Sudan University of Science and Technology

College of Graduate Studies

Evaluation of Paper Properties Made from Bagasse and kenaf Fiber, and their Blends

تقويم خصائص الورق المصنع من البقاس والكناف وخلطاتهما

Faiza Elamin Abd Elsawi Ahmed

B.Sc Forestry Science

Main Supervisor: Prof. Trageldian Hussein Nasroun

Co Supervisor: Dr. Salaheldin Dafa alla Mohieldin

A thesis:

Submitted in Fulfillment of the Requirements for the Degree of Master of Science in Forestry

College of Forestry and Range Science

October 2019

DEDICATION

This work is dedicated to my mother, father and brothers, sisters and friends and all those who helped me throughout this research.

ACKNOWLEDGEMENTS

I would like to express my special thank to my Supervisor Prof. Tageldin Hussein Nasroun and Co. Supervisor Dr. Salaheldin Dafalla Mohieldin who I owe a great debt of gratitude for his suggestion of the research project, their supervision, proper guidance, criticism and continuous assistance throughout this study.

I am also grateful to Prof. Zienab A. Osman for her assistance in how to write proposal.

My thanks are due to Prof. Osman Taha for his help in fiber maceration.

Thanks for ministry of high education and research sciences give it a chance to fund the project

I am also indebted to the institute of materials science – Sudan University of science and technology, the measurements of fiber morphology I am also indebted to the Institute of Engineering Research and Materials Technology –NCR and Sudan University of Science and Technology.

Special thanks are due to my family for their help, assistance and encouragement.

Finally, I would like to thank all those friends who have influenced me in some way and helped me throughout.

Table of contents

Contents

	Page
ACKNOWLEDGEMENTS	i.
TABLE OF CONTENT	ii.
LIST OF TABLE	iii.
LIST OF FIGURES	iv.
ABSTRACT.Engleish and Arabic	v.
CHAPTER ONE .INTRODUCTION	
1. Introduction	1
1.1 Background	11
1.2 Objectives	5
1.3 overall objective	5
1.3 Specific objective s	5
CHAPTER TWO.LITERATUREREVIEW	
2.1General	6
2.2Fiber characteristics	6
2.3 Raw Materials	8
2.3.1wood fiber	8
2.3.2Non-wood fibrous raw material	9
2.3.2.1 Bagasse	10
2.3.2.2 Kenaf	11
2.4Pulping Processes	16
2.4.1 Mechanical pulping	16

2.4.2 Chemi- mechanical pulping 17
2.4.3 Thermo- mechanical pulp 19
2.4.4 Chemical pulping 20
2.4.4.1 Soda process 20
2.4.4.2 Kraft process 21
2.4.4.3Sulphite process 22
2.4.4.4 Other chemical processes 23
2.4.4.5 Pulping of nonwood fiber 23
2.5 paper properties 26
2.5.1Effect of moisture content 27
2.5.2 Basis weight, grammage 27
2.5.3 Caliper 28
2.5.4 Bulk Density 28
2.5.5 Burst index 29
CHAPTER THREE. MATERIALS AND METHOD
3.1. Materials 30
3.1.1 Kenaf 30
3.1.1 Sugarcane Bagasse 30
3.2. Methods 30
3.2.1Fiber Morphology 30
3.2.2 Chemical analysis 31
3.2.3 Pulping and pulp evaluation 32
3.2.4 Beating and hand sheets formation 32
3.2.5 Evaluation of paper properties 33
CHAPTER FOUR. RESULT AND DISCATION
4.1Chemical Composition 34
4.2 properties of Pulp 39

4.3 Properties of Paper 39

CHAPTER FIVE.CONCLUSIONS AND RECOMMENDATIONS

Conclusions 55

Recommendations 56

Reference 57

LIST OF TABLE

No. of Table		Page
1	Pulping conditions for bagasse and kenaf	**32**
2	hand sheet and testing	**33**
3	hand sheet and testing	**35**
4	Morphological indices (ratios) of bagasse and kenaf fibers.	**39**
5	Fiber dimensions for the three raw materials	**39**
6	show pulp properties for the different raw materials and mixtures	**40**
7	Effect of active alkali and beating time on bulk density of bagasse paper	**40**
8	effect of Active alkali and beating time on burst index for bagasse paper	**41**
9	effect of Active alkali and beating time on burst index for bagasse paper	**42**
10	effect of beating time on properties of paper made from kenaf bast.	**43**
11	effect of Active alkali and beating time on tensile index and Burst index of paper made of kenaf core	**45**

12	effect of Active alkali and beating time on bulk density and brightness of paper made of kenaf core	**46**
13	Effect of beating time on bulk density and brightness of paper made from cooking mixtures of kenaf core and kenaf bast	**47**
14	Effect of pulping mixtures of kenaf bast and kenaf core and beating time on tensile index and burst index	**48**
15	Effect of mixing kenaf core and kenafbast pulps and beating time on bulk density and brightness of paper	**49**
16	Effect of mixing kenaf core and kenaf bast pulps and beating time on tensile index and burst index of paper	**50**
17	Effect of mixing kenaf core /bagasse pulp and beating time on paper properties	**51**
18	Effect of bagasse/kenaf bast blend and beating time on tensile index and burst index on paper	**52**

19	Effect of kenaf bast /bagasse blend and beating time on bulk density	**53**
20	Effect of kenaf bast, kenaf core and bagasse blend and beating time on tensile index and burst index on paper.	**54**

LIST OF FIGURES

Figures		Page
1	macerated of kenaf core fiber	**37**
2	macerated of bagasse fiber	**37**
3	macerated of kenaf bast	**37**

Abstract

Due to the shortage in forest based raw materials for paper, the possibility of alternative cellulosic fibrous raw materials have been explored. Among these Kenaf and bagasse draw the attention as promising nonwood fibrous materials. In the present study, fiber characteristics and chemical composition were investigated for the to raw materials. The optimum conditions for their cooking were determined and their blending potentiality was examined. Bagasse has shown the higher cellulose content (51%) with low lignin (17%) while cellulose and lignin contents for kenaf core were (42.0) and (25.0) respectively. The higher ash content was observed in bagasse 3.0%, while kenaf core has shown the lower ash content(2.9%).with regards to fiber characteristics The lumen diameter and double cell wall thickness for bagasse were (10.19 and 7.37µm) and; kenaf bast were (7.75, 2.33 respectively). It was found that the Lumen width affects the beating of the pulp. The Runkle ratio for kenaf bast was (0.31µm) which was lower than bagasse (0.62µm), low Runkle ratio gave higher paper strength, the coefficient of cell rigidity was (0.91µm) for bagasse and kenaf bast for (0.11µm), Pulp yields for the studied materials were 49 and 49.5% for kenaf bast and, 43%-44% for kenaf core 17% and 16%active alkali respectively. The increase in alkali charges has lowered the screened yield from 49.9% to 45% and kappa number from 21 to 18 for bagasse using active alkali charge of 12% and 13% respectively. Bagasse gave acceptable yield and kappa number. Mixtures (50:50 and 70:30) of kenaf core to bast were cooked with 16% active alkali charge to produce the same yield (42%).With

regards to paper properties. the burst index for bagasse, at active alkali (12%, 13%) was found to be 2.6kpa*m/g and (2.9kpa*m/g) respectively. Bulk density was 15.41g/cm^3 but increased with beating time. Tensile index for Bagasse using active alkali (12%, 13%) was (31and 15.4Nm/g) and increased with beating time to 62 and 78 Nm/g.The bast fiber showed higher tensile index compared to commercial pulp woods(105Nm/g) without beating. The mixture of kenaf bast and kenaf core by ratio (50:50) active alkali (16%) gave tensile index of (61.6Nm/g) and burst index of (1.3kpa*m/g), while burst/core mixture of (70:30) gave tensile index 75.9 and burst index (4 kpa*m/g).Longer fiber with lower cell wall thickness showed significant advantages in physical properties of the produced paper.

تقويم خصائص الورق المصنع من البقاس والكناف وخلطاتهما

الخلاصة

يجري البحث عن مصادر بديله للالياف السليولوزية الصالحة لصناعة اللب الورق نتيجة للتناقص المستمر في الموارد الخشبية علي نطاق العالم لامداد صناعة الورق بالمواد الخام بصورة مستدامة. ومن خلال هذا البحث ظهر الكناف والبقاس كمصدرين غير خشبين لانتاج نوعيات جيدة من الورق واخضعت المادتين للدراسة في هذا البحث حيث اجريت لها تحليلات كيميائيه وقياسات موفولوجية وتم اختيار ظروف التعجين المناسب للمادتين و نسبة مختلفة من خليط المصدرين. من حيث التحليلات الكيميائية ظهر ان البقاس يحتوي علي اعلي نسبة سوليلوز (51%)وادني نسبة لجنين مقارنة مع الكناف حيث النسبة (42%) للسليولوز و(25%) لجنين كما وان البقاس احتوي علي اكبر نسبة من الرماد (3.0%) مقارنة مع الكناف (9.2). ومن حيث الخائص المورفولوجية للالياف كان قطر الفراغ الخلوي ومذدوج سمك الجدر الخلوي للبقاس 19.10 ميكرون و37.7 ميكرون مقابل 7,75ميكرون و 33.2ميكرون للكناف علي التوالي. كذالك كانت نسبة رانكل اعلاه في البقاس (62.0)مقارنة مع لحاء الكناف و تتحن قوة الورق مع انخفاض قوة رانكل. وكان مقابل قساوة الالياف اعلاه مع لحاء الكناف (5,77)مقابل 0,62 للبقاس وكانت نتائج عائد العجينة متقاربة 49%و49,5 للحاء الكناف لتركيزي القلوي 16% و17% علي التوالي و43%و44% للبقاس لتركيزي القلوي علي التوالي. و نسبة زيادة تركيز القلوي 12% الي 13%في خفض عائد العجينة 49,9%الي 45 % و خفض رقم كابا 21الي 18 وعند تعجين خليط من لحاء الكناف و لب الكناف بنسب 50:50 و 70:30 بتركيز قلوي 16% كان العائد كما هو 42%. وفيما يختص بخصائص الورق المنتج كانت قوة الانفجار للبقاس الذي تم تعجينه بتركيز قلوي% 12الي13علي التوالي. وبلغت الكثافة النوعية 15,41جم/سم^3 2.9 2.6 kpa*m/g) kpa*m/gوزادت مع زيادة مدة ضرب العجينة اما قوة الشد للبقاس الذي تم تعجينة بتركيز قلوي 12%الي الي 13% فقد بلغت(31 و 15,4) علي التوالي وزادت مع زيادة مدة الضرب وكانت قوة الشد اعلاه مع لحاء الكناف مقارنة مع الورق المصنع من الياف الاخشاب غير المضروب . وكانت قوة الشد للورق المنتج من خليط لب الكناف ولحاء الكناف بنسبة 50:50

والذي تم تعجينه بسنبة تركيز 16% كانت قوة الشد61,6Nm/g وقوة الانفجار kpa*m^2/g 1.3 بينما كات نتائج الخليط بنسب 70:30 لحاء كناف ولب كناف 75.9 قوة الشد. و 4 قوة انفجار واظهرت الالياف الطويلة سمك جدار خلوي رفيع ميزة معنوية لخصائص الورق المنتج منها.

