THE STUDY ON THE PRODUCTION OF PULP AND PAPER HAND SHEET FROM *ABELMOSCHUS ESCULENTUS* (OKRA STEM)

BY

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CERTIFICATION

I certify that this project was carried out by OSUNKOYA, OLUWATOFARATI TOSIN at the Department of Chemical Sciences, Mountain Top University, Ogun State, Nigeria under my supervision.

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DEDICATION

I dedicate this project to ALMIGHTY GOD for his guidance and protection and also for the gift of life and for enabling me to complete my academic work in good condition and also to my loving parents for their continuous support MR. & MRS. OSUNKOYA. May ALMIGHTY GOD continue to bless you. Amen.

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I appreciate the ALMIGHTY GOD for his love and protection during the period of my stay in school and for the grace to successfully complete my academic pursuit in good health and sound mind. I would also like to acknowledge my parents, MR. & MRS. OSUNKOYA for the encouragement love and support financially and for all the prayers and also my siblings (Oluwadara, Oluwatofunmi, Oluwasegun and Oluwagbemiga Osunkoya) for their constant and unfailing support.

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ABSTRACT

The increase in the global consumption of paper and allied products has remained a topical issue in recent time. Wood contributes the major raw material used for the production of pulp and paper worldwide and this has led to the incessant depletion of forestry products with resultant environmental degradation. This present work involves the use of raw material of *Abelmoschus esculentus* (okra stem), a non-woody cellulosic biomass wastes for pulp and paper industries.

Pulp production of the *A. esculentus* was carried out using Kraft pulping process with NaOH and Na_2S alkali cooking liquor and various characterizations was carried out using the Technical Association of the Pulp and Paper Industry (TAPPI) Standards. The paper characterization i.e. tensile and tear strength property of the Kraft paper hand sheets and hydrogen peroxide bleached paper were analyzed using the Saumya Universal Testing Machine (UTM) model UTM D2.

The yield of the Kraft Pulp obtained was 62 % while the hydrogen peroxide bleached pulp gave a pulp yield of 75 % resulting in 13 % increase in the yield of pulp. The Kappa number obtained was 29.8. The values for the Ash content, Lignin content, Moisture Content, NaOH Solubility, Hot Water Solubility, Cold Water Solubility and Extractive content were 6.60 %, 6.78 %, 5.0 %, 33 %, 13.26 %, 8.43 % and 48.20 % respectively.

The results of the paper characterization that bleached paper gave 1.60 Kgf, 0.40 mm, 106.67 Kg/cm^2, 1000.00 Kg/cm^2 and 3.80 mm values for Yield Load, Yield elongation, Tensile Strength at Yield Load, Tensile Strength at Breaking Load and Elongation at Maximum Load respectively. While the Kraft paper hand sheets gave the values of 4.70 Kgf, 0.50mm, 313.33 Kg/cm^2, 433.33 Kg/cm^2 and 1.20 mm for Yield Load, Yield elongation, Tensile Strength at Yield Load, Tensile Strength at Breaking Load and Elongation at Maximum Load respectively.

The overall results showed that *Abelmoschus esculentus* (Okra stem) can be used as a viable alternative biomaterial for the production of pulp fibers to boost the availability of fibers for the production of pulp and paper products.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Papermaking is considered as one of the ancient crafts and one of the modern industries in the world and. The science and technology of paper making techniques explain the processes, equipment, and materials used in producing paper and allied products. Some applications of these paper products are widely used for printing, writing, and packaging, among other purposes and useful products. The modern technology currently in use in paper manufacturing employs the industrial machineries with articulated processes; however paper sheet still finds wide varieties of industrial applications especially in specialized craft designs and artistic expression. In its technical form, paper is described as an aqueous deposit of any vegetable fiber in form of sheet (Papermaking, 2007).

In paper production process entails the dilute suspension of separate cellulose fibers in water. This is later drained through paper former equipment that allows the bonding of the fibers to form a mat of randomly interwoven fibers. Water is then removed from the paper sheet by pressing through a suction pump. After the drying process, a flat and uniform strong paper sheet will be formed.

Before the development and widespread acceptance of automated machines, all the papers were made manually by hand, designed or laid a sheet at a time by skilled, specialized and trained laborers. Up till now, some people still produce paper by hand use tools and technologies quite similar to those existing hundreds of years ago, as originally developed in China and Asia, or those further modified in Europe. Handmade paper is still valued for its uniqueness and the skilled craft involved in making each sheet, in comparison with the great amount of homogeneity and excellence at lesser prices achieved amongst industrial produces (Papermaking, 2007).

