage the higher the fiber strength (Arsyad, 2017). The fiber strength of treated and raw mature and immature coconut fibers can be explained by the nature of their SEM micrographs. The diameter of the treated fibers was lower when compared with untreated. Izani and colleagues reported that the tensile strength dependent on the diameter of the fiber (Izani et al., 2013).

4.5.6 Morphological characterization of coconut fibers

The SEM micrographs of untreated and treated immature fibers are displayed in Figures 4-9 and 4-10 respectively.

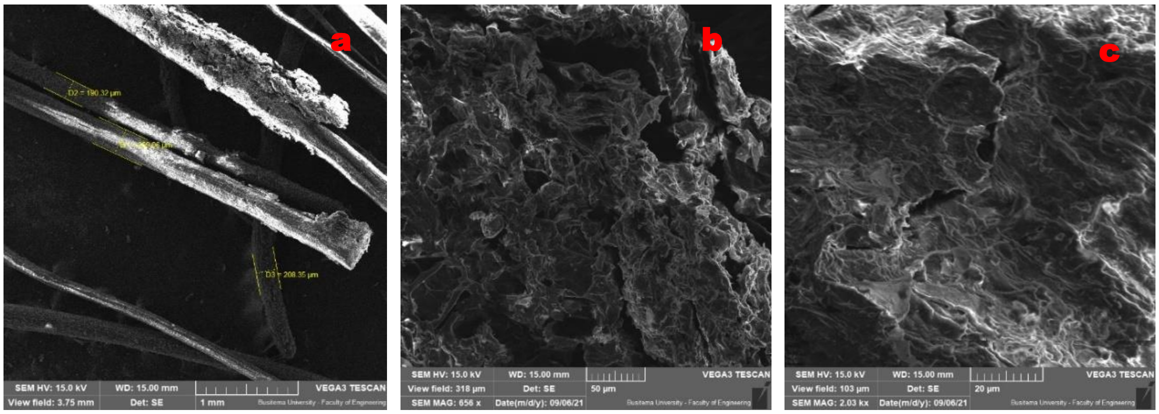

Figure 4-1 SEM micrographs of untreated immature coconut fibers (a) diameter measurement (b) and (c) surface morphology

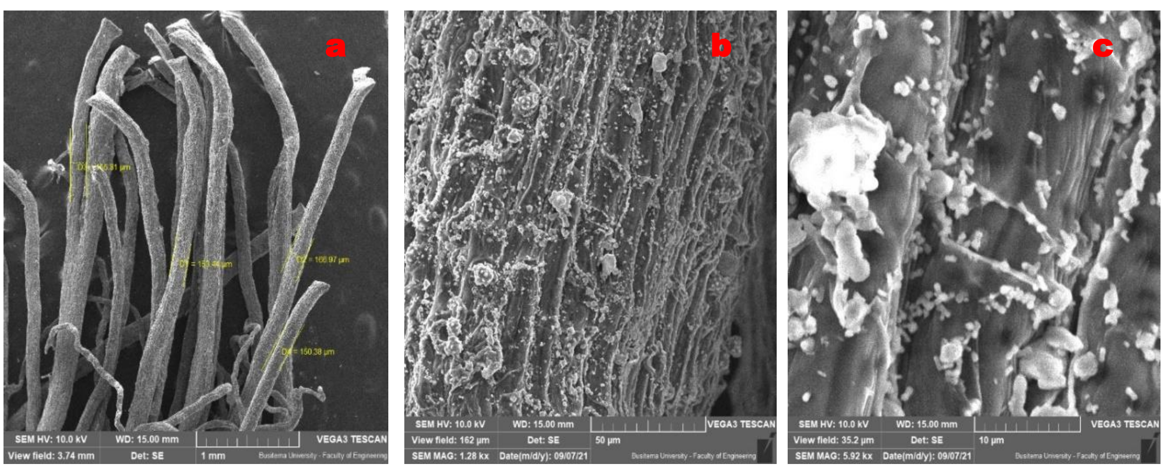

Figure 4-2 SEM micrographs of treated immature coconut fibers (a) diameter measurement (b) and (c) surface morphology

Figures 4-9 b and c display the morphology of the untreated immature fibers with smooth surface unlike the rough surface displayed by alkali-treated fibers shown in Figures 27 and c. The untreated coconut fibers contain wax, lignin, cellulose, hemicellulose, and other impurities; therefore, a fine structure is observed in Figure 4-10 (c). The treated coconut fibers show the effect of the alkali treatment which disrupted the fine surface revealing rough surfaces. According to (Arsyad, 2017), alkali treatment yielded better interlocking sites and a large cellulose volume. The rough surface of the fiber after alkali treatment differs greatly from that of the untreated fibers. The elevated surface roughness of coconut fiber is a consequence of enhanced cellulose exposure in the fiber (Arsyad et al., 2015). The diameter of the untreated immature fibers decreased after alkali treatment. The treated fibers had a diameter ranging between 150 – 167 µm (Figure 4-10 a) while that of untreated was 190 – 260 µm (Figure 4-9 a).

The SEM micrographs of untreated and treated mature fibers are displayed in Figures 4-11 and Figure 4-12 respectively.

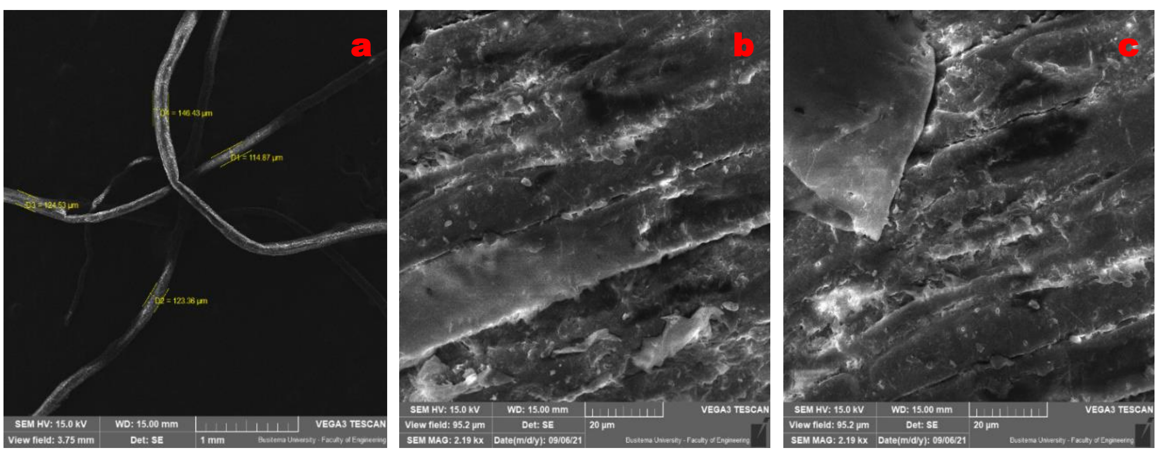

Figure 4-3 SEM micrographs of untreated mature coconut fibers (a) diameter measurement (b) and (c) surface morphology