CHAPTER ONE

INTRODUCTION

1.1 Background

The history of papermaking can be traced back to about ad 105, when Ts'ai-Loun Created a sheet of paper using old rags and plant tissues. In its slow travel westwards, the art of papermaking reached Arabia in the middle of the eighth century, from where it entered Europe via Spain in the 11th century. By the 14th century, a number of paper mills existed in Europe, particularly in Spain, France, and Germany. For centuries, paper had been made from linen, hemp and cotton rags. After cleaning, sorting and cutting, these were boiled with potash or soda ash to remove the remaining dirt and color. The operation was continued in a "breaking engine" by adding fresh water until the cloth was separated into single fibers. Until the paper machine was constructed in 1799 by Louis-Nicholas Robert, the final sheet-formation process was carried out manually. Throughout the 18th century the papermaking process remained essentially unchanged, with linen and cotton rags furnishing the basic fiber source. However, the increasing demand for paper during the first half of the 19th century could no longer be satisfied by the waste from the textile industry. Thus, it was evident that a process for utilizing more abundant material was needed. Consequently, major efforts were undertaken to find alternative supplies for making pulp. As a result, both mechanical and chemical methods were developed for the efficient production of paper from wood. Mechanical wood pulping was initiated in

1840 by the German Friedrich Gottlob Keller. The wood-pulp grinding machine was first commercialized in Germany in 1852 (Heidenheim) on the basis of an improved technology developed by Voelter and Voith. However, mechanical pulping did not come into extensive use until about 1870 when the process was modified by a steam pretreatment which softens the inter-fiber lignin. Paper made from mechanical wood pulp contains all the components of wood and thus is not suitable for papers in which high brightness, strength, and permanence are required. The clear deficiencies compared to paper made from cotton rags made it necessary to strengthen the development of chemical wood pulping processes, focusing on the removal of accessorial wood components such as lignin and extractives. The first chemical pulping process was the soda process, so-named because it uses caustic soda as the cooking agent. This process was developed in 1851 by Hugh Burgess and Charles Watt in England, who secured an American patent in 1854. A year later, the first commercial soda mill using poplar as raw material was built on the Schuylkill River near Philadelphia under the direction of Burgess, who served as manager of the mill for almost 40 years. Because this process consumed relatively large quantities of soda, papermakers devised methods for recovering soda from the spent cooking liquor through evaporation and combustion of the waste liquor and recausticizing of the sodium carbonate formed. To compensate for the losses, sodium carbonate had to be added to the caustic zing unit.

World demand for paper has increased at an average annual rate of 4.7% over the past decade. The future growth will reduce to the existing wood resources by 2-3% leading to inadequate supply to

meet this growing demand for paper especially in the Asia-Pacific region and Eastern Europe. In addition, logging is coming under increasing pressure from environmentalists concerned about habitat destruction and other longer-term impacts of forest harvesting. It is, therefore, necessary to consider alternative fiber sources to meet the possible shortfall of wood fiber for papermaking. Suitable nonwood fibers are abundantly available in many countries and are the major source of fiber for papermaking in some developing nations (Ashori, 2006).

The use of nonwood plants for papermaking purposes has for some time been a subject of debate. Reasons such as the scarcity of raw materials have not permeated developed countries, where paper recycling is increasing at a sustained rate. Countries such as China or India, however, have used nonwood plants (e.g. bamboo) and agricultural residues (e.g. sugar cane bagasse, cereal straw) for papermaking with good results (Viler, 2009).

As compared to wood, nonwood raw materials are similar in cellulose, lower in lignin and higher in pentosans (hemicelluloses) and silica content (Judt, 1993). The advantages of nonwood fibers are that they are mostly by-products (agricultural residues); often cheaper are wood; in large quantities of annual crops; need little refining; and make excellent filler and good printing and smoothness (Biermann, 1996). Furthermore, the potential availability and economics of using agricultural residues is more interesting despite of their limitations (Reddy and Yang, 2005). For instance, this can provide added income to farmers without compromising the production of main food and even non-food crops (UNEP, 2009). The problems associated with the utilization

of these nonwood fiber resources include: collection and transportation; storage and handling; washing; bleaching; papermaking; and chemical recovery (Hammett, italics, 2001).

Non-wood materials may require special handling and pulping systems (Lewis and Jackson, 2002). These may include wet cleaning; depithing; and decortications according to their type. Brown stock washing is different according to the drainability; straws need larger area as they drain slowly (Hurter, 2002). Although most of the nonwood materials would require specialized handling and pulping systems, some can be dealt with without major equipment changes in the existing mill. Replacement with straw fibers in the paper furnish may require reduced refining of the wood fibers to control drainage while maintaining the paper properties (Tschirner, italics, 2003).

Kenaf (Hibiscus cannabinus) is a herbaceous annual plant grown in many parts of the tropics and in some subtropics and warm temperate areas for its bast fibers to substitute jute in cordage and sacking. In many studies kenaf was found to respond well to different chemical and semi chemical pulping processes to produce acceptable yield of pulp with satisfactory properties. Bagasse is commonly used as a substitute for wood in many tropical and subtropical countries for the production of pulp, paper and paper board, such as India, China, Colombia, Iran, Thailand and Argentina. It produces pulp with physical properties that are well suited for generic printing and writing papers as well as tissue products but it is also widely used for boxes and newspaper production.

As the forest cover of the Sudan is estimated to be >10%, of the area of the country these alternative fibrous raw materials represent the right choice to suggest for the establishment of pulp and paper production in Sudan. Kenaf and bagasse are available on seasonal bases and hence they may compensate for each other to insure continuous raw material supply.

1.2 Research Objective

1.3 Overall objective

The overall objective of this study is to determine alternative fibrous raw material to wood and suitable technologies for pulp and paper industry.

1.4 specific objectives

To determine fiber morphological characteristics and chemical composition of kenaf and bagasse.

To explore optimum pulping conditions for each of fibrous raw material.

To study the potentiality and suitability of cooking mixtures of the tow fibrous raw material

To evaluate the properties of pulp and paper produced from all these combinations.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

The discovery of wood as a suitable fibrous raw material for the manufacture of pulp and paper was a breakthrough in this industry. Wood is a natural composite material and a chemical complex of cellulose, lignin, hemicelluloses, and extractives. Cellulose is the framework substance, comprisin40 -50% of wood in the form of cellulose micro fibrils, whereas hemicelluloses are the matrix substances present between cellulose micro fibrils. Lignin, on the other hand, is the encrusting substance solidifying the cell wall associated with the matrix substances. The significance of lignin as the encrusting substance can be demonstrated by examination of the lignin skeleton created by the acid removal of carbohydrates. Among the most important wood quality indicators for industrial processes, wood density is a property of interest, because it is directly related to the type and quality of product to be obtained, and is the most informative property about the physical–mechanical be haviour of wood for timber, pulp and paper production (Lima et al. 2000; Raymond and Muneri 2001; Magaton et al. 2009).

2.2Fiber characteristics

Early research on the effect of fiber properties on paper strength (Dadswell & Wardrop, 1954; Arlov, 1959; Barefoot et al., 1964) led to

the general belief that paper with desirable strength properties could only be made from long-fibered wood species, softwood pulps.

Subsequent studies have shown that fiber length possibly is not the overriding factor in producing paper with acceptable strength (Annergren et al., 1963; Alexander & Marton, 1968; Horn, 1974).

Wood-fiber characteristics that have often been associated with paper strength-in particular, paper made from hardwoods-are the length to diameter ratio (L/D), and Runkel ratio–twice the cell wail thickness/lumen diameter (2w/l). Both are fiber parameter which, by the very nature of their required measurements, should be associated with wood fiber and not with pulp fiber. The L/D ratio has been shown to be unreliable in providing basic information on strength properties dependent upon fiber bonding (Samariha, 2011)

Fibre dimensions was determined by reducing representative chips of raw materials into core and was placed into an equal volume of glacial acetic acid and hydrogen peroxide in ratio 1:1 in a covered bottle. The solution was placed in the oven for 4 hours at temperature of about 100° for maceration. The macerated cores were disintegrated by shaking the bottle for some days to release the fibres. Random samples of macerated fibres was mounted on slides and examined under a light microscope. Fibres were viewed and measured using a stage micrometer under ×80 magnification. The fibre for each material were mounted on a slide and the fibres length (L), fibre diameter (D), lumen width (d), and cell wall thickness was measured. The following morphological indices (derived values) also called important criteria in papermaking was determined as follows according to (Kirci,2006).

(Ekhuemelo, 2016)

In hardwoods, wood density is determined by its anatomical structure, as vessels features, fiber width, cell wall thickness, parenchyma proportion and chemical composition. Thus, species with similar density can differ in fiber properties and cell dimensions, which affect the quality of pulp and paper produced (Sandercock et al. 1995; Downes et al. 1997; Butterfield 2006; Gomes et al. 2015; Gominho et al. 2015). In chemical pulping processes, it is known that the pulping and bleaching performance is highly dependent on the abundance, structure and reactivity of lignin, cellulose and hemicelluloses. In particular, lignin content and its composition are important parameters in pulp production for the delignification rates, chemical consumption and pulp yield (Carrillo,2017).

Lignin constitutes 23% to 33% of the wood substance in softwoods and 16% to 25% in hardwoods. Although lignin occurs in wood throughout the cell wall, it is concentrated toward the outside of the cells and between cells. Lignin is often called the cementing agent that binds individual cells together. Lignin is a three-dimensional phenylpropanol polymer, and its structure and distribution in wood are still not fully understood. On a commercial scale, it is necessary to remove lignin from wood to make high-grade paper or other paper products.

2.3 Raw Materials

2.3.1wood fiber

The wood fiber used by the paper industry originated primarily in forests. Paper production related fiber raw material can be divided in to

tow main pulp categories. Namely virgin wood pulps, which are produced by using primary wood fibers and non-wood as raw material, and recycled fiber pulps, which return back to circulation in material recycling. In addition, non fiber materials like minerals and additives are used as raw material in paper production. (Ervasti, 2016).

All woods are composed of cellulose, hemicelluloses and lignin. Cellulose and hemicelluloses are polysaccharides while lignin is an oxygenated polymer of phenyl propane units. In addition there is a variable quantity of extraneous chemicals known collectively as extractives and small amounts of inorganic elements such as calcium, magnesium and potassium. The inorganic ash content is usually 0.1-0.3% by weight and rarely exceeds 0.5%, except in some tropical hardwoods where a high silica content (several percent) can cause rapid wear and blunting of machine tools (Walker, 2006).

2.3.2Non-wood fibrous raw material

Paper production is mainly based on fibrous raw material which may consist of primary or secondary fibers. Primary fibers are obtained directly from plant raw materials, mainly from wood and annual non-wood plants Secondary fibers are produced from recovered paper. Rags are used only in very small amounts. Worldwide, wood represent 90% of the raw material source. The use of annual non-wood plants is especially suitable for regions with low wood resources, larger areas that are used for agriculture and larger surpluses of agricultural remains (e. g. straw). Fiber production from non-wood plants is more expensive and causes more environmental pollution than that from wood. Chemical pulp from jute, flax, hemp, sisal and bagasse are

suitable for special paper grades (e.g. filtration papers, lightweight printing papers). In tropical and subtropical countries, pulp wood is grown mainly in plantations (Sexita, 2006).

2.3.2.1 Bagasse

Sugarcane bagasse is one of a highly fibrous residue remaining after extraction of juice from cane stem which can be used as a source of roughages for ruminants. Sugarcane bagasse annual production in Sudan is more than three million tons. Small proportions of these quantities are burnt during the production cycle of sugar and the rest creates problems of its disposal. Utilization of Sugarcane bagasse for animal feeding is limited due to their bulkiness that hinders their transport to areas of consumption and their poor digestibility due their high content of fiber which contain more than 60% of its dry matter in the form of cellulose, hemicelluloses and lignin. Found that sugarcane bagasse contained about 50% cellulose, 27.9% hemicelluloses, 9.8% lignin and 11.3% cell content that included 1.3% CP. The limitation in availability of energy to the ruminant animals from ligno-cellulose of agricultural by-products is due to physical and chemical association between structural carbohydrate and lignin and the crystalline arrangement of the cellulose polymer in plant cell wall (Ahmed, 2013).