Paper serves as a dominant and essential drive of modern communication in our daily activities in the society because of its wide range of use in education (for the printing and publishing of books), offices (for printing and photocopying of documents), at home (to clean and dry things) and generally for keeping information (MBendi, 2005). Paper is considered to be among the most versatile and common products in the society (Gaboni, 2005).

Over the years, wood contributes about 90% of the conventional raw material used for pulp and paper production in the world (Madakadze *et al.*, 1999). However, the depletion of forest resources to obtain wood had created a negative effect on the surroundings and human lives (Mohanty *et al.*, 2005). This has been a main concern because of the adverse environmental implication arising from of the depletion of forestry resources (Vivek and Maheswari, 1998). Due to adverse effects of wood depletion and the high price of wood pulp, quite numbers of countries are turning back to other sources of fiber. A review on the global production and consumption rate of paper products showed that 45 countries produced non wood paper, accounting for 9 % of the world's paper supply (Weston, 1996). It has been shown that the process of producing paper from non-wood fiber material is less expensive than that of wood fiber (Weston, 1996). Sam (2004) in his research resolved that the world’s consumption of paper has increased by 400 % in the past 40 years. The study also observed that the consumption of paper products every year is about 300 million tons. Currently, global papermaking fiber consumption is likely to increase from approximately 300 million tons from 1998 to about 425 million tones in 2010 and has been on the increase now (Pande, 2017).

The pulp and paper making industry has faced criticism from environment bodies like Natural Resources Defense Council for constant depletion of wood and clear cutting of old growth forest. The industry's development is to grow and extend globally to countries like Russia, China and Indonesia with little wages and environmental oversight. According to Greenpeace, farmers in Central America illegitimately rip up vast tracts of forest for cattle rearing and soybean production without any consequence attached, and companies who also buy wood from private land owners contribute to incessant deforestation and depletion of the Amazon Rainforest. Alternatively, the situation is a bit different where forest growth has been on the growth for a number of years. In Sweden, it was resolved that for each tree that is cut down, two are planted. Papers manufactured from other non-wood fibers, (cotton being the most common) and agro-wastes have a tendency to be valued higher than wood-based paper. According to Quimby (1975), paper residuals can be successfully recycled back to the original products from which they were generated if these are kept separate from other residuals. Some residuals (e.g. tin and iron) can be recycled following mixed collection and separation by mechanical means. Paper residuals, alternatively, lose high-grade qualities on being mixed with other residual and are not mechanically separable by current techniques. This means that a system for separate storage at the site of generation and separate collection needs to be designed and implemented for better recycling. It is necessary to note that biomaterials that are being considered as a potential fiber source for pulp and papermaking process should possess suitable qualities needed for industrial applications. A series of researches were done to analyze the effect of recycling on the quality of rapper. All potential sources of fibers for paper making must have satisfactory water retention capacity. Some of the TAPPI (Technical Association of the Pulp and Paper Industry) testing parameters include; analyses of the tensile and tear strength properties, determination of fiber length, and characterization of morphological fiber properties, abrasion strength and freeness test.

Despite monitoring, guidelines as well as developments made by the industry itself, papermaking still serve as a concern from an environmental perspective, due to its use of harsh chemicals, its need for large amounts of water, and the resulting contamination risks.

Paper making, irrespective of the scale, involves production of a dilute suspension of fibers in water, forcing the suspension to drain from a screen thereby producing a mat of interwoven fibers. Water is then removed from the mat of fibers using a press (Rudolf et al., 2005). The method of manual production of paper has undergone minute changes over time, despite advances in technologies. The principles of manufacturing handmade paper are therefore generalized into five steps:

1. Separating the useful fiber from the rest of raw materials. (e.g. cellulose from wood, cotton, etc.)
2. Beating the fiber into pulp
3. Adjusting the colour and other properties of the paper by the addition of special chemicals
4. Screening of the resultant solution
5. Pressing and drying to get the actual paper

Screening of the fiber involves the use of a mesh produced from a non-corroding and non-reactive material, for example brass, stainless steel or a synthetic fiber, which is placed in a woody frame related to the form of a window, this tool being known as a paper mould. The dimension of the paper sheet is governed by the open area of the frame. The mould will then be submerged into solution at a strategic position, mostly in vertical direction and drawn out horizontally to ensure a uniform coating of the mesh. Excess water is expelled from the paper former by pressing technique. This collection of wet mats of paper sheet is pressed using a hydraulic press in a way that ensures that the fiber is not crushed. The damp fiber can then be dried using vacuum or air drying. Sometimes, each paper sheet can be rolled to flatten, refine or harden the surface. Lastly, the paper sheet can then be cut into desired or standard shape such as A4, letter, legal and thereby packed (TAPPI, 2015).