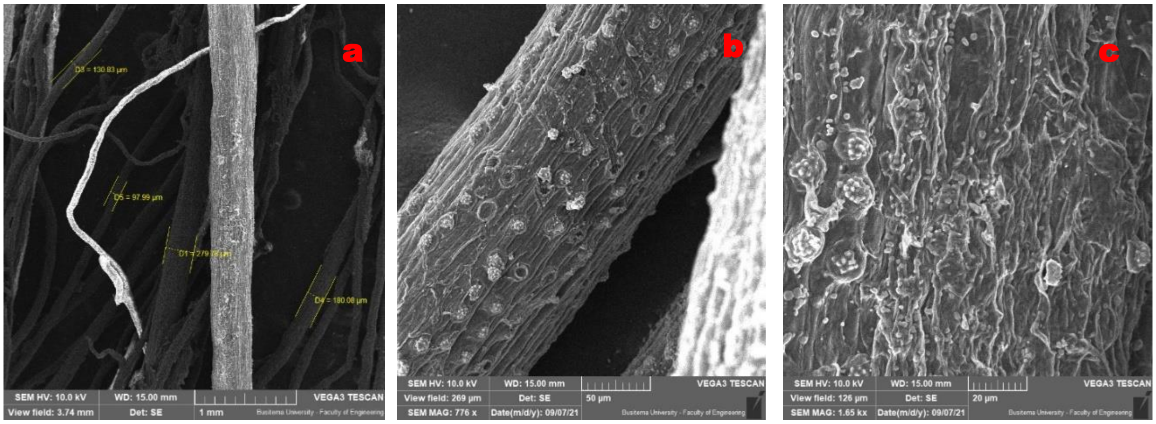

Figure 4-4 SEM micrographs of treated mature coconut fibers (a) diameter measurement (b) and (c) surface morphology

The micrographs of the untreated mature fibers have a diameter in the range of 123 – 146 µm (Figure 4-11a) while that for the treated was in the range 97 – 130 µm as in Figure 4-12a. There was a change in the diameter due to the treatment. The surface morphology of the untreated fibers reveals a fine and smooth surface as shown in Figure 4-11 b and c. This can be attributed to the presence of wax, impurities, lignin, and hemicellulose (Izani et al., 2013).

The treated fibers show a rough and fine surface as a result of the removal of impurities as shown in Figure 4-12 b and c. The sodium hydroxide interacts with the wax, lignin, and other impurities eliminating them thus, the cellulose is much exposed of chemical (Azeez & Onukwuli, 2016). It also decreases fiber diameter and results in a rougher surface. The exclusion of surface contaminants on plant fibers is beneficial for fiber-matrix adhesion because it allows for mechanical interlocking as well as the bonding reaction.

4.5.7 Fourier Transform Infrared Spectrometry

Figures 4-13 and Figure 4-14 shows images obtained using FTIR spectrophotometer for raw untreated coir fiber and alkali-treated coir fibers extracted from immature and matured coconut husk wastes. The notation used for immature coir fiber is IM_untreated and IM_treated for raw untreated and alkali-treated fibers respectively. The notation for matured coir fibers is M_untreated and M_treated for raw untreated and alkali-treated fibers