Bagasse was evaluated for the production of pulp and papers. It has fairly long fiber length and low lignin content suitable for paper making. Samples paper were produced and tested for mechanical strength properties. They exhibited standard qualities for tearing resistance above TAPPI T414 for all grades of papers except test liner, hence its papers can be used for writing, printing, corrugating medium and insulating board applications (Ibrahim, 2011).

Soda pulping of bagasse at mild cooking condition (Bag1), carried out as reference cook with an active alkali level of 12.4% (as Na2O) on oven dry raw material, 60 min heating up time to the maximum temperature of 160 ◦C and 60 min cooking time, gave screened pulp yield of 55.8% and a still rather high kappa number of 14.3. Under harsher conditions (90 min cooking time at 165 ◦C) the kappa number could only marginally be reduced and the screened yield dropped to 53.2%, but the pulp showed much higher tear strength. The addition of 0.1% anthraquinone to the cooking liquor at lower active alkali charge of 10.9% and 60 min cooking time at 155 ◦C, gave a screened yield of 55.5% at a lower kappa number of 12.2.(Khristova, 2006).

2.3.2.2 Kenaf

Kenaf (Hibiscus cannabinus L.) is a member of the family Malvaceae and the third largest fiber crop of economic importance after cotton and jute (Agency for International Development, 1968). It is indigenous to Africa and the species H. cannabinus most likely originated from Sudan, although it is commonly cultivated for both food and fiber in West Africa. Fiber in both the retted and raw forms is used in the manufacture of cordage and newsprint. Leaves and small branches, when ground, have high digestibility and can be used as a source of roughage and protein for cattle and sheep (Bada and Kalejaiye 2010). As a source of cellulose fiber for pulp production (Francois et al., 1992; Webber III, 1996), the economic importance of kenaf is made more important due to diminishing stocks of hardwood and softwood trees in the world. (ADEGBITE, 2018).

The strength properties for kenaf of handmade papers obtained from the pulp blending of long-fiber kenaf bark and short-fiber corn husk in different ratios. Tear index, modulus of elasticity, elongation at break and tensile index of paper from pulp of corn husk vary significantly when combined with pulp of kenaf bark. Blending of pulps from agricultural wastes such as corn husk and pulps from other non-wood materials such as kenaf contributes to the improvement of the paper strength properties and has the potential of producing paper of differing qualities and can find use in wide variety of applications (Fagbemi, 2014)

In papermaking, blending or mixture of fibers is one of the ways to enhance mechanical properties of paper. The objective of this study was to evaluate the properties of paper manufactured from mixture of oil palm empty fruit bunch (EFB) and kenaf fibers. Using kenaf whole stem fibers improved the mechanical properties of the blended papers and complied with the standard requirement for writing and printing grade paper (Rafidah, 2017).

Nonwood fibers, also referred to as ‘‘alternate fibers’’, are nonwood cellulosic plant materials from which papermaking fibers can be extracted. The most widely used nonwood for papermaking are straws, sugar cane bagasse, bamboo, kenaf, hemp, jute, sisal, abaca, cotton linters, and reeds. Most nonwood plants are annual plants that develop full fiber potential in one growing season. There is a wide variety of nonwood plant fibers that can be used for papermaking. Nonwood such as bagasse, wheat and rice straws, bamboo, and kenaf are being used in the manufacture of pulp and paper all over the world. Kenaf (Hibiscus cannabinus), for example, is being explored as a useful raw material

for papermaking in developing and developed countries. Total kenaf production in 1999–2000 was 0.51 million tons, among which production from China accounted for 44%, India for 39%, Thailand for 12%, and the remainder coming from Indonesia, Vietnam and elsewhere (Ashori, 2006).

Nonwood is a critical fiber resource in regions with inadequate forest resources, and will continue to play an increasingly important role in these regions. Environmental pressures, restrictions on forest uses and significant increases in wood and recycled fiber costs are also forcing many paper companies in the traditionally forest-rich countries to take a renewed look at nonwood fibers. Nonwood are abundantly available in many countries and are the major source of fiber for papermaking in some developing countries, particularly China and India. Approximately 2.5 billion tones of nonwood raw materials are available each year worldwide; however, most of this raw material is currently untapped for pulp and papermaking (Ashori, 2006).

Another perennial rhizomatous grass that is considered as a potential raw material for papermaking is reed canary grass (RCG). RCG (Phalaris arundinaceous) is native to temperate regions of the Northern hemisphere, where it is sometimes used as forage crop. Being already adapted to short vegetation periods and low temperatures it is the only viable grass option for countries such as Sweden or Finland (Lewandowski et al., 2003). RCG can be grown on most soil types, including marginal lands, provides high biomass yields for at least 10-15 years after its establishment and can produce twice as much pulp annually than temperate hardwood (e.g. birch) (Finell, 2003). RCG harvesting, similar to switch grass, can take place either in the autumn

or spring, but delayed spring harvesting offers several benefits. The plant's moisture content then is 10-15%, simplifying storage, while pulp yields are higher, fines contents lower, fiber lengths higher and ash and silica contents lower (Pahkala et al., 1997; Pahkala and Pihala, 2000). As with other non-wood fiber sources, ash and silica contents tend to be higher than in wood, making some form of fractionation before pulping beneficial. Removing leaves, dust and dirt by means of air fractionation can reduce silica contents by 40% (Pahkala et al., 1997), while mechanical fractionation has been proposed for producing stem chips for pulping and leaf meal for energy generation (Bouzios, 2017).

Agricultural residues are residues accumulated after the harvest of annual plants, i.e. seasonal crops available during summer or autumn. Only about 8% of global paper and paper board production is based on agricultural wastes. 92% of world production depends upon wood whether softwood or hardwood. Many countries, which lack forests, are obliged to utilize agricultural residues as raw materials for paper and board manufacture. However, in countries rich in forests, there is a trend to use agricultural residues – if available – in order to reduce deforestation (Yehia, 2017).

It is expected that the percentage of utilization of agricultural residues for paper and paper board manufacture will gradually increase. A percentage of at least 10% is anticipated for the near future. The fiber content of the plant is important. The plant contains in addition to fibers, many non-fibrous cells e.g. parenchyma cells. Fibers themselves very much in different plants regarding their length, width, fine or microstructures, as well as their chemical composition. In one and the

same plant there are different types of fibers. The same fiber type is not equal in dimension but contains a spectrum of different dimensions. For this reason, one speaks of "average fiber length". The length of the fiber is one of the most important parameters affecting paper strength. Agricultural wastes very much in morphological structure, anatomical structure, as well as chemical composition (Yehia, 2017).

The chemical composition of nonwood plant fibers varies widely depending on the type of plant and the soil and growing conditions. all nonwood are characterized by a lower lignin content than wood and a higher pentosan or hemicelluloses content stalk fibers are closer to hardwoods in chemical properties than to softwoods - the major difference is in the higher ash and silica content of these nonwood oilseed flax bast fiber has similar chemical properties to hardwoods; however, it has physical properties superior to softwoods cotton staple and linters fibers are in a class of their own with respect to chemical properties - they contain an alpha cellulose content double that of softwoods and only a fraction of the lignin contained in all of the other fibers. The wide variety of physical and chemical properties offered by nonwood plant fibers provides virtually endless opportunities for papermaking. Combinations of common and specialty nonwood pulps will permit the production of virtually any grade of paper to meet any quality requirements demanded in the global market. Adding possible combinations which include wood pulp, nonwood pulp and recycled wastepaper pulp increases the possibilities for developing paper with specific sheet properties designed to meet specific customers' needs (Robert, 2002).

2.4 Pulping Processes

Pulping technology deals with the liberation of fibers fixed in the wood or plant matrix. Paper technology is the knowledge of how to unify the fibers to form the paper web (Monica, et al, 2009). There are a number of pulping processes, and variants of each. Most of the basic processes were developed initially to use a particular wood resource; to supply major markets where papers with specific properties were required; or to supply a market niche (Walker, 2006).

2.4.1 Mechanical pulping

Treatment in post-refining or reject refining plays an important role in developing mechanical pulp to its desired quality level, involving fibrillation of fibers which is essential for promoting the bonding between fibers. However, the fibrillation of mechanical pulp is different from that of chemical pulp. Fibers are developed under complicated cyclic compressive and shear forces during refining (Kang, 2006).

The discovery of mechanical pulping was a landmark event in the history of paper, indeed in the history of the world. The development of stone ground wood (SGW) pulping in Germany in the 1850's, followed by sulphite pulping about 10 years later, paved the way for the widespread use of wood fiber in paper. This in turn enabled mass print media such as the penny press to displace what was formerly a 'rich man's product," paper made from various non-wood fibers. The grits of a grindstone accomplish two actions: removal of fibers from the wood (comminution) and development of the fibers into a paper-

grade pulp. Comminution is accomplished by rubbing and sliding actions, as opposed to grinding, where the main action is due to cutting by the sharp edges of the grits (Atack and May 1958).

Grits in GW create rolling friction and consequent heat from hysteresis, to the extent that the wood may char just under the surface. Consequently water is added. Once fiber ends are loosened, they turn in the direction of grinder rotation, and are eventually released very much as intact fibers (Atack 1977). The free pulp is further "developed" in what is called re-grinding, a heterogeneous process that causes fiber length loss (Kerekes, 2015).

2.4.2 Chemi- mechanical pulping

Chemimechnical pulping involves a gentle chemical treatment stage combined with mechanical defibration such as disc refining. The yields of these pulps are generally in the range of 80–95%, and their properties are intermediate between those of high-yield chemical pulps and mechanical pulps. Chemithermomechanical pulp (CTMP) is produced with pressurized refining. Relatively low chemical doses are applied, and the yield is typically above 90%. Chemimechnical pulp (CMP) can be produced with refining at atmospheric pressure; the chemical treatment stage is more severe than in the CTMP process, and the yield is typically below 90%. CMP is also the general name for all chemimechnical produced pulps. CTMP and CMP have been developed for the better use of hardwood and the improvement of the bonding ability of the stiff long TMP-fibers, with the first pulping lines beginning operation during the 1950s and 1960s for hardwood applications. The breakthrough in chemimechnical pulping occurred

during the 1970s as result of the improved TMP technology. Because the key sub process in chemimechnical pulping is refining, all developments of the TMP process could also be utilized for CMP production. This caused a rapid growth in the production of softwood CTMPs during the late 1970s and 1980s.

Soda pulping and traditional bleaching has been used for bagasse pulping, and this technology is in its mature stage. However environmental concerns and efficient use of raw material require the development and application of more efficient technologies such as chemimechnical pulping for bagasse. Results chemimechnical pulping of bagasse indicated that applying mild chemical treatment sodium sulphite and sodium hydroxide compare to soda pulping produce pulp with tensile, tear, burst strength .the yield and opacity of this pulp were measured as 65% and 94% ISO Respectively. This pulp can be used supplementary pulp for the production of news paper in fiber deficient regions with available supply of bagasse (Khakifirooz, 2013).