Handmade paper is produced in laboratories to study paper production and in paper mills to determine the quality of the production process.

Over the years, several agricultural consumable crop remnants such as rice husk, pineapple leaf corn husks etc. which do not have direct applications in the community has been regarded as probable pulp sources (Rymsza, 2007). Nigeria has abundance of agro waste material that has not been fully utilized to maximum production. Example of such agro waste material include okra stem. Okra (*Abelmoschus esculentus)* consists of cellulose, holocelluloses, hemicelluloses and lignin along with some extractives such as gum and resin (Saleem Ullah *et al.*, 2017).

Since most agro waste materials contain cellulose in form of fibers, they present possible sources for pulp with lesser environmental degradation threat than wood in the production of pulp, paper, as well as being a source of energy (Ekhuemelo *et al.*, 2006). Thus the use of okra stem for the production of pulp and paper is investigated in this study.

1.2 Statement of the Problem

In the time past, wood has been the major source of basic raw material for making paper but it has been observed that there have been incessant depletion of wood due to deforestation which has led to certain environmental hazards/destruction such as erosion, lack of shelter for some animals etc. This has necessitated the use of other alternative biomaterials like okra stem (*A. esculentus)* for the manufacture of pulp and paper products.

1.3 Aims and Objectives of the Study

The major aims and objectives of the study are:

i. to reduce environmental issues from the depletion of wood,

ii. to solve the quest for the search of an alternative raw material for the production of pulp and paper,

iii. to maximize the use of agro wastes in paper production,

iv. to reduce the environmental pollution from agro wastes,

v. to produce and characterize paper hand sheet from Okra stem (*A. esculentus)*.

1.4 Significance of the study

The study is carried out to complement the works of various researchers who thirst to solve the problem of deforestation of wood by making use of other agro wastes such as banana stem, corn husk etc. by carrying out a research on the manufacture of paper using Okra stem (*Abelmoschus esculentus)*.

1.5 Definition of Terms

- **Pulp** can be defined as lignocellulosic fibrous material prepared by chemical or mechanical extraction of cellulose fiber from wood, fiber crops, waste paper or rags. It is a very important raw material in papermaking.
- **Lignocellulosic material** is a material that contains a complex of lignin and cellulose in woody plants cell walls.
- **Lignin** is the supporting compound present on cell walls of tree which makes the wood carry the weight of the tree crown. It also gives pulp its brown colour.
- **Cellulose** is described as a complex carbohydrate.
- **A carbohydrate** is defined as an organic compound that comprises of carbon, hydrogen and oxygen that function as sources of energy for living things.
- **Paper** is a thin material produced by pressing together moist fibers of cellulose pulp derived from lignocellulosic waste materials like wood, rags or grasses, and drying them into flexible sheets.
- **Biomass wastes** are materials gotten from plants that use sunlight to grow which include plant and animal material such as wood from forests, material left over from agricultural processes, forestry processes, organic wastes, industrial wastes, human wastes and animal wastes.

CHAPTER TWO

2.1 Biomass Wastes

Biomass is termed as a regenerative organic material that can be used for the production of energy. It is the material obtained from plants that grows with sunlight examples of such includes wood from forestry products, agricultural wastes and residues, biomass wastes materials. Wastes from human activities and animal activities. It can also be defined as material obtained from plant or animal that can be used for the production of energy, generation of heat and also in numerous industrial processes for the production of a range of products (Ur-Rehman *et al.*, 2015). International Union of Pure and Applied Chemistry (IUPAC) define biomass as materials produced by the growth of microorganisms, plants or animals (Nagel *et al.*, 2002). Biomass is carbon-based mixture that containa hydrogen, oxygen, nitrogen alongside other minute amounts of some other atoms such as alkaline earth, heavy metals etc.

Biofuels are manufactured from biomass wastes and they can be categorized into two categories namely:

First generation biofuels are generated from food sources such as sugarcane and cornstarch. The sugars present are fermented to produce bioethanol, an alcohol fuel which serves as an additive to gasoline or in a fuel cell to produce electricity (Martin, 2010).