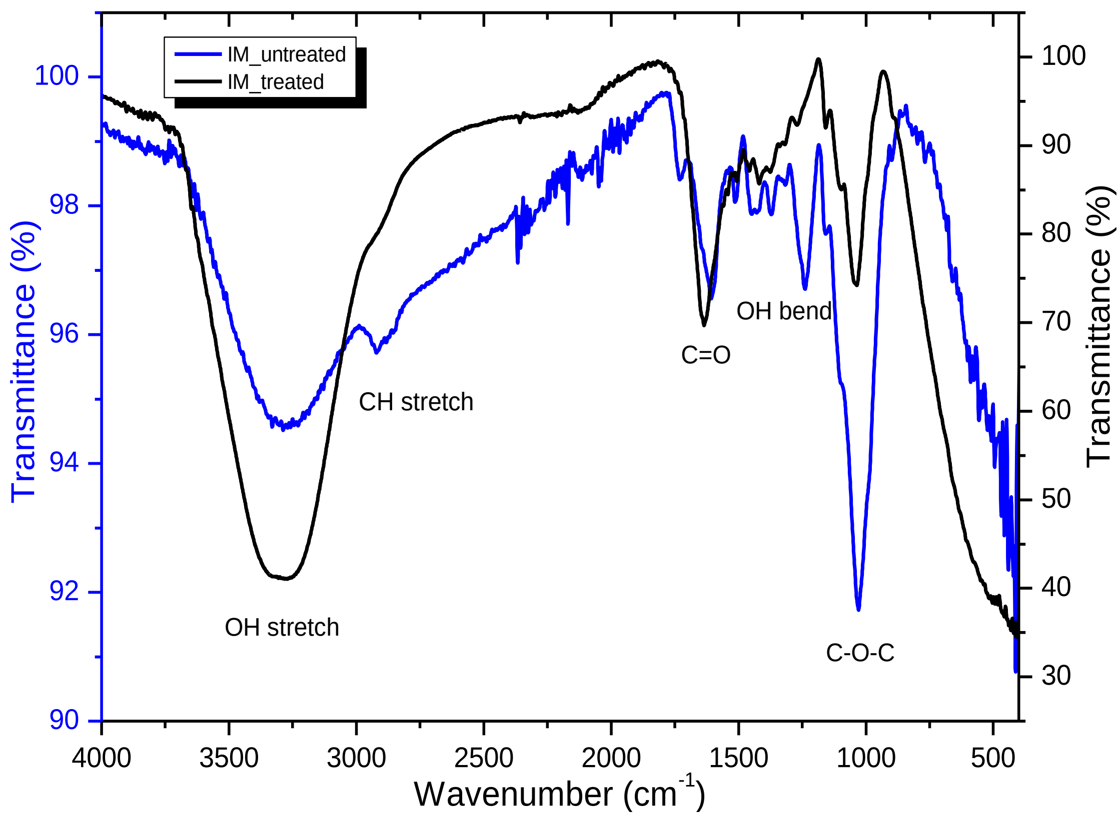

Figure 4-5 Comparison of IM_untreated and IM_treated

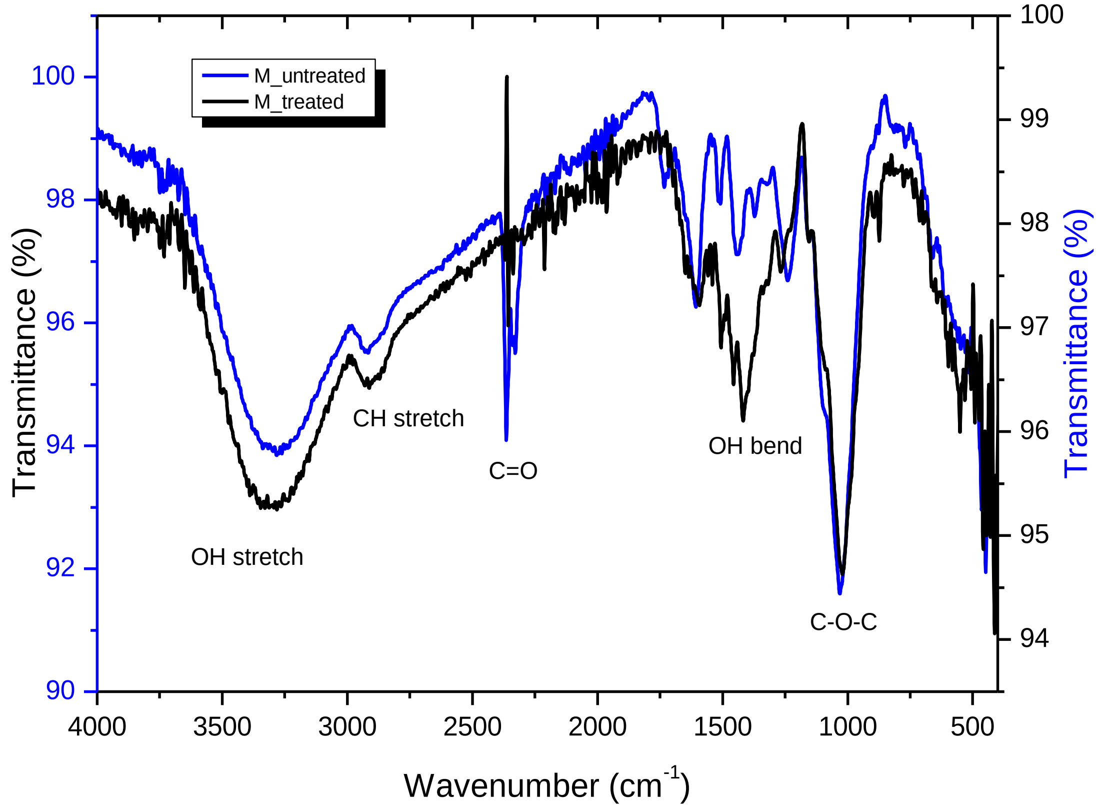

Figure 4-6 Comparison of M_untreated and M_treated

This investigation revealed fundamental differences between the untreated and treated fibers. The treatment with the alkali presented some little changes in FTIR spectra for treated coir fibers. The broadened bands at around 3300 cm^{-1} in both Figure 4-13 and Figure 4-14 were observed in all spectra, indicating the presence of -OH groups in the structure which suggests OH stretching vibration from the cellulose and lignin structure of the fiber (Dharmaratne et al., 2021); (Baskaran et al., 2018); (Rosa et al., 2010). Figure 4-13 shows bands at 1030 cm^{-1} and 1048 cm^{-1} for raw untreated and treated immature coir fibers and Figure 4-14 bands at 1024 cm^{-1} for both raw untreated and treated mature coir fibers. These peaks are attributed to the existence of C-O-C stretch, which arises from cellulosic characteristic peaks (Garside & Wyeth, 2003).

The peak in Figure 4-13 and Figure 4-14 at around 1400 cm^{-1} in all spectra corresponds to the water absorption. The peaks were attributed to the stretching of hydrogen bonds and bending of hydroxyl (OH) groups bound to the cellulose structure. According to (Nurazzi et al., 2021), these results are an indication that the cellulose component was not removed during the chemical treatment carried out on the coconut fiber. (Zuluaga et al., 2009), reported that the vibration at 2900 cm^{-1} to 2850 cm^{-1} shows the existence of –CH groups, where the lignin and waxes were eliminated after the different chemical treatments.

The peaks at 2823 cm^{-1} for untreated fiber and 2786 cm^{-1} for treated immature coconut fibers as shown in Figure 4-13 are distinctive of the carbonyl group found in coconut fiber. The respective peaks for raw and treated mature coconut coir fibers are 2799 cm^{-1} and 2769 cm^{-1} as shown in Figure 4-14. These peaks were attributed to C=O stretching of the ester linkage between the carboxylic groups of lignin and/or hemicellulose. A decrease in the C=O peaks was observed following the chemical treatment. As reported by (Herrera-Franco & Valadez-González, 2005) the decrease was likely due to the partial removal of hemicellulose and lignin, confirming the efficacy of the treatment.

From the Fourier Transform Infrared spectra analysis there is no significant difference in molecular structure between immature and mature fibers. However, there is a slight difference in wavelength range carbonyl stretch of the ester linkage between the carboxylic groups of hemicellulose and lignin. Immature fiber had a spectral of 1623 cm^{-1} and 1786 cm^{-1} for untreated and treated respectively while mature fiber had 2399 cm^{-1} for both untreated and treated fibers. This variation is attributed to fiber maturity

4.5.8 Thermogravimetric characterization

Figures 4-15 and Figure 4-16 show the TGA thermograms and DTGA curves for treated and untreated mature fibers respectively.