2.4.3 Thermo- mechanical pulping

Thermo mechanical Processes in the refiner process cause Fiber defibration from the fiber compound middle lamella as follow: _ Softening of the lignin in the middle lamella and in the primary wall of the wood fiber by Many process parameters are considered responsible for the character and properties of the mechanical pulp produced, including: (a) the pressure and temperature during thermal pretreatment; (b) the duration of thermal pretreatment; (d) the specific energy consumption; (e) the energy distribution within the refining stages; (f) the consistency in the refining zone of the first refining

stage; (g) the wood chip quality; (h) the refiner design; and (i) refining intensity caused by plate design and rotational speed. The duration of thermal pre-treatment has only minimal influence on pulp quality, since in practical terms this stage lasts for only 1–3 min, and a minimum time. The difference between Chemithermomechanical and chemimechnical pulping relates mainly to the process conditions utilized and is apparent mainly in terms of the intensity of chemical treatment and pulp yield (Sixta, 2006).

During the last few decades, the energy prices for mechanical pulping (MP) have risen considerably and the industry has tried to reduce the energy consumption of the process. Diminishing energy for refining, however, leads to products with lower quality. Therefore, research is focusing on reducing energy consumption while maintaining or improving pulp quality. As a step towards this goal, in 2008 Holmen Paper AB invested in a new thermo mechanical wood refining process at the Braviken mill. Single-stage high-consistency refining is one of the key steps in this innovative energy-saving process, which has shown to have a strong influence on fiber development (Muhic´ italics 2010). The final pulp quality is influenced by the first fiber treatment (Ho¨glund and Wilhelmsson 1993; Ha¨rko¨nen italics 2003). The surface ultra structure in these cases had S2 layers with long ribbon-type fibrillation. (Dinesh, 2011).

2.4.4 Chemical pulping

It is known that the pulping and bleaching performance is highly dependent on the abundance, structure and reactivity of lignin, cellulose, and hemicelluloses. In particular, lignin content and its composition are important parameters in pulp production for the delignification rates, chemical consumption and pulp yield (Carrillo, 2017).

Since the fibers in wood and plants are glued together with lignin, the chemical way to produce pulp is to remove most of the lignin and thereby release the fibers. The delignification of wood is achieved by degrading the lignin molecules and introducing of charged groups, keep the lignin fragments in solution and eventually remove them by washing. No pulping chemicals are entirely selective towards lignin; also the carbohydrates of the wood are to varying extent lost. Approximately half of the wood material is dissolved in chemical pulping. No chemical pulping method is able to remove all lignin in the pulping stage, at least not without severe damage to the carbohydrates. The delignification is therefore terminated with some lignin remaining in the pulp. The amount of lignin left in the pulp is estimated by determining the kappa number of the pulp. (Monica, 2009).

2.4.4.1 Soda process

Soda pulping, invented in England by Burgess and Watts in 1851, uses sodium hydroxide as the cooking chemical. Finding little enthusiasm in England for this new process, Burgess brought the method to the U.S. in 1854 and the first mill was started in 1866. Many of the early soda mills converted to the kraft process once it was discovered. The soda

process still has limited use for easily pulped materials like straws and some hardwoods, but is not a major process. Anthraquinone may be used as a pulping additive to decrease carbohydrate degradation. A recent development is the use of oxygen in soda pulping. While oxygen bleaching is not very specific to delignification compared to other bleaching methods, it is fairly specific to delignification relative to other pulping methods (.Biermann, 1996)

2.4.4.2 Kraft process

In 1879, Dahl, a German chemist, used sodium sulfate as a makeup chemical for soda pulping to regenerate NaOH; actually Na_2S was formed and, unexpectedly, gave much faster delignification and stronger pulps, since shorter cooking times are used resulting in less carbohydrate degradation. This led to the kraft (or sulfate) process, which is now the dominant process. Although related work on the process had been done earlier, Dahl discovered the kraft chemical recovery process, which is perhaps more important than the kraft cooking process. The first kraft mill went into operation in 1890 in Sweden because the German papermaking industry did not accept this

The process was developed and grew quickly from 1915 to 1930, especially in the southern U.S. where the resinous pine species did not pulp well by the sulfite process with calcium base. Kraft pulping is a full chemical pulping method using sodium hydroxide and sodium sulfide at pH above 12, at 160-180°C (320- 356°F), corresponding to about 800 kpa (120 psi) steam pressure, for 0.5-3 hours to dissolve much of the lignin of wood fibers. The active chemicals in the Kraft liquor are Na2S and NaOH. Other chemicals in Kraft liquors are

important because they are involved in the recovery process; these include Na_2CO_3 and Na_2S0_4. Still other chemicals such as NaCl are important as contaminants that may build up in the system. The amounts of chemicals are reported on Na20 basis in North America. Various combinations of these chemicals are given special

Names because these combinations can predict how the liquor will behave better than considering the amount of chemicals themselves. Pulping chemicals are reported as concentrations in liquor or as a charge on dry wood. (Biermann, 1996)

2.4.4.3 Sulphite process

The sulfite pulping process is a full chemical pulping process, using mixtures of sulfurous acid and/or its alkali salts (Na^{+1}, NH_3, Mg^{+2}, K^{+1} or Ca^{+2}) to solubilize lignin through the formation of sulfonate functionalities and cleavage of lignin bonds. By 1900 it had became the most important pulping process, but was surpassed by Kraft pulping in the 1940s. It now account for less than 10% of pulp production. Woods with high pitch contents or certain extractives (such as the flavones dihydroquercitin in Douglas-fir) are not easily pulped at the lower pH. Once the dominant pulping process, now less than 10% of pulp is produced by the sulfite method in this country, partly due to environmental considerations. Some advantages of sulfite pulping are bright, easily bleached pulps, relatively easily refined pulps, pulp that forms a less porous sheet that holds more water than Kraft pulps (for use in grease-resistant papers), and pulps with higher yield than Kraft (Biermann,1996).

2.4.4.4 Other chemical processes

Extended delignification chemical pulping and bleaching of chemical pulps are both delignification reactions. Of course, bleaching reactions are much more specific for lignin removal than pulping, but are much more expensive. Improvements in pulping that allow cooking to lower lignin contents and new processes before conventional bleaching are referred to as extended delignification. A variety of pretreatment processes (many of which are experimental) applied to pulp lower the amount of bleaching chemicals required, leading to lower levels of chlorinated organic materials. Organosolv pulping Organosolv pulping is largely an experimental pulping procedure using organic solvents such as methanol, ethanol, acetic acid, acetone, etc. to remove lignin. It has the advantages of having no sulfur emissions and a simple chemical recovery process which would allow relatively small mills to be constructed. Klason was the first to try to remove lignin from wood by dissolving it in acidified alcohol solutions in solutions of 5% HCl in ethanol in 1893. Cooking dry spruce chips for 6-10 hours led to dissolution of 28-32% of the wood. The AlCell (alcohol cellulose) process of Repap enterprises using 50% ethanol and 50% water at 195 °C for approximately 1 hour has been demonstrated at 15 t/d. The company plans to build a 300 t/d mill in Newcastle, N.B. to pulp hardwoods. (Biermann, 1996)

2.4.4.5 Pulping of nonwood fiber

Pulping of nonwood: Pulping equipment used to produce wood pulp typically is not suitable for pulping non woods. Again, bamboo chips are the exception. Nevertheless, pulping technology for nonwood is

well established. The Kraft, soda and sulfite processes are used throughout the world to produce a range of semi-chemical and chemical pulps from a wide range of nonwood raw materials. Unlike wood, the characteristics of pulps produced using the Kraft and soda process are similar and the process selection is based mainly on makeup chemical cost and availability. Most non woods currently are pulped using the soda process, but there is no reason why the Kraft process could not be used. Non woods may be pulped using either batch rotary digesters or continuous horizontal tube digesters (Hurter, 2002).

Maceration process was used to characterize the fiber. Soda-AQ pulping with various combinations of active alkali (18-22%) and cooking time (90-150 minutes) at fixed temperature was done. Physical properties evaluated were bulk density, brightness, opacity, scattering coefficient, tear, burst and tensile index. As concentration of active alkali and cooking time increased, the physical properties values also increased, except for the opacity and scattering coefficient. The optimum condition for producing the strongest paper is using 22% active alkali in 120 minutes. The most common pulping process for non-wood fibers is the soda process. The addition of anthraquinone (AQ) in the soda pulping process has given encouraging results, generally increased delignification rates even with reduced alkali charges. AQ acts as the most cost effective sulfur free accelerator and is widely used in alkaline pulping. For instance, (Ang italics, 2010) have successfully produced paper from Malaysian kenaf fibers using three alkaline pulping processes which were Kraft, Kraft-AQ and soda-AQ. The results indicated that the sulfur free soda-AQ pulping

imparted higher brightness, tensile and tear indices as well as similar burst index to the paper properties in comparison to that Kraft based-paper (Maina, 2014).

Compared to wood, nonwood raw materials are similar in cellulose, lower in lignin and higher in pentosans (hemicelluloses) and silica content. The advantages of non-wood fibers are that they are mostly by-products (agricultural residues), often cheaper than wood, large annual crops, need little refining, and make excellent filler and good printing and smoothness. Furthermore, the potential availability and economics of using agricultural residues is more interesting despite of their limitations. For instance, this can provide added income to farmers without compromising the production of main food and even non-food crops. Resources include: collection and transportation; storage and handling; washing; bleaching; papermaking; and chemical recovery.

Special qualities, of the nonwood fibers, and how they affect the technical aspects involved in pulping and papermaking must be understood. Pretreatments aim at rendering the non-wood fibrous raw materials more suitable for the pulping and papermaking process. Pretreatments include physical, hydrothermal, chemical and biological practices. Disadvantages include transportation and storage problems; comparatively high silica content; very quick degradation (high losses) These disadvantages have prevented the emergence of non-wood plant fibers as a source of cost competitive pulp for both printing/writing and cellulose products particularly in regions of the world where wood supplies are adequate. The use of non-wood fibers, however, is

common in wood-limited countries, such as China and India, which are the two largest producers of non-wood pulp (Mohieldin, 2014).

2.5 paper properties

Paper is used for a wide range of applications such as hygiene, printing or packaging. Depending on the application, different properties are required. In order to find if the paper is suitable for the chosen application, one has to perform measurements. As with many things in the scientific domain, there are standards as to how to test these properties in order to get results that can be compared to each other. ISO (International Standardization Organization) and SCAN (Scandinavian Pulp, Paper and Board Testing Committee) are common in Sweden where this study takes place. Internationally, there is also TAPPI (Technical Association of the Pulp and Paper Industry, USA), CPPA-TS (Canadian Pulp and Paper Association- Technical Section) and APPITA (Australian Pulp and Paper Industry Technical Association) (Eriksson, 2005), TAPPI STANDARD. All of these are responsible for developing standards and instructions as to how to properly.(Sundblad,2015)

One important aspect is also conditioning. Paper is a hydroscopic material and the flexibility of the fibers can somewhat depend on temperature. Therefore, it is important for the environment to have constant temperature and humidity, and these are the same when comparing results. It is also important that the samples are in the environment for a period of a couple of hours before testing. erform testing.(Sundblad,2015).

2.5.1Effect of moisture content

The moisture content of paper has an important effect on paper quality; therefore, paper properties must be measured under standard conditions of temperature and relative humidity [generally 23 °C (73 °F) and 50% relative humidity] since these affect the equilibrium moisture content (EMC). As stated above, the EMC affects strength and other properties of paper. According to TAPPI T 402, paper should be placed in a hot, dry room (20-40°C or 68- 105 °F, at 10-35% relative humidity) before placement in the standard room so that the moisture content of paper approaches its EMC by adsorbing water from the atmosphere. Due to the conditioned when you perform routine quality control at a paper mill? Clearly, if the paper is not conditioned to known moisture content, then the results may be misleading.