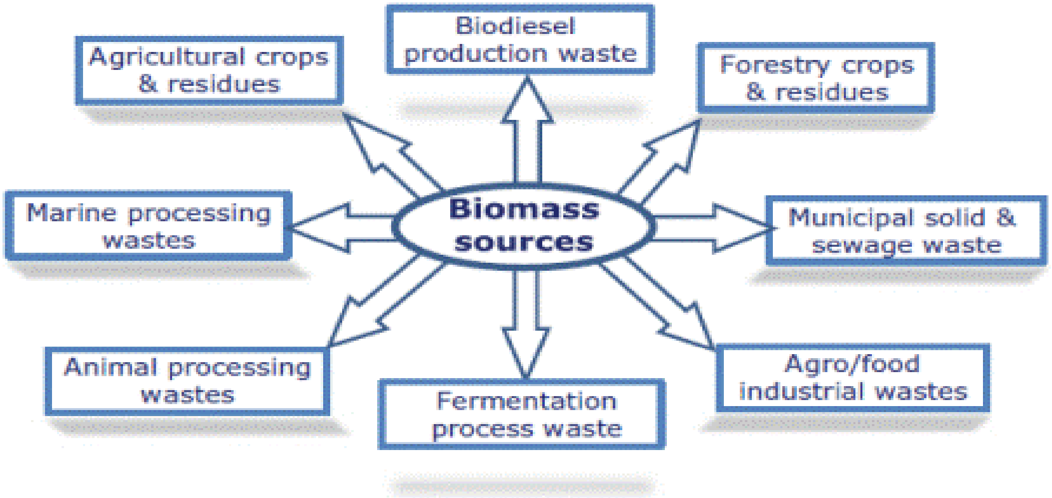
Second generation biofuels can be derived from non-food biomass sources such as agricultural/municipal waste. Second generation biofuels have a great potential but the resources are not fully utilized (Kozikana ***et al.***, 2015).

Biomass makes up 4.8 % of U.S. energy consumption and about 12 % of U.S. renewable energy. It has been recorded that in the U.S. there are currently 227 biomass plants operating, in the U.K, 35 are operating, 15 are under construction and 17 have been proposed (Mabel, 2011).

2.1.1 Sources of Biomass Wastes

Biomass can be derived from a range of sources which are:

- Wood from forest and woodlands
- Forestry plantains
- Forestry residues
- Agricultural residues e.g. straw, stover, green agricultural wastes etc.
- Agro-industrial wastes such as rice husk
- Animal wastes
- Industrial wastes e.g. black liquor
- Sewage
- Municipal solid wastes
- Food processing wastes
- Aquatic plants etc.



2.1.2 Principle of Biomass Conversion

Biomass can be transformed to biofuel by different methods which are:

- Thermal Conversion use heat as a dominant mechanism to convert the biomass into a better and more practical form (Akhtar ***et al*** **.**, 2018).
- Chemical Conversion uses coal-based processes (Liu *et al.*, 2011). Biomass is converted into multiple commodity chemicals (Conversion technologies, 2012).
- Biochemical Conversion: the use of enzymes of bacteria and other microorganisms to break down the biomass.
- Electrochemical Conversion: Biomass is directly converted to electrical energy via electrochemical (i.e. electrocatalytic) oxidation of the material using a fuel cell.

Basic Principle of how biomass waste is converted into energy using:

1. Plant waste

   Leftover wood and crop waste from factories and farms can burned to produce electricity

   a. Wood scraps, sawdust and crop wastes are collected from farms/manufacturing plants

   b. The waste is burned to heat water and produce steam

c. The steam is then sent to a turbine which spins to power a generator

d. The generator generates electricity and sends to transmission lines.

2. Biogas

Wastes produced by animals creates a gas called methane which ca be captured to produce electricity.

a. Animal waste is collected in a large tank or pond with bacteria

b. As the bacteria decomposes, the waste is converted to the gas i.e. methane gas

c. Methane is burned o heat water and generate steam

d. The steam produced turns a generator turbine to generate electricity which is sent to transmission lines (Green Mountain Energy, 2019).