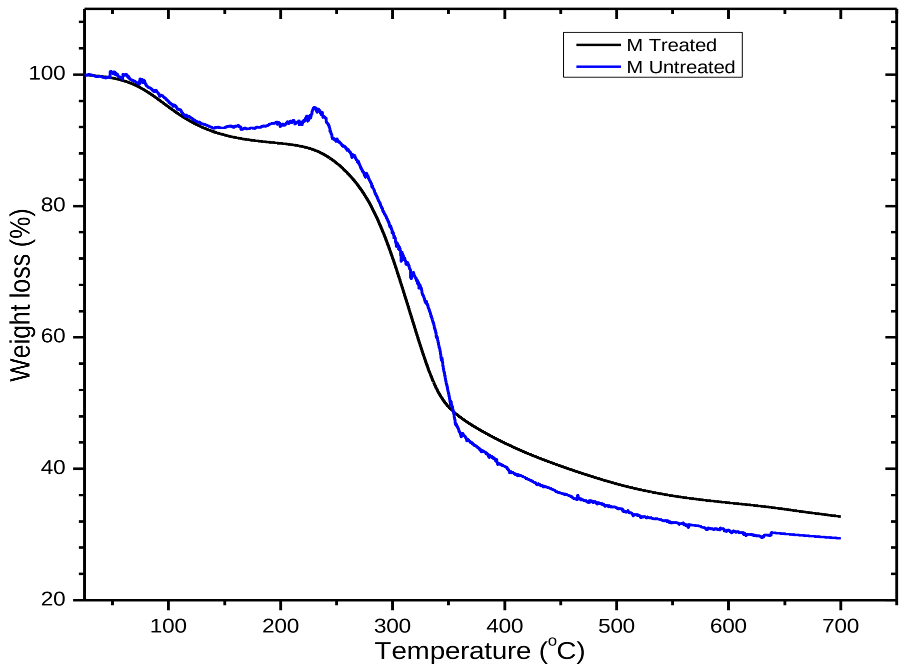

Figure 4-7 TGA thermograms for treated and untreated mature (M) fibers

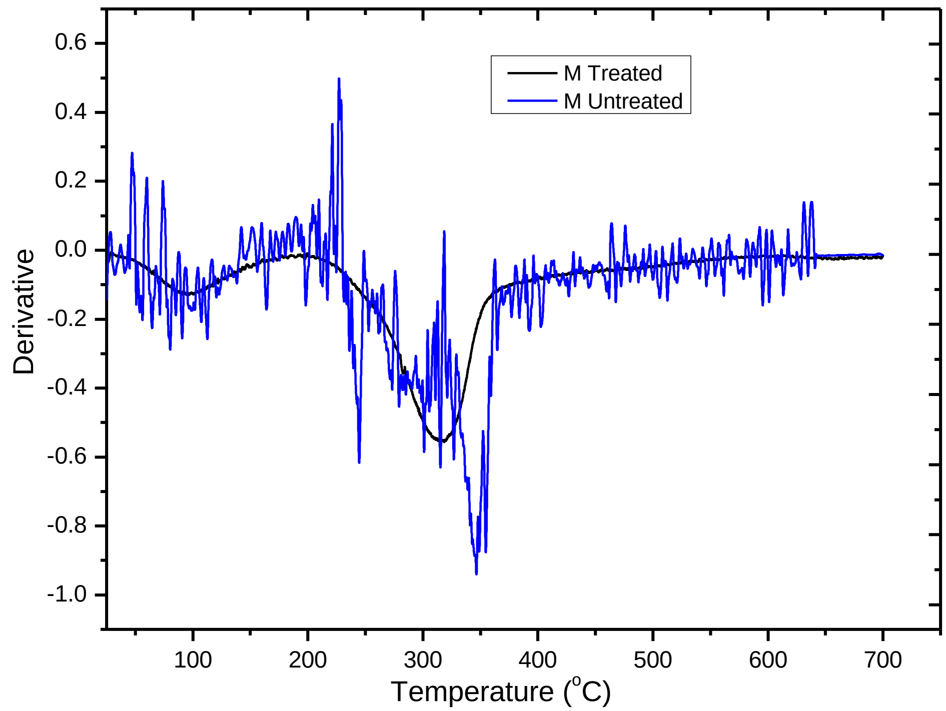

Figure 4-8 DTGA thermogram for treated and untreated mature (M) fibers

Figure 4-15 shows that both raw and treated mature coconut fibers had an initial degradation between 80 °C – 200 °C which is a result of moisture loss of all the fibers. (Mulinari et al., 2011) studied the TGA curves of coconut fibers and associated the degradation at 100°C to loss of water bound in the fibers.

The mature treated fibers display two stages of decompositions only. The second stage has a transition temperature that initiates from 250°C to 360°C, a result of the decomposition of the cellulose materials. (Izani et al., 2013) reported that the decomposition of cellulose for coir fibers to be in the range of 200°C - 400°C. The mature untreated fibers display two more degradation stages. The degradation at 250 - 280°C can be associated with hemicellulose degradation while the decomposition at 290 - 350°C is associated with cellulose decomposition.

The treatment affected the mature fibers leading to an increase in the decomposition temperature. The lignin decomposition was not observed in the treated fibers because the alkali treatment resulted in the elimination of lignin. There was however, an increase in the amount of the ash content from 29% to 32% for mature untreated and treated fibers respectively. The increase could be attributed to sodium ions that require high temperatures to decompose.

The DTGA thermogram for treated fiber show an endothermic peak centered at 95°C that is attributed to moisture loss as in Figure 4-16. The endothermic peak at 322°C corresponds to the cellulose decomposition peak (Poletto et al., 2014). The untreated mature fibers show irregular shaped DTGA thermogram which is attributed to presence of lignin, hemicellulose, ash, and organic matter.

Figures 4-17 and Figure 4-18 show the TGA thermograms and DTGA curves for treated and untreated immature fibers respectively.