2.5.2 Basis weight, grammage

The weight of paper per ream, normally expressed on an air-dry basis is known as the basis weight. For example, a printing paper is reported at 20 pounds per and one grade of lightweight linerboard is 26 pounds per 1000 ft^ the basis weight is measured either directly during paper manufacturing with the j3-ray gauge or off-machine by weighing a precisely cut piece of paper with a balance (TAPPI Standard T 410, which includes a table of ream sizes with conversion factors.) Electronic balances (in preference to mechanical balances) should always be used to increase speed, Accuracy and precision.

2.5.3 Caliper

The nominal thickness of paper is known as its caliper. Caliper is measured in mm for paper or points for paperboard, both of which are in 0.001 in. The metric unit is mm. The caliper of paper is measured by using a micrometer with circular Contact surfaces of 16 mm (0.63 in.) diameter as described in TAPPI Standard T 411.

2.5.4 Bulk Density

The density of a sheet of paper is its mass per unit volume, which is also called the apparent density. Normally density is expressed as *glove?* The density of papers is typically 0.5-0.8 *glove?* For comparison, cell wall material has a density of 1.5 g/cm^3 which means most paper has a high volume of air space. The density is an indication of the relative amount of air in the paper which, in turn, affects optical and strength properties of paper. Density is calculated from the basis weight and caliper of paper . Bulk is the reciprocal of density and is expressed as cmVg (Biermann, 1996).

2.5.5 Tensile index

Both tensile and shear moduli are functions of temperature, and of time in the case of viscoelastic polymers. We shall restrict our discussion to the temperature dependence of the isochronal moduli. (Because the tensile and shear moduli are related to each other through the use of an equation involving the Poisson's ratio, the comments made here on the shear modulus G can be extended to the tensile modulus E , as well.). (Gilleo, 2006).

2.5.6 Burst index

The burst index is obtained by dividing the burst strength by the basis weight. To solve for the burst strength it is necessary to take the burst index and multiply by the basis weight. The burst strength obtained by this method is in kpa. It is necessary to convert kpa to psi to obtain the desired units. Although a flat crush was not performed here, the conversion factor from kpa to psi is always die same. This exercise shows that to convert tensile or burst indexes to tensile or burst strength the basis weight must be known. It is possible to convert a tensile or burst index back and forth from the English to the metric system without knowing the basis weight (Biermann, 1996).

CHAPTER THREE

MATERIALS AND METHOD

3.1. Materials

Tow non-wood fiberous materials were used in the investigation. These included kenaf and bagasse.

3.1.1 Kenaf

Kenaf (*Hibiscus cannabinus*) studied was grown in Shambbat farm – Khartoum North-Sudan.

3.1.2 Sugarcane bagasse

The Bagasse (*Saccharum officinarum*), a by-product of the stem of sugarcane after crushing and juice extraction, was collected from Algneed Sugar Factory, Gezira State, Sudan. The studied sample was air dried and depithed.

3.2. Methods

The kestalks were air-dried, bast fiber was removed from the stalk manually, and the core stalks were chopped to pieces of about 1 inch long.

3.2.1Fiber Morphology

Maceration process was carried out to determine the morphology or physical dimension of fibers. The fibers were cut into matchstick size of 25 to 30 mm in length. This was followed by the addition of 5ml hydrogen peroxide, and 5ml acetic acid into three (3) different test

tubes. The test tubes were boiled in water bath until fibers were completely white. Subsequently, the fibers were washed gently using distilled water, placed in separate test tubes and shakened in a distilled water to get the individual fibers. One drop of safranin-O was added into the fiber and left for 1 hour. A few of the individual fibers from different test tube were mounted on to a glass slide (20 slide) 7for kenaf bast, 8 Bagasse and 6 kenaf core. The fiber length (FL), fiber diameter (FD), lumen diameter (LD),double cell-wall thickness (DCWT) were then measured using the Quant meter Image Analyzer equipped with a microscope.

Morphological indices of kenaf and bagasse fibers were calculated from the above measurements as follows:

A) Slenderness Ratio (Felting coefficient) (SR)

SR = Fiber length/Fiber diameter

B) Runkle Ratio (RR)

RR = 2 X Cell wall thickness/Lumen diameter

C) Fiber Flexibility Ratio (Elasticity coefficient)(FF)

FF = Fiber lumen diameter/ Fiber diameter

3.2.2 Chemical analysis:

Proximate chemical analyses of the fibrous raw materials were carried out according to the following standards. Ash content according toTAPPI T211, cold water and hot water extractive according to TAPPI T211, cellulose content according to TAPPI T17, lignin content

according to TAPPI T222om-96, 1%NaOH extract according to TAPPI T212.

3.2.3 Pulping and pulp evaluation

The soda pulping experiment of oven dried kenaf (core, bast) and bagasse were conducted in a laboratory, cylindrical digester. This digester includes an electrical heater, a motor actuator, and instrument required for measurement and control temperature and pressure. The raw material was 500g oven dried of bagasse, and kenaf (core, bast). Pulping conditions of soda processes to obtain pulp was as follows:

Table 3.1 Pulping conditions for bagasse and kenaf

Control condition	**Bagasse**	**Kenaf(core,bast)**	**Kenaf mixture**
Oven dry weight(g)	500	500	500
Active alkali as Na_2O %	12-13	16-17	16
Liquor : fiber ratio	5:1	6:1	6:1
Max temp. ^oC	160	170	170
Time to max temp, min	40-45	1h	1h
Time at max temp ,min	1h	1h	1h

At the end of cooking the pulp was washed by water and mechanical standard terpo pulper. Evaluation of pulp was followed by paper. Fibers were then disintegrated using a disintegrator according to (TAPPI T205).The cooked pulp was then screened with a screen plate according to (TAPPI T 275).The yield of pulp and reject were determined by measurement in the laboratory. The screened yield was determined from duplicate analysis. The kappa number was determined according to (TAPPI T236om-99) of samples was also determined by duplicate experiments.

3.2.4 Beating and hand sheets formation

The hand sheets were formed according to TAPPI T 220-sp-01 Standards the hand sheets prepared were conditioned according to TAPPI T 402-SP-9. The different pulps were beaten to different beating times in accordance to TAPPI T-200-sp-01 bagasse had three beating times 0, 4 and 5min. Kenaf bast, also had three beating times 0, 1,2min. While kenaf core had tow beating times 0, 5min. TAPPI standard darinablity resulting from the different beating times were measured according to TAPPI T 227om-1199.

3.2.5 Evaluation of paper properties

Evaluation of paper the quality produced from this investigation was based on five properties, namely: bulk density, tensile index TAPPI T-404-cm-92, burst indexTAPPI T-403om-97, brightness TAAPI T 452om-02 and . Details of **table 3-1**

Table 3-2 stander used for hand sheet formation and testing

Testing	**Standard**
Beating of pulp	TAPPI T-200-sp-01
Freeness	TAPPI T 2270m-1199
Sheet formation	TAPPI T-220m-sp-01
Conditioning	TAPPI T-402-sp-98
Tensile index	TAPPI T-404-cm-92
Burst index	TAPPI T-403om-97

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Chemical Composition

Table (4.1) shows the proximate chemical composition and some solubility values in kenaf core and bagasse. Bagasse had shown the higher cellulose content 51% with low lignin content 17% while cellulose and lignin contents in kenaf core were 42.0% and lignin 25.0 % respectively. Lower cellulose and lignin contents were reported for Sudanese bagasse. (Haroon, 2017). In pulp and paper, high cellulose content is preferable because it leads to high yield pulp as well as better paper quality. Moreover, low lignin content is desirable in the pulp and paper because less chemicals and energy are required during the pulping process. Furthermore, low lignin will also produce paper with good optical properties and therefore requires less bleaching and ultimately reducing both the energy needed for processing and the hazardous chemical wastes released to the environment (Kassim, 2015).

The higher ash was observed in Bagasse (3.0%), while kenaf core had showed the lowest 2.9%. Lower ash content is desirable as it expected to decrease chemicals required during pulping and bleaching. The high ash content could lead to bad softness and whiteness of the paper, resulting in reducing of physical properties of the paper (Yu Jiang, 2019). Solubility in water is the measure of the extractive compositions

of the lignocellulosic material. High extractives values indicate high presence of tannins, alkaloids and starch. However, core shown the higher amount of extractives in hot and cold water (10.6, 30.0%) compared to bagasse (3.5and 6.0%) respectively. These values are very high compared with that found in hardwood.

Table 4.1 Proximate chemical composition of kenaf core and bagasse.

Chemical composition%	Kenaf core	Kenaf core*	Bagasse	Bagasse**
Cellulose(K.H)	42.0	45.7	51.0	43.0
Ethanol Extraction	1.83	-	5.49	-
n-Hexane Extraction	1.38	-	4.23	-
Lignin	25.0	19.6	17.0	15.2
Cold Water extract	30.0	-	3.5	10.6
Hot Water extract	10.0	4.4	6.0	11.3
NaOH (1%) extract	26.0	29.3	16.7	15.5
Ash	2.90	2.9	3.0	5.0

* Khristova, italics 2002
** Haroon, 2017

4.2 Fiber Morphology

Table 4-2 shows the fiber measurements for the three raw materials (bagasse, kenaf core and kenafbast). An important feature of non-wood fibers is the wide variability among the lengths of the fibers. In addition to fiber length, analysis of fiber characteristics such as fiber diameter, lumen width, cell-wall thickness and their derived morphological factors have become important in estimating pulp

quality of fibers. Kenafbast fibers resemble softwood fiber with a length of 2.48mm (Table4.2), has drawn quite good research interest for paper pulp and new composites industries. Meanwhile, bagasse fibers however with (0.80mm) fiber length could be compared to that of hardwoods. The kenaf core fibers. Were found to be the shortest (0.64mm) and the widest (26.92µm) among the studies materials. Short fibers do not produce adequate surface contact and fiber-to-fiber bonding. Pulps of kenaf core and bagasse are lower in paper strength because of their shorter fibers than those of with kenafbast longer fibers (Fagbemigun, 2014)

Lumen width affects the beating of the pulp. The larger the lumen width, the better the beating of the pulp because of the penetration of liquids into empty spaces of the fibers. Bagasse having the highest value in lumen diameter compared with kenafbast (Omotoso, 2015). While the bast fibers are expected to produce pulp with good strength properties, the latter pulp will have poor strength. Double Cell wall thickness for bagasse (6.77µm) and kenafbast (2.33µm), this is low value than bagasse. The decrease of lumen diameter and increase in the secondary cell wall thickness increase the fiber strength (Maria, 2013).