2.1.3 Advantages of Biomass Energy

1. Renewable Source of Energy: It uses wastes from living sources that is unlimited.
2. Clean Energy: Biomass contains neutral carbon content. The carbon dioxide (CO_2) that is absorbed by plants during photosynthesis is recycled once decomposed thereby having little or no effect on greenhouse gas.
3. Abundant: There is no problem of depletion of source.
4. Less Dependency on Fossil Fuels: Biomass is a good alternative of energy source for the fossil fuels because it is a cleaner and safer source of energy than fossil fuel and it has same energy production than fossil fuel.
5. Multiple Uses: Biomass energy can make a lot of products through different forms of organic matter. Example is the use of its oil to make ethanol, plastics, medicines and other bioproduct from oil.

6. Relatively Cheap: The energy is a way cheaper compared to coal and oil, it costs about 1/3 lesser than fossil fuels.
7. Domestic Production: Biomass energy can be produces domestically which brings about a reduced need to rely on imported fuels. (Earth Eclipse, 2019).

2.1.4 Disadvantages of Biomass Energy

1. Though Biomass is a clean energy, it also creates pollution that can be associated to that of coal and other energy sources.
2. Deforestation: Wood serves as a major source of biomass energy and to produce considerable amount of power, there must be large consumption of wood and other waste products which leads to deforestation that destroy homes and great number of plants and animals.
3. Inefficient: Some biodiesel products such as ethanol produced by biomass is inefficient compared to gasoline. There is need to mix it with gasoline to so that it can be used in combustion engines. Also, use of ethanol for a long period of time can be harmful to engines.
4. Requires space: Biomass energy plants are majorly found in developed areas, thereby causing more traffic and more pollution which is also a source of problem (Conserve energy future, 2019).

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2.2.1 Wastes

Waste has been a major environmental concern since the industrial revolution. Wastes are undesired or useless material; it can also be defined as a substance that is worthless, defective, of no use and also discarded after primary use.

The Basel Convention of Transboundary Movements of Hazardous Wastes and Disposal of 1989 defines wastes as substances or objects which are disposed of or are intended to be disposed. (Basel Convention, 1989).

2.2.2 Types of wastes

1. Solid wastes – These are the unwanted substances that are discarded by human society.
2. Liquid wastes – Wastes generated from human activities and industrial processes.
3. Gaseous wastes – These are the wastes in form of gases generated from factories, burning of fossil fuels, etc.

2.2.3 Sources of wastes

a. Municipal waste: This includes trash or garbage from households, offices, market places, public places etc.

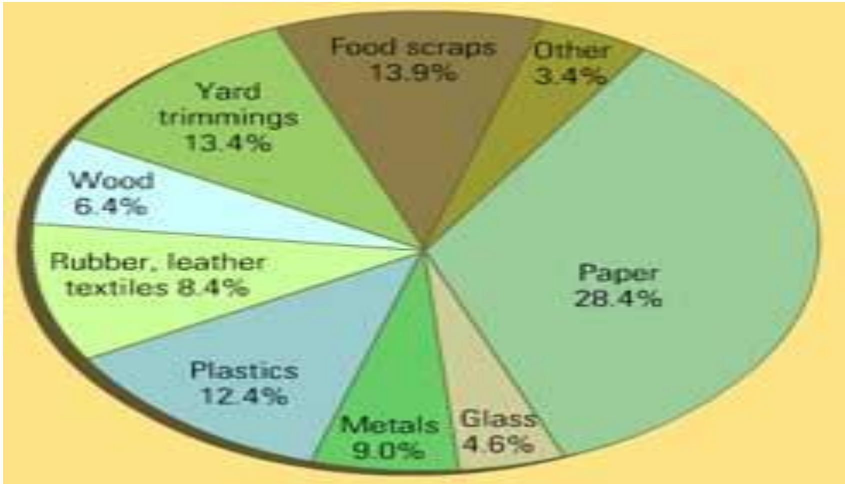


Figure 1: A pie chart showing the Municipal Source of Waste in USA 2010

b. Medical/Clinical wastes: it refers to waste produced from health care facilities such as hospitals, clinics, surgical theatres, vetinary hospitals and labs. They can also be referred to as harzardous wastes.

c. Agricultural wastes: these are wastes generated from agricultural activities which include the activities from horticulture, growing of fruits, livestock breeding, etc.

d. . End-of-Life Automobiles: These include cars that are old and are not working again dumped by people on the road or in the fields.