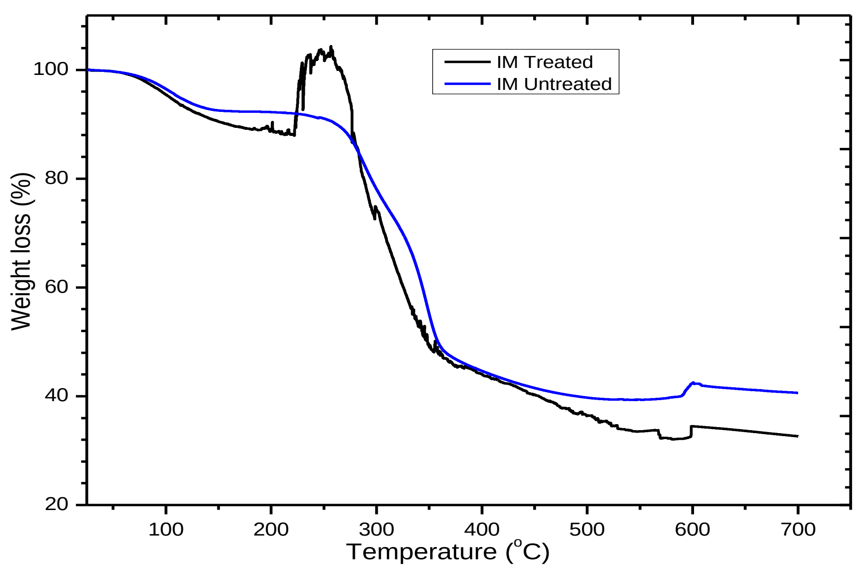

Figure 4-9 TGA thermograms for treated and untreated immature (IM) fibers

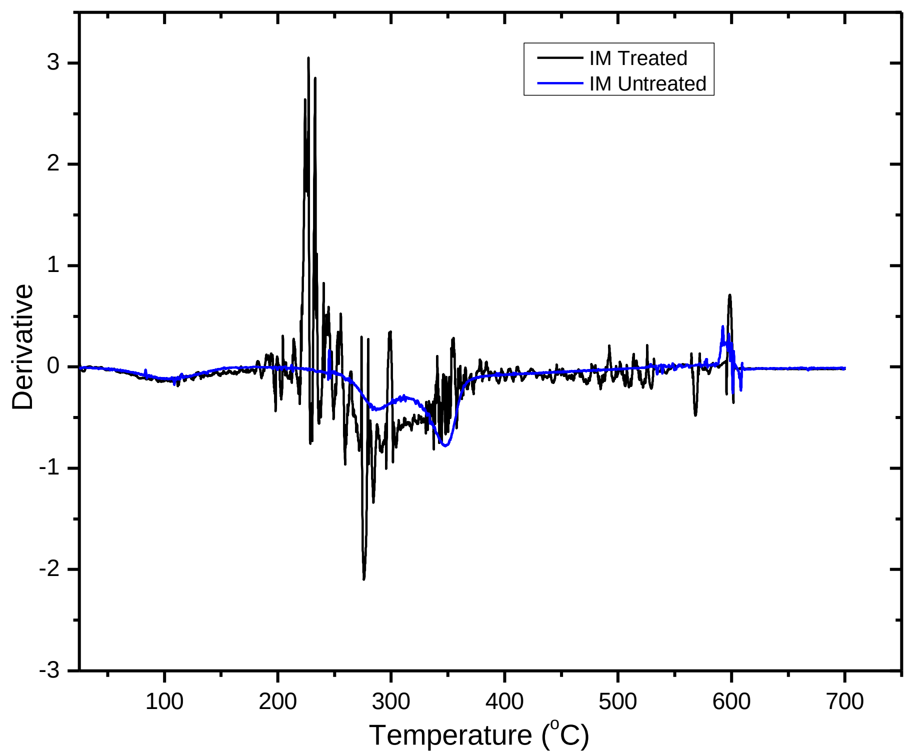

Figure 4-10 DTGA thermogram for treated and untreated immature (IM) fibers

The immature fibers both untreated and treated show initial degradation of 75 ℃ - 210 ℃ that is a result of loss of volatilities and moisture (Figure 4-17). The treated fibers tend to have a high percentage loss of moisture between 280 ℃ - 350 ℃ due to the numerous OH groups in the cellulose structure that form hydrogen bonds with water. The untreated fiber displays the second degradation in the range 280 ℃ - 310 ℃ which is associated with hemicellulose decomposition.

The third degradation happened in the range 315℃ - 350 ℃, which is due to the decomposition of cellulose. In the immature untreated fibers, there is an exothermic peak which is followed by second stage degradation between 280 - 350℃ associated with cellulose decomposition. Lignin decomposition occurs in the range of 250 - 450℃ because it is a stable constituent, therefore, not easily degraded (Saravanakumaar et al., 2018).

The residual ash content was found to be 40 and 32% for immature untreated and treated fibers respectively as shown in figure 35. The treatment affected the removal of volatile, organic matter, hemicellulose, and lignin causing a decrease in the ash content. The removal of the lignin and hemicellulose result in the exposure of the cellulose, which was easily decomposed. The thermal stability of the treated fibers both mature and immature was improved after the alkali treatment because of the elimination of hemicellulose and lignin (Izani et al., 2013).

The DTGA thermograms (Figure 36) of immature treated fibers display a minor peak centered at 100℃ as a result of water loss. There are many irregular endothermic and exothermic peaks due to cellulose and hemicellulose decomposition. The untreated display two minor peaks centered at 100 ℃ and 295 ℃ due to moisture loss and hemicellulose decomposition respectively. The major peak centered at 345℃ was attributed to cellulose decomposition (Poletto et al., 2014).

4.6 Industrial Application of the Fiber Coir Fiber

In recent years, there has been a skewed path of development, ignoring the necessity to achieve an ecological balance along with it. This is evidenced by major environmental challenges around the world, such as deforestation, pollution, and rapid resource depletion, particularly of non-renewable resources. There is therefore a quest for sustainable development where the available resources are utilized without jeopardy for utilization by the future generations. One pivotal area where this can be realized is in material choice for the industrial application.

Coir fiber is one of the promising choices for utilization due to the growing expansion of global environmental concerns and the necessity for novel bio-engineering. The fiber has the benefit of being biodegradable, readily available, and environmentally benign. Table 4-12 shows properties of coir fiber as determined from this study. The properties determined for coir are within the range of values reported by other researchers. Properties for immature and mature fibers have no significant difference implying that both fiber types can be used for similar application.

Table 4-1 Determined properties of coir fibers

Properties	Immature fiber		Mature fiber	
	Raw	Treated	Raw	Treated
Fiber diameter (μm)	197.44 ±45.02	156.65 ±7.23	123.09 ±17.05	172.17 ±79.28
Fiber density (kg/m^3)	1306.51	1556.58	2941.38	1073.30
Moisture content (%)	9.08	7.91	11.04	8.62
Tensile strength (MPa)	104.36	176.66	267.10	145.60
Surface morphology	Fine	Rough	Smooth	Rough

In Kenyan the use of plastic bags has been banned due to environmental concerns. Coir can be well architecture for packaging in various products. The roughness property in coir makes it appropriate to be used as a long-lasting biodegradable geotextile for a variety of soil bioengineering applications. The air permeability in the coir is a quality of concern for use in furniture as well as mattresses. From the surface morphology of coir, the improved abrasion is a property for consideration in products for domestic cleaning by hand application.