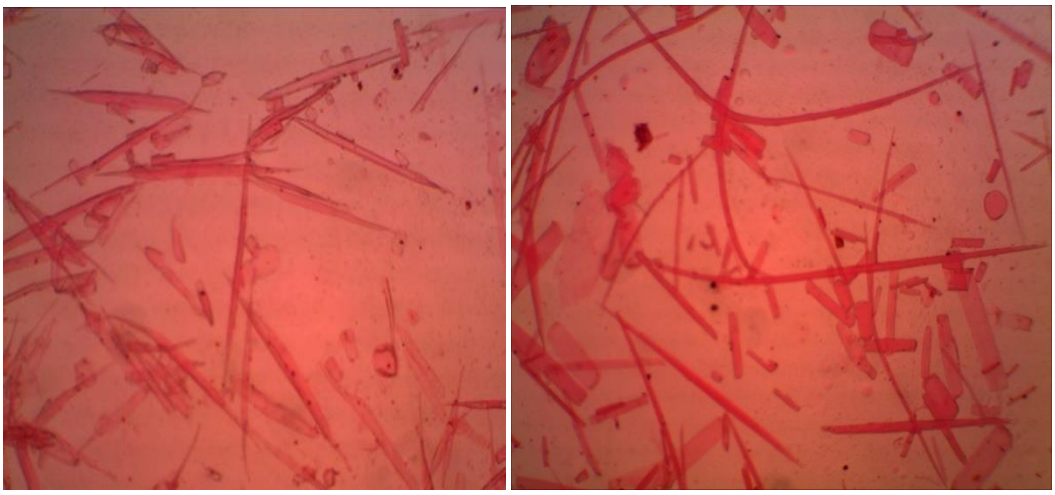
Table 4.2 Fiber dimensions for the three raw materials (Bagasse,kenaf ,core and bast:

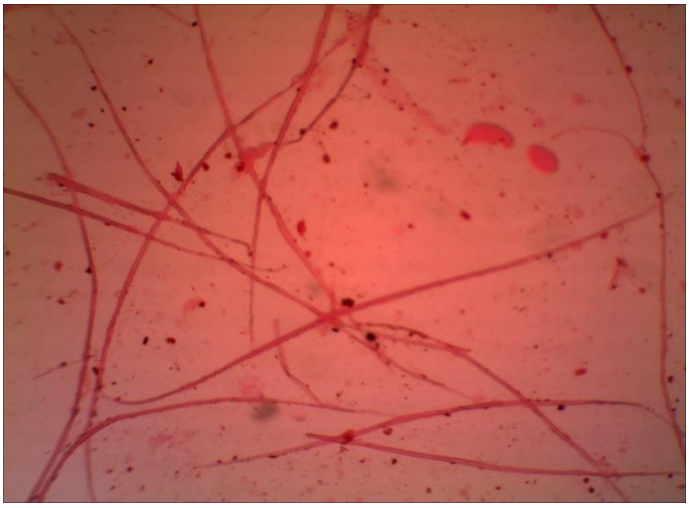
Materials	FL(mm)	FD(µm)	LD(µm)	DCWT(µm)
Bagasse	0.8	17.68A	10.19A	6.77A
Kenaf Core	0.64	26.92	23.85	3.08
.0Kenafbast	2.48	10.12B	7.75B	2.33B

Value significant	-	0.0002	0.0296	0.0001

Figures1: (A) macerated kenaf core, figures (B) macerated bagasse fiber , figures (c)macerated kenaf bast

A B





c

Analysis of variance showed significant difference in FD between the two species (p=0.0002) with bagasse having the higher value (17.68µm) than kenaf (10.12µm). The lumen diameter and Double cell

wall thickness were (10.19, 6.77µm) for bagasse and (7.75, 2.33µm) for kenafbast respectively.

Morphological indices (ratios) of bagasse and kenaf fibers are given in Table (4.3). Kenafbast fibers were by far higher in slenderness ratio (245.06) compared to kenaf core (23.78) and bagasse (45.25). Runkle ratio for kenafbast was found to be (0.31) quite lowers than bagasse (0.62). Rankle ratio is the most important parameter in influencing the fiber papermaking properties. Lower runkle ratio gives high paper strength (Brindha, 2012). The ratio for kenafbast (0.31) than bagasse (0.75), low runkle ratio gives high paper strength (Brindha, 2012). The cell coefficient of rigidity was (0.91) for bagasse and (0.11), for kenaf bast. High fiber rigidity is unaccepted for pulp and paper (Majid, 2014).

The fiber flexibility for bagasse (0.61) and kenafbast (0.78).This ratio with length of fiber and wall thickness determine the flexibility of paper (folding properties).Therefore; kenafbast is expected to be good for paper making (Ekhuemelo, 2016). Flexibility ratio is another important criterion for evaluating fiber quality.

Table 4.3 Morphological indices (ratios) of bagasse and kenaf fibers.

Materials	Slenderness	Runkel's Ratio	Flexibility Coefficient	cell coefficient of rigidity
Bagasse	45.25A	0.62A	0.61	0.91A
Kenaf Core	23.78	0.13	0.88	-
Kenafbast	245.06B	0.31B	0.76	0.11B
Value significant	-	0.0033	0.0138	0.0009

4.3 Pulp properties

Table 4-4 shows pulp properties for the different raw materials The properties of the pulps obtained from the kenaf core and kenafbast showed acceptable yields and kappa numbers. The results revealed that there were some differences in pulp properties of the investigated kenaf core and kenafbast produced by the same pulping conditions. Pulp yields for the studied materials were as follows: Bagasse yielded (45% and 41%) with 21 and 18 kappa number at 12% and 13% active alkali respectively. These yields are within the acceptable ranges. This indicates that increasing the active alkali can shortened the cooking time by more than 10%. As indicated by Bhardwaj (2019). kenafbast (49.5-49%), kenaf core (44%-43%) in the same order with alkali charge (17%-16%) respectively. It could be noticed that increasing the alkali charges has negligible effect on those parameters. A Mixture (50:50 and 70:30) of kenaf core and bast were cooked with 16% active alkali charge, both mixtures ratios produced the same yield (42%). It was observed that kenafbast gave the highest pulp yield regardless the

alkali charge; this could be attributed to the high cellulose content in kenafbast. The increase alkali charge did not change yield or kappa number significantly. Low kappa number, as the case of all of the studies materials, indicates low consumption of bleaching chemicals, which directly led to decreasing the effluent load (Daljeet, 2017).

Table 4-4 show pulp properties for the different raw materials and mixtures:

Properties	Bagasse		Kenaf core		Kenafbast		KB/KC/Mixture	
							50:50	70:30
	AA12 %	AA13 %	AA16 %	AA17%	AA16 %	AA17 %	16%	16%
Screen yield %	45.0	41.0	44.0	43.0	49.5	49.0	42.0	42.0
Reject%	1.1	0.45	0.90	1	0.17	0.12	2	1.5
Kappa number	21	18	21	22	19	18	22	22

AA=active alkali, KC kenaf core, KB kenafbast

4.3 Properties of Paper

Properties of Paper Made from Bagasse:

Handsheets were formed for all of the obtained pulps and also for pulp blends at different ratios. The freeness (drainability or beating time) was determined for the different beating intervals (Table 4.5). It could be noticed from the table that bagasse required minimum beating time. Refining of pulps is one of the most important stages in the paper production process and influences strongly the sheet formation and its physical properties. Beating time, as reflected in freeness of pulp, is generally used as an index in the pulp and paper industry to reflect water filtration speed. The rate of drainage of 1 L of pulp is related to the work done on the fiber during beating and refining. A greater beating degree causes a lower water filtration speed (Jinbao, 2019).

Table 4.5 shows the effect of active alkali percentage and beating time on bulk density of paper made from bagasse, Bagasse cooked at relatively low alkali charge (12-13%) produced paper of acceptable brightness (37) and bulk density between 5.88 g/cm³ for unbeaten pulp to 9.97g/cm3 pulp beaten for 5 minutes..

Table 4.5 Effect of beating time and active alkali and beating time on bulk density of bagasse paper:

Properties	Bagasse with AA12%		Bagasse with AA13%			
Beating time (min)	Darinablity	Bulk density (g/cm3)	Beating time (min)	Darinablity	Bulk density (g/cm3)	Brightness %

Zero	27	5.88	Zero	23	5.88	37
4	55	9.05	6	40	9.11	
5	57	9.31	8	50	9.97	

AA=active alkali

The Burst index for bagasse paper as shown in table (4-6) was found to range from 0.7 to 2.9kpa*m2/g for the unbeaten and beaten pulp respectively with 13% AA.the burst index for bagasse active alkali 12% 0.8 for the un beaten and 2.5kpa*m^2/g beaten.

Table 4-6 effect of Active alkali and beating time on burst index for bagasse paper:

Bagasse with 12%AA			Bagasse with 13%AA		
Beating time(min)	Darinablity	Burst index kpa*m^2/g	Beating time(min)	Darinablity	Burst index Kpa*m^2/g
Zero	27	0.8	Zero	23	0.7
4	55	2.2	6	40	2.6
5	57	2.5	8	50	2.9

AA active alkali

Table 4-7 shows the effect of AA% and beating time on tensile index of bagasse paper. The tensile index ranged between 31.0 Nm/g for unbeaten pulp with 12% active alkali and 78.0 Nm/g with 13% active alkali 12% beaten to 5 min. (Ibrahim, 2011) who studied Nigerian bagasse pulp reported somewhat different results; tensile index was 51.4. It could be noticed that lowering the active alkali charge from

13% to 12% did not only increase the screened yield, but also resulted in sheets with lower strength properties without beating time.

Table 4-7 effect of AA and beating time on tensile index for bagasse paper:

Bagasse with 12%AA			Bagasse with 13%AA		
Beating time (min)	Darinablity	Tensile index Nm/g	Beating time (min)	Darinablity	Tensile index Nm/g
zero	27	31.0	Zero	23	51.4
4	55	66.5	4	40	62.5
5	57	75.7	5	50	78.0

Table 4.8 shows the effect of beating time on properties of paper made from kenafbast cooked with 17% AA. The highest tensile index was for paper made from unbeaten pulp and decreased with beating time. . This decrease in tensile strength with beating time is due to the fact that the long fibers of kenafbast are cut down to shorter segments during beating, the other properties did not show any trends.

The handsheets produced from kenafbast and kenaf core cooked at different condition (16-17% AA) has shown good initial brightness (30% respectively). The bulk density for kenafbast was 10.30g/cm^3 with beating time obtained at 46^{o}SR

Table 4-8 effect of beating time on properties of paper made from kenafbast:

Kenafbast with 17%Active alkali					
BT(min)	Darinablity	Tensile index Nm/g	Burst index Kpa*m2/g	Bulk density g/cm3	Brightness %
zero	36	105	4.8	10.24	30
1	43	85	5.7	9.38	-
2	46	79	5.1	10.30	-

*BT= beating time

Kenafbast fiber recorded the highest tensile index (105Nm/g) for unbeaten pulp and decreased with beating time (table 4.8). Unfortunately, beating has negatively affected the tensile index, indicating shortening of the long bast fiber during the beating process. The burst index of kenaf bast was 4.8 (36^oSR) 5.7 (43^oSR) and 5.18kpa*m^2/g (46^oSR), showing that the beating should be kept at the minimum degrees.

Table 4.9 showed that the tensile index of kenaf core cooked with 16% AA ranged between 23.8Nm/g for the unbeaten pulp and 45.7Nm/g for pulp beaten for 5 min, However, the Burst index also increased with beating from 0.7 to 1.6 kpa*m^2/g, respectively. The paper from kenaf core cooked with 17% AA showed similar trends.

Table 4-9 effect of Active alkali and beating time on tensile index and burst index of paper made from kenaf core:

Kenaf core 16%AA				Kenaf core 17%AA			
B T(min)	Darinablity	Tensile index (Nm/g)	Burst index kpa*m2/g	BT (min)	Darinablity	Tensile index (Nm/g)	Burst index kpa*m2/g
Zero	27	23.5	0.5	Zero	27	23.8	0.7
5	40	45.7	1.5	5	40	40.5	1.6

BT-beating time

The presence of fines and parenchyma cell with higher surface area in kenaf core reflected in its lowest freeness and highest drainage time compared to kenafbast fibers pulp (Mosselo, 2010).