CHAPTER 5: CONCLUSION AND AREAS OF FURTHER RESEARCH

5.1 Research Conclusion

This research aimed to comparatively analyze characterization of coir fibers extracted from immature and mature husk wastes. There have been numerous studies on properties of brown fibers and sparingly regarding white fibers. From this study, just like brown coir fibers, the white fibers as well have properties that make the fibers suitable for industrial applications. Through utilization of husk waste, the research also addressed the challenge of accumulated husk waste. It also alludes potential economic value in husk waste which can be tapped by the local community as a means of income and job creation. From this study the following conclusions can be drawn

i. There has been increase in coconut palm trees population in the Kenyan coastline over the years quantified to 109,889 MT by AFA - Nuts and Oil Crops directorate in 2019 - 2020 and this has eventually increasing the coconut fruit production thereby generating husks waste.

ii. It is evident that there is significant waste generated from the coconut husk waste resulting from coconut tender water consumption and extraction of nut. The survey done revealed a 70 tons of immature husk waste generated monthly.

iii. The waste generated has no proper management as majority of the vendors dump the husk waste. There is little knowledge of husk waste to be used as a bio waste where majority of the respondents are aware of the use as fuel and ornaments in which the former has major challenge to environment conservation. There is therefore great need to look for ways to look for ways to utilize the waste in a sustainable and environmental manner which will eventually add value to the coconut sector.

iv. Coir fibers were extracted using a mechanical decorticator after seven months drying period for immature coconut husk waste. Extraction process realized the coconut fibers and coco peat where the study was only on fiber. Fiber extracts were characterized for mechanical, physical, surface morphology, structural analysis and thermal properties.

v. The fiber alkali treatment appeared to slightly enhance the strength of the fibers in comparison to the untreated fibers. The alkali treatment also significantly increased the tensile strength of immature fibers. The fiber diameter was determined using SEM to be between 123.09μm to 197.44μm and density between 1073.30 kg/m^3 and 2941.38 kg/m^3. Tensile strength was calculated to be 104.36MPa for immature untreated, 176.6MPa for immature treated, 267.10MPa for mature untreated and 145.60MPa for mature treated coconut fibers respectively.

vi. The surface morphology of the untreated fibers reveals a fine and smooth surface. This can be attributed to wax, impurities, lignin, and hemicellulose. The treated fibers show a rough and fine surface as a result of the removal of impurities. The sodium hydroxide interacts with the wax, lignin, and other impurities eliminating them thus, the cellulose is much exposed. It also decreases fiber diameter and results in a rougher surface.

vii. The fiber extracted was characterized with functional groups to determine the status of chemical constituent components in the fiber. The presence of -OH groups in the structure suggests OH stretching vibration from the cellulose and lignin structure of the fiber. These results are an indication that the cellulose component was not removed during the chemical treatment carried out on the coconut fiber. The distinctive of the carbonyl group found in coconut fiber were attributed to C=O stretching of the ester linkage between the carboxylic groups of lignin and/or hemicellulose. A decrease in the C=O peaks was observed following the chemical treatment likely due to the partial removal of hemicellulose and lignin, confirming the efficacy of the treatment. From the Fourier Transform Infrared spectra analysis there is no significant difference in molecular structure between immature and mature fibers. However, there is a slight difference in wavelength range carbonyl stretch.

viii. The thermal stability of the treated fibers both mature and immature was improved after the alkali treatment because of the elimination of hemicellulose and lignin.

5.2 Recommendations

5.2.1 Recommendation from this study

i. It is recommended that research be done on fiber comparative analysis from the predominant varieties where samples are obtained not from the waste but directly from the farm.

ii. The decorticator used for fiber extraction was done using a mechanical basis decorticate hence other methods of fiber extractions can be explored and a comparative analysis could be done to determine their impact on fiber properties.

iii. Husk waste drying period can be varied to determine their effect on fiber properties.

iv. Development of an evaluation tools for fiber capabilities to enhance their selection in application.

5.2.2 Recommendation for further research

i. There is need for further research to determine the correlation between the husks drying time and the decortication parameter to the quality of fiber extracts.

ii. Study on optimum alkalization parameters namely concentration, immersion time, temperature and fiber loading percentage to explore influence on fiber properties is recommended.

iii. Further study for application of coir fiber in medical textile is recommended.

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APPENDICES

Appendix A: Questionnaire

GREEN COCONUT HUSK WASTE SURVEY

PURPOSE:

This questionnaire is solely designed for academic research purposes as part of the requirement for the award of Master of Science in Industrial Engineering degree. The questionnaire survey aims to determine the quantity of coconut husks waste generated from consumption of coconut tender water.

TARGET:

The survey targets vendor in coconut tender water (madafu) business in Mombasa county

CONFIDENTIALITY:

The response received are completely anonymous and confidential. The research outcome and report will not include reference to any individual who participated in this survey. The survey compiler has a sole ownership of all partially filled or completed questionnaires which will be destroyed after completion of research.

SECTION A: SOCIO-DEMOGRAPHIC DATA

1. Name initials of the respondent: (*optional*)…………………………………………………….
2. Age (years):
   15-19 [ ] 20-29[ ] 30-39[ ] 40-49[ ] 50-59[ ] Over 60[ ]
3. Gender:
   Male [ ] Female [ ]
4. Educational level:
   None [ ] Primary [ ] Secondary [ ] Tertiary [ ] University [ ]
5. County of residence:
   ………………………………………………………………………………………….……
6. Location of your coconut (madafu) selling business
   ....

SECTION B: HUSK WASTE GENERATION AND MANAGEMENT

1. Which region(s) do you get the green coconuts from?
   ....
2. What varieties of coconuts do you stock/sell?
   ....
3. How do you transport the coconuts from the wholesalers to your point of sales?
   Human labor [ ]   Motorbike[ ]   Tuk-tuk [ ]   Matatu [ ]
4. What season do you have your best sales?..
5. What season do you have your worst sales?...
6. For how long have you been selling coconuts here?
   0-1 years [ ]   2-4 years [ ]   5 -7years [ ] 8-10 years [ ]   Over 10years [ ]
7. How many immature coconuts on average do you sell in a day?...
8. Do you sell at a fixed location? Yes [ ]   No [ ]
   If No, what are the location (s) that you work within?..
9. What happens to the coconut husk waste after tender water is consumed? (*tick appropriately*)
   Recycle [ ]   Reuse [ ]   Dump [ ]   Sale[ ]   Store for collection [ ]
10. Who collects your waste for disposal?
    County government [ ]   Companies [ ]   Individuals [ ]
    (*Please specify*)
    ..………………………………………………………………………….
11. How much do you pay for disposing the husk waste?..
12. Do you know any uses of coconut husk waste? Yes [ ]   No [ ]
    If Yes, then what are the uses? ……………………………..…………………
13. Is there any coconut sellers association/Sacco you may have known of or registered to?
    Yes [ ]   No [ ]

Appendix B: Collection of Samples

Figure A-1 Freshly collected Immature husk waste

Figure A-2 Dried Immature husk waste

Appendix C: Parameter Determination of Husk Wastes

Figure A-3 Weight measurement of immature coconut husk waste before drying

Figure A-4 Weight and length measurement of immature coconut husk waste after drying

Appendix D: Fiber Extraction

Figure A-5 A mechanical decorticator used for fiber extraction

Appendix E: Separation of Fibers

Figure A-6 Fiber screener used for separation of fibers

Appendix F: Diameter Measurement for Coir Fibers

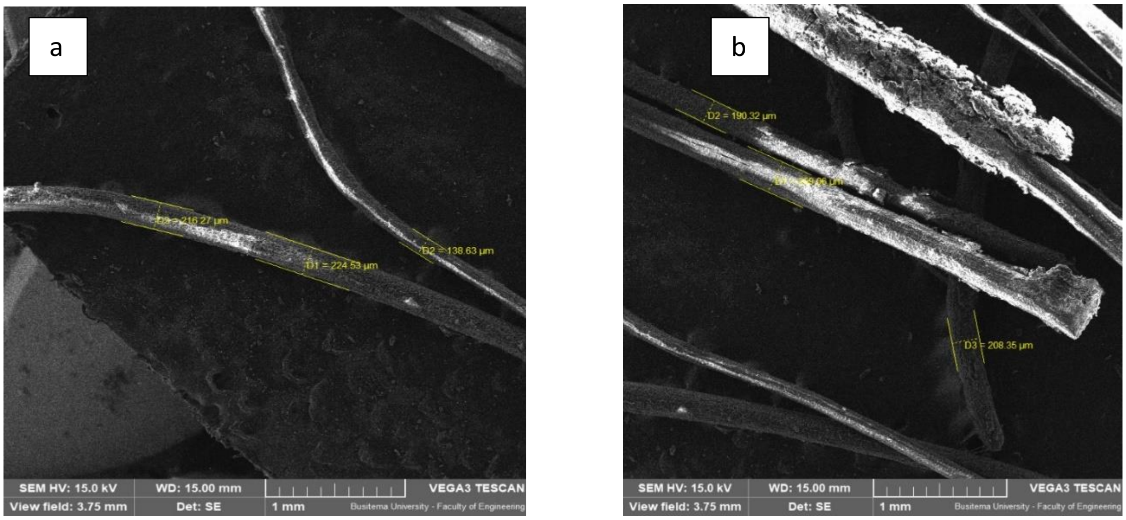

Figure A-7 Diameter measurement for Immature untreated coir fiber

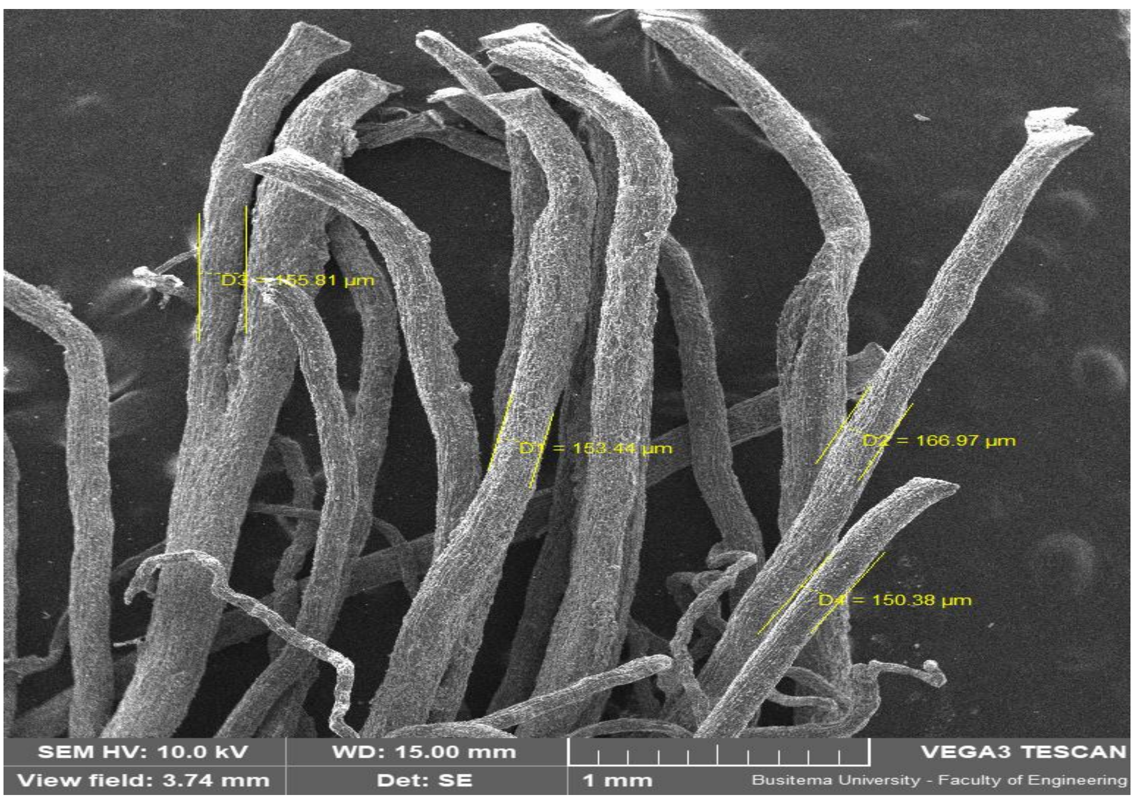

Figure A-8 Diameter measurement for Immature treated coir fiber

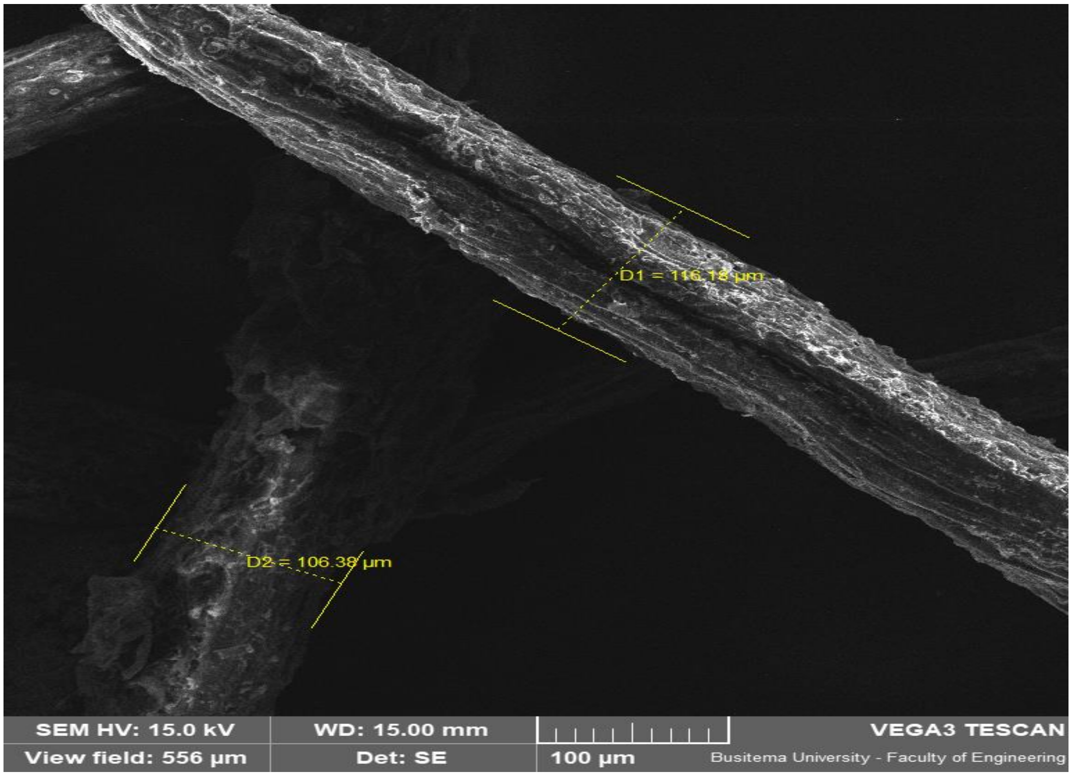

Figure A-9 Diameter measurement for Mature untreated coir fiber

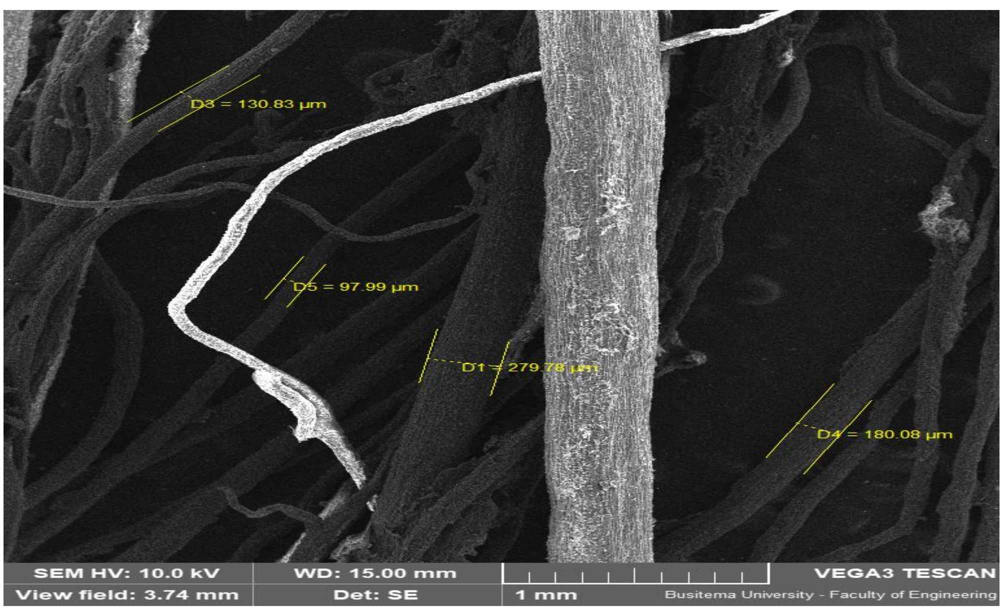

Figure A-10 Diameter measurement for Mature treated coir fiber

Appendix G: Publication

ANNALS OF THE UNIVERSITY OF ORADEA FASCICLE OF TEXTILES, LEATHERWORK

CHARACTERIZATION OF FIBER EXTRACTS FROM IMMATURE COCONUT HUSKS WASTE ALONG THE KENYAN COASTAL REGION KOITUMET

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***Abstract**: This paper presents a study on the characterization of fiber extracted from immature coconut husk waste that was collected along the coastal region of Kenya. The husk wastes were naturally dried and fibers mechanically extracted. Fiber extracts were treated using 20% NaOH for 3 hours. The thermogravimetric analysis, Fourier transform infrared spectroscopy, and morphological analysis, using scanning electron microscopy of the fiber were investigated. From the results obtained, the alkali treatment of fiber extracted from immature coconut husks waste presented nearly minute changes in Fourier Transforms