Table 4.10 shows that bulk density of paper made from kenaf core cooked with 16% AA increased slightly with beating time. However, the increase was more significant when the AA was increased to 17%,but the bulk density decreased when The AA was increased to 17%.

Table 4-10 effect of Active alkali and beating time on bulk density and brightness of paper made of kenaf core:

Kenaf core withAA16%				Kenaf core with AA17%			
BT (min)	Darinablity	Bulk density g/cm3	Brightness %	BT (min)	Darinablity	Bulk density g/cm3	Brightness %
Zero	27	10.37	30	zero	27	5.75	30
5	40	11.58		5	40	9.44	

*BT= beating time

Table 4-11 shows the effect of cooking mixtures of Kenafbast and kenaf core fibers using two different ratios (50:50 and 70:30) and cooked in 16% active alkali on physical properties of paper. The pulp from 50:50 ratios gave an acceptable brightness (25%) and bulk density increased from 6.28 to 6.98g/cm^3 with increasing beating time in the first mixture (50:50) and slight increase from 9.71 to 9.77 in the second ratio. Table 4.12 shows that burst index for the first mixture was found to increase from 1.3 to 1.9kpa*m^2/g with increased beating time, while tensile index increased from 61.6 and 68.5Nm/g with increased beating time. Higher values were obtained for all of the studied properties when a higher ratio of kenafbast fibers were used (70:30), where tensile index increased from 75.9 to 90.9Nm/g; while burst index increased from 4 to 4.7kpa*m^2/g. It could also be noticed

from the table that mixing kenafbast and core)required minimum beating time to make an appreciable increase in tensile index.

Table 4-11 Effect of beating time on bulk density and brightness of paper made from cooking mixtures of kenaf core and kenafbast cooked at 16% active alkali.

Mixtures kenafbast and core 50:50				mixtures kenafbast and core 70:30			
BT (min)	Darinablity	Bulk density g/cm3	Brightness %	BT (min)	Darinablity	Bulk density g/cm3	Brightness %
Zero	36	6.28	25	Zero	39	9.71	20
2	41	6.98	25	2	50	9.77	20

BT=beating time

Table 4.12 shows the strength properties of handsheets prepared from mixed kenafbast and bagasse pulps at different ratio 50:50 and 70:30. The results revealed improvement in all of the strength properties with increased beating time and increased portion of kenafbast. The brightness was found to be 27 and 28. Incorporating other natural fibers may enhance mechanical properties of the paper such as its tensile index (Rafidah, 2017).

Table 4-12 effect of pulping mixtures of kenafbast and kenaf core and beating time on tensile index and burst index

mixtures kenafbast and core 50:50				mixtures kenafbast and core 70:30			
BT (min)	Darinablity	Tensile index Nm/g	Burst index kpa*m^2/g	BT (min)	Darinablity	Tensile Nm/g	Burst index kpa*m^2/g
Zero	36	61.6	1.3	Zero	39	75.9	4
2	41	68.5	1.9	2	50	90.9	4.7

BT=beating time

Table 4-13 shows effect of mixing kenafbast and kenaf core pulps and beating time on physical properties. The brightness of kenafbast and kenaf core blend (50:50, 70:30) was 25 and 22%, respectively. the bulk density for the first ratio (50:50) increased from 6.34 to 12.06 g/cm^3 with increasing beating time, while the change was not significant in case of the second ratio,

Table 4.13 effect of mixing kenaf core and kenafbast pulps and beating time on bulk density and brightness of paper:

Blend kenafbast and kenaf core50:50				Blend kenafbast and kenaf core70:30			
BT (min)	Darinablity	Bulk density g/cm^3	Brightness %	BT (min)	Darinablity	Bulk density g/cm^3	Brightness %
zero	38	6.34	25	Zero	39	11.25	22
1	45	10.17	25	1	45	10.93	22
2.30	50	12.6	25	2.30	50	11.1	22

BT=beating time

Table 4.14 shows the effect of mixing kenaf core and kenafbast pulps and beating time on tensile index and burst index of paper: Best values were obtained when the blending ratio of kenafbast to kenaf core was 70:30, where tensile index increased from 62.7 to 95.5 Nm/g with increasing beating time whereas burst index increased from 2.5 to 4.0 kpa*m/g. In case of 50:50 ratio the tensile index increased from 40.9 to 73.1 Nm/g while burst index increased from 1.1 to 3.3 kpa*m/g. Tensile and burst strength are known to increase with fiber length and refining which leads to better distribution of fibers and better fiber contacts (Gonzalo, 2017).

Table 4.14 Effect of mixing kenaf core and kenafbast pulps and beating time on tensile index and burst index of paper:

blend kenafbast and kenaf core70:30				Blend kenafbast and kenaf core 50:50			
BT (min)	Darinablity	Tensile index Nm/g	Burst index kpa*m/g	BT (min)	Freeness (0SR)	Tensile index Nm/g	Burst index kpa*m/g
zero	38	62.7	2.5	Zero	38	40.9	1.1
1	45	90.5	3.4	1	45	73.1	2.6
2.30	50	95.5	4	2.30	50	71.1	3.3

BT=beating time

Table 4.15 shows the properties of paper made from a 50:50 mixture of kenaf core and bagasse pulps. The tensile index of this blend increased with beating time from 28 to 55Nm/g while the burst index increased from 0.50 to2.2 kpa*m/g. The bulk density, however, ranged between (10.10 and 6.29 g/cm3), while the brightness obtained was 37 %.The tensile index obtained here is lower than those with other combinations. This is due to the fact that both kenaf core and bagasse have short fibers compared to kenafbast.

Table 4-15 effect of mixing kenaf core /bagasse pulp and beating time on paper properties

Bagasse and kenaf core 50:50					
BT (min)	Darinablity	Tensile index Nm/g	Burst index kpa*m/g	Bulk density g/ cm3	Brightness %
zero	28	28	0.5	10.10	37
5	41	41	1.7	6.29	37
7	55	55	2.2	9.18	37

BT=beating time

Table 4.16 shows the effect of bagasse/kenafbast blend and beating time on tensile index and burst index of paper. When the ratio was 50:50 the tensile index increased from 53.5 to 87.4 Nm/g with increasing beating time, while burst index increased from 1.8 to 3,6 and then dropped to 3.5 kpa*m/g with increasing beating time. In case of the other ratio (70:30) the tensile index increased from 41.8 to 66.3 Nm/g, while burst index increased from 1.1 to 3.0 kpa*m/g., because the proportion of bagasse with shorter fibers was higher.

Table 4-16 Effect of bagasse/kenafbast blend and beating time on tensile index and burst index on paper:

Bagasse and kenaf bast50:50				Bagasse and kenaf bast70:30			
BT (min)	Darinablity	Tensile index Nm/g	Burst index kpa*m2/g	BT (min)	Freeness (0SR)	Tensile index Nm/g	Burst index kpa*m2/g
zero	31	53.5	1.8	zero	31	41.8	1.1
1	40	67.4	3.6	2	41	47.6	2.3
2	50	87.4	3.5	3	52	66.3	3

BT=beating time

Table 4.17 show the Effect of mixing kenafbast /bagasse pulps and beating time on bulk density and brightness on paper: The bulk density decrease with beating time (10.4-9.38 g/cm^3) and brightness (27%) did not change much with beating time in case of the 50:50 ratio, while bulk density increased from 9.25 to 11.23 g/cm^3 with beating time and brightness was 28%with increase mixing ratio(70:30) .

Table 4-17 Effect of kenafbast /bagasse blend and beating time on bulk density index and brightness on paper:

Bagasse and kenaf bast50:50				Bagasse and kenaf bast70:30			
BT (min)	Darinability	Bulk density cm3/g	Brightness %	BT (min)	Darinability	Bulk density g/cm3	Brightness %
zero	31	10.24	27	zero	31	9.25	28
1	40	10.04	27	2	41	9.51	28
2	50	9.38	27	3	52	11.23	28

BT=beating time

Table 4.18 shows the effect of mixing kenaf bast, kenaf core and Bagasse pulps (60:20:20) and beating time on paper properties. The tensile index decreased from 79.5 to 58.8 and then increased to 94.1 Nm/g with beating time. The burst index showed the same trend by decreasing from 4.5 to 2.0 and increasing again to 3.9 kpa*m/g, Bulk density, on the other hand, showed the opposite trend by increasing from 6.54 to 9.91 and then decreasing slightly to9.57 kpa*m^2/g with beating time; while brightness remained at 25 % .

Table 4-18 Effect of kenaf bast, kenaf core and Bagasse blend and beating time on tensile index and burst index on paper:

kenaf bast and core and Bagasse	60:20:20				
BT (min)	Darinablity	Tensile index Nm/g	Burst index kpa*m/g	Bulk density g/cm3	Brightness %
zero	36	79.5	4.5	6.54	25
1	43	58.8	2	9.91	25
2	55	94.1	3.9	9.57	25

Bleachability of the pulp from this material meaning that lower chemical charges are required compared to those of paper produced annual plant (Haroon, 2018)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

The following conclusion of the present study:

1. Kenaf bast has long fibers and produced paper with higher strength than kenaf core and Bagasse.

2. This raw material high cellulose and low lignin, in pulp and paper, gave high pulp yield as well as better paper quality. Moreover, low lignin content is desirable in the pulp and paper because less chemicals and energy are required during the pulping process.

3. Tensile index and burst and bulk density of paper made from Bagasse increased with increased active alkali and increased beating time

4. Tensile index and burst index of paper made from kenaf core increased with increased active alkali and beating time

5. Tensile index and burst index of made from mixed pulp from kenaf bast and kenaf core increased with increased with the increase of kenaf bast component.

6. Tensile index and burst index of paper made from Bagasse and kenaf bast blend decreased with increased Bagasse component and increased with increased beating time

RECOMMENDATIONS

Bagasse and kenaf as satiable fibrous raw materials for paper production in Sudan.

While Bagasse and kenaf core pulps can produce medium to low grades of pulps, they should be mixed with kenaf bast for production of better quality papers.

Further studies on the pulping of kenaf and Bagasse mixtures at different particle sizes and ratios, should be carried out.

REFERENCE

Abeke Omotoso.M, A. Owolabi1 (2015) Pulp and Paper Evaluation of Solid Wastes from Agricultural Produce, *International Journal of Chemistry*; 7, No. 2, ISSN 1916-9698.

Adegbite. A. (2018), Response of selected kenaf cultivars to Meloidogyne incognita under greenhouse conditions, *international of advance agricultural research*, (6), ISSN 2053-1265.

Ashori .A, (2006) Nonwood Fibers—A Potential Source of Raw Material in Papermaking, *Polymer-Plastics Technology and Engineering*, (45): 1133–1136.

Ahmed.M.H, Slih A, Abd Elnasir M. A. F.m, and Abdurrahman M, (2013), Effect of Urea-treatment on Nutritive value of Sugarcane Bagasse, *ARPN Journal of Science and Technology*, 3, NO. 8, 2225-7217.

Ajay. C., K. Anju, and Ghosh., U.K, (2013) Blending impact of softwood pulp with hardwood pulp on different paper properties, *tappsa journal volume.*

Brindha.D,Vinodhini.s and Alarmlumangai.K,(2012)fiber dimension and chemical contents of fiber from passiflora foetida, l. andtheir suitability in paper production, *Science Research Reporter* 2(3): 210-219.

Bhardwaj.N.K, Kaur.D, Chaudhry.S, Sharma.M, and Arya.S,(2019), Approaches for converting sugarcane trash, a promising agro residue,

into pulp and paper using soda pulping and elemental chlorine-free bleaching, Journal of cleaner production.

Biermann, C. J. (1996). Hand Book of Pulping and Papermaking. *Elsevier Science & Technology Books*, 754pp.

Bouzios .S, Worrellb E.,(2017) , Towards a Multiple Input-Multiple Output paper mill: Opportunities for alternative raw materials and sidestream valorisation in the paper and board industry, *Resources, Conservation & Recycling* ,1(25) , 218- 232 .

Carrillo. I, C. Vidal, J. P Elissetche & Regis. T. M,(2017), Wood anatomical and chemical properties related to the pulpability of Eucalyptus globulus: a review, *Journal of Forest Science*, DOI: 10.2989/20702620.2016.1274859.

Daljeet. K., Nishi .K. Bhardwaj, and Rajesh ,(2017) A study on pulping of rice straw and impact of incorporation of chlorine dioxide during bleaching on pulp properties and effluents characteristics, *Journal of Cleaner Production*, 10.1016/j.jclepro.2017.09.111.

Ekhuemelo, D.O., and Udo, A. M,(2016), Investigation of Variations in the Fibre Characteristics of Moringa Oleifera (Lam) Stem for Pulp and Paper Production, *International Journal of Science and Technology* (5) , No. 1

Ervasti, I,(2016) Wood fiber contents of different materials in the paper industry material chain expressed in round wood equivalents (RWEs), *Silva Fennica* (50) no. 4 article id 1611, 1-22. DOI: 10.14214/sf.1611

Fahmy .Y. T.Mobarak, El-Sakhawy.F. M., and Fadl, M .H (2017), Agricultural Residues (Wastes) for Manufacture of Paper, Board, and Miscellaneous Products: Background Overview and Future Prospects, *International Journal of ChemTech Research*, 10(2): 425-448.

Fagbemigun .T. K., O.D. Fagbemi, O. Otitoju, E. Mgbachiuzor, C.C. Igwe,(2014), *International Journal of AgriScience* 4(4): 209-213,ISSN:

2228-6322. FAO (2011). Pulp and Paper Capacities: Survey 2010-2015. *FAO, Rome*, 99pp.

Fagbemi1.O. D, Taiwo K. Fagbemigun1, O. Otitoju1, E. Mgbachiuzor1 and C. Igwe1.C. , (2014), Strength Properties of Paper from Pulp Blend of Kenaf Bark and Corn Husk: A Preliminary Study, *British Journal of Applied Science &Technology*, **4** (28): 4124-4129

Gonzalo.A., F. Bimbela, J.L. Sánchez, J. Labidi, F. Marín,and J. Arauzo(2017), Evaluation of different agricultural residues as raw materials for pulp and paper production using a semi chemical process, *Journal of Cleaner Productio.*

Gilleo K. B,(2006), Rheology and Surface Chemistry-PFundamentals and Testing, Wiley-Interscience, Sheldahl, Inc. Northfield, Minnesota, Printed in the United States of America on acid-free paper *n*, 2017.04.036.

Gartside, G., Langfors. N. G. and Miller, K. (1983). The effect of milling on the papermaking.

Haroon A. M. , Yu Liu,and L. A. Lucia(2018) Sudanese Dicots as Alternative Fiber Sources for Pulp and Papermaking,*DRVNA INDUSTRIJA* 69 (2) 175-182.

Hammett, A.L., Youngs, R.L., Sun, X., and Chandra, M., 2001. Non-wood fiber as an alternative to wood fibber in China's pulp and paper industry. *Holzforschung*; 55: 219-224.

Haroon .A.M.S., yuliu, Lucian.A.L, and, and Chen (2017), evaluation of Sudanese sorghum and bagasse as a pulp and paper feedstock, *BioResources*, 12(3), 5212- 5222.

Idris.M. k., Yassin .K. E.(2015) , Determination of the Effects of Bagasse Ash on the Properties of Portland Cement , *Journal of Applied and Industrial Sciences*, 3(1)6-11, ISSN: 2328-4595.

Ibrahim, H.,Bugaje, I. M., and Mohammed, I. A,(2011) Utilization of Bagasse as Raw Material for the Production of Pulp and Paper in Nigeria, *International Journal of Engineering and Mathematical Intelligence*, 2, No. 1 – 3.

Jiang .Y.u, Q. Wu, Z. Wei, J. Wang, Z .Fan, Z. Pang, Z. Zhu, S. Zheng, and X.Lin, Y.Chen,(2019) Papermaking potential of Pennisetum hybridism fiber after fertilizing treatment with municipal sewage sludge, *Journal of Cleaner Production*(208),889-896.

Judt, M. (1993). Non-wood plant fibres, will there be a come-back in paper-making? Industrial Crops and Products; 2: 51-57.

John C.F. walker,(2006), Primary Wood Processing, *Published by Springer*, P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

Kang, T., Somboon, P. and Paulapuro, H, (2006) Fibrillation of Mechanical Pulp Fibers. *Paperija Puu*. 88(7), p.409-411.

Kaur. D, BhardwaN. K. j, and Lohchab.R. K.,(2017), A study on pulping of rice straw and impact of incorporation of chlorine dioxide during bleaching on pulp properties and effluents characteristics, *Journal of Cleaner Production, Journal of Cleaner Production*, (17).

Khan.G. Kazi.S N, Syed, M. A, Nasar .S and A Kakar (2018) Comparative analysis of heat transfer coefficient for wood and non-wood pulp fiber, *Materials Science and Engineering* (414)012-027

Khristova. O. K, Pattb .R, Karar. I., and Khider T (2006), environmentally friendly pulping and bleaching of bagasse, *ndustrial Crops and Products*, (23), 131– 139.

Khider .T. O., A Look at Pulp and Paper Industry in Sudan, (2013), *FOREST PRODUCTS & INDUSTRIES*, 2 (6), 2325-453.

Lewis, M. and Jackson, M. (2002). Nalgrass: A Nonwood Fiber Source Suitable for Existing US Pulp Mills. In: Trends in New Crops and New Uses. J. Janick and A. Whipkey (eds.). *ASHS Press, Alexandria*, VA: 371 -376.

Lois-Correa, J.A,(2012)Depithers for Efficient Preparation of Sugar Cane Bagasse Fibers in Pulp and Paper Industry, *Ingeniería. Investigación y Tecnología,* XIII, núm. 4, 417-424.

Lwako K. O. M., Byaruhanga Joseph K., and K. J. Baptist,(2013),A Review on Pulp Manufacture from Non Wood Plant Materials, *International Journal of Chemical Engineering and Applications*, (4)281.

Maina. N. M., R. A Taliba, C, Ibrahimd R. I, Abdul Rahmana .R, Mohamed.A.Z. (2014) Suitability of Coir Fibers as Pulp and Paper, *Agriculture and Agricultural Science Procedia*, (2) , 304 – 311.

Majid.K, Reza.B, (2014) Short communication. Radial variations of wood different) properties in Diospyros lotus, *InstitutoNacional de Investigación y TecnologíaAgraria y Alimentaria (INIA) Forest Systems* 23 (1): 171-177.

Maria. E .A F, T. V. C.Pereiraa,O. F.M.Gomesb, F. d. Andrade Silvaa,R. Dias T.Filhoa,(2013), The effect of fiber morphology on the tensile strength of natural fibers, *mater res technol*, **2(2)**:149–157.

Monica. EK.M, Gellerstedt.G, and Gellerstedt.G. G, (2009). Wood Hardling: pulp chemistry and technology, volume 2, Heniksson (eds): walker de Gruyer Gmbit co.Berlin:13-34.

Mohieldin S.D.,(2014), Pretreatment Approaches in Non-wood Plants for Pulp and Paper Production: A Review, JOURNAL OF FOREST *PRODUCTS & INDUSTRIES*, 3(2), 84-88 ISSN:2325–4513(PRINT) ISSN 2325 - 453X

Mosselo.A.A, and Harun.J, Ibrahim.R, Resalati .S.R.F, Paridah.md.t, andYusoff.M.N,(2010) evaluation of linerboard properties from malasysian culaveted kenaf soda anthera qunone pulps versus commercial pulps, *BIORESOURES* 5(3),1595-1604.

Mohd Kassim.A. S, A. M. Aripin, N. Ishak, M. H. Zainulabidin,(2015) Cogon Grass As an Alternative Fibre for Pulp and Paper-Based Industry: On Chemical and Surface Morphological Properties, Applied Mechanics and Materials Vols. 773-774,pp 1242-1245.

Rahman .S. jafari p, Resalati .H, and Rejman C,(2011),newsprint from soda Bagasse pulp in admixture with hardwood CMP pulp , *newsprint*

Bio resource , 6(3) . 2483- 2491 .

Rafidah. D., Ainun, Z. M. A., Hazwani, H. A, Rushdan .I, Luqman, C. A., Sharmiza, A.2, Paridah, M. T.1 and Jalaluddin, H,(2017),Characterization of Pulp and Paper Manufactured from Oil Palm Empty Fruit Bunches and Kenaf Fibres, *TROPICAL AGRICULTURAL SCIENCE*, 40 (3): 449 – 458.

Reddy, N. and Yang, Y. (2005). Biofibers from agricultural byproducts for industrial applications. *Trends in Biotechnology*, 23(1): 22-27.

Richard J. Kerekes (2015) Perspectives on High and Low Consistency Refining in Mechanical Pulping, "Perspectives", *BioResources* 10(4), 8795-8811.

Robert W. Hurter, P. Eng., MBA (2002), *strategic market management system pulp and paper*, 4-5330 Canotek Road, Ottawa, Ontario, Canada K1J 9C1.

Saba.A.N. M.T. Paridah and M. Jawaid (2015) Mechanical properties of kenaf fibre reinforced polymer composite: A review, *Construction and Building Materials*, vol76, 87–96.

Saeed .H. A. M., Y. Lucian A. Lucia1, and H. Chen1(2017),characterization and evaluation of pulp and paper from Sudanese wood species for pulp and paper making, *International Journal of Recent Scientific Research*, (8), 19110-19118.

Saeed H. A. M. , Yu Liu1, L. A. Lucia, and Honglei. C, (2019) Sudanese Dicots as Alternative Fiber Sources for Pulp and Papermaking, *drvna industrija* 69 (2) 175-182.

Samariha. A, Kiaei2.M, Talaeipour.M and Mohammad Nemati,(2011), Anatomical structural differences between branch and trunk in Ailanthus altissima wood, *Indian Journal of Science and Technology*, 4 No. 12.

Sexita, .H. potthast A., and KrotschekA. W, (2006), Hand Book of paper and paper board, Edited by Herbert HolikWiley – *VCHVerlagbGmbHCO Printed in the Federal Republic of Germany*.

Sundblad.A, Predictions of pulp and paper properties based on fiber morphology (2015), master *thesis in macromolecular materials stockholm,* sweden.

Tschirner, U., Ramaswamy, S. and Goel, A. (2003). Effect of Cereal Straw Fibre Addition to Papermaking Furnish. *Pulp & Paper Canada*; 104(10): 26-29.

Upadhyaya .J.s, D. Dutt, B. singh and CH tyagy, (2008) Hibiscus cannabinus and Hibiscus sabdariffa as an alternative pulp blend for softwood: optimization of soda pulping process, *Indian journal of chemical technology*, (15)

UNEP (2009). Converting Waste Agricultural Biomass into a Resource: Compendium of Technologies. *United Nations Environmental Programme*, 437pp.

Viller. J. C., Revilla, E., Gómez, N., Carbajo, J. M. and Simón, J. L. (2009). Improving the use of kenaf for kraft pulping by using mixtures of bast and core fibers. *Industrial Crops and Products*, (29): 301–307.