Infra-Red spectra for treated coir fibers. The thermal stability of the treated immature coconut fibers was improved after the alkali treatment because of the elimination of hemicellulose and lignin. Immature treated fibers display a minor peak centered at 100℃ as a result of water loss. The untreated fibers display two minor peaks centered at 100 ℃ and 295 ℃ due to moisture loss and hemicellulose decomposition respectively. The surface morphology of the untreated fibers reveals a fine and smooth surface where as that of treated fibers shows a rough and fine surface as a result of the removal of impurities. Treatment also decreases fiber diameter and results in a rougher surface. Fiber alkali treatment appeared to slightly enhance the properties of the fibers in comparison to the untreated fibers.*

***Key words:** characterization; coir fiber; extraction; surface morphology; FTIR; TGA*

To link to this article: http://textile.webhost.uoradea.ro/Annals/Contents%2027.html

Appendix H: Similarity Index

Sabore MSc Thesis

ORIGINALITY REPORT

21%	%	21%	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	R. M. Leão, S. M. Luz, J. A. Araujo, K. Novack. "Surface Treatment of Coconut Fiber and its Application in Composite Materials for Reinforcement of Polypropylene", Journal of Natural Fibers, 2015 Publication	1%
2	Mohammad K. Hossain, Mohammad R. Karim, Mahmudur R. Chowdhury, Muhammad A. Imam, Mahesh Hosur, Shaik Jeelani, Ramsis Farag. "Comparative mechanical and thermal study of chemically treated and untreated single sugarcane fiber bundle", Industrial Crops and Products, 2014 Publication	1%
3	M. Haseena, K. V. Kasturi Bai, Sugatha Padmanabhan. "Post-harvest quality and shelf-life of tender coconut", Journal of Food Science and Technology, 2010 Publication	1%
4	M.A. Norul Izani, M.T. Paridah, U.M.K. Anwar, M.Y. Mohd Nor, P.S. H'ng. "Effects of fiber	1%