Figure 2: Example of End of Life Automobile

e. Industrial wastes: Wastes from production industries that manufacture glass, food, plastics, etc.
f. Construction waste: These are wastes from the construction of roads and building.
g. Electronic waste: This is waste from electronic and electrical devices such as DVD and music players, etc. Some electronic wastes contain lead, mercury, cadmium and brominated flame retardants which are harmful to humans and the environment (Waste Recycling, 2019)

2.2.4 Effects of Wastes

Some of the effects of waste in the ecosystem include:

1. Pollution such contamination of drinking water, degradation of underground water used for irrigation, soil pollution etc.
2. Degradation of land
3. Spread of diseases
4. Release of harmful gases such as carbon dioxide, Sulphur dioxide, nitrogen dioxide, methane etc.
5. Spoilage/Degradation of landscape
6. Health hazards such as reduction of blood oxygen, irritation in the respiratory tracts ofq human, injury in blood-formation organs and nervous system etc.

2.3.1 Agricultural wastes

A significant source of environmental pollution is from agro waste and over the years have been a major concern to the society. Agro wastes are the wastes produced from agricultural operations including waste from farms, poultry houses and slaughterhouses. Agro wastes have the potential of damaging the environment and it also exposes workers to harmful biological material (hazards).

2.3.2 Agricultural Waste Characterization

According to Wilson (2011), it was found that the thermal characterization of biomass feedstock has a high H:C ratio and relatively low O:C ration. Faraco (2011) showed that residues from cereal crops, tomato, grape and olive tree produces abundant lignocellulosic waste which can be used as a potential raw material for ethanol production.

2.3.3 Types of Agricultural wastes

a. Solid Waste: includes any type of refuse produced by an agricultural establishment. They also include sludge from water treatment plants and wastes created during agricultural work.

b. Hazardous Wastes: includes corrosive, explosive or highly flammable materials. It also includes chemicals that are dangerous to humans, animals and environment.

c. Used oil: wastes produced by agricultural machinery. Oil used repeatedly gathers other materials such as chemical, water or dirt and it reduces performance of the machines.

d. Other types include wastes from fertilizer, pesticides, chemicals, slaughter houses, livestock, poultry etc.

2.3.4 Effect of Agricultural Waste

Agricultural wastes produce several harmful effects which includes health risks and contamination of water bodies and the atmosphere. It can also cause short-term and long-term effects on ecosystems, land and environments which occur due to the introduction of toxins into the soil and water. The water becomes contaminated along with pathogens such as viruses and bacteria which leads to health issues such as blue baby syndrome, neurological ailments etc.

2.4 Agricultural Waste as a Source of Raw material for Pulp and Paper Production

Nigeria has abundance agro wastes which are yet to be utilized; the agro wastes have been found to contain cellulose, hollocelluloses, hemicelluloses and lignin along with other extractives.

Some researches had shown that Okra stem can be used as a raw material for biorefinery utilization. In the research, it was found out that Okra stem contained 65% carbohydrates (cellulose, hemicelluloses and other polysaccharides), 20.5% lignin and 5% extractives; it also shows that the content of proteins and inorganics was 6.6% and 3.3% respectively. The various researches indicated that the Okra stem can be a potential feedstock for versatile bio-refinery purposes including pulping and manufacturing of chemicals. (Saleem *et al., 2017*)

Over the years, many agro wastes have been used (such as plantain stalk, pineapple stalk, corn stalk etc.) for the production of pulp and paper but there is still search for more agro wastes for production of pulp and paper. This has led to this research, the discovery other biomaterials that can be used in pulp and paper manufacturing other than wood pulp. In the quest of the search, Okra stem (*Abelmoschus esculentus*) has been found to also be a source of solution to the quest.

Paper has also been reviewed as an essential material for day-to-day activities but the production of paper from wood has negative effect on the environment such as deforestation, pollution etc. Due to the various environmental effect caused by the falling of wood for the production of paper, agro wastes has been the replacement of wood over the years. Researches are being made on how wastes can be turned to wealth (i.e. conversion of agro wastes to pulp and paper). The quest to reduce the pollution caused by agro wastes and to reduce the environmental effect caused by falling of trees day by day has led to the research on the use of agro wastes to produce pulp and paper.

According to the research made by the USA in 2010, it was observed that paper has the highest percentage among the municipal wastes. Municipal wastes include trash or garbage from households, schools, offices, market places, restaurants and other places.

2.5 Pulp

Pulp can be defined as lignocellulosic fibrous material prepared by chemical or mechanical extraction of cellulose fiber from wood, fiber crops, waste paper or rags. It is a very important raw material in papermaking. Research has shown that any tree can be used for papermaking but coniferous trees are preferred since the cellulose fibers in the pulp are longer thereby making stronger paper.

Wood and other non woody materials used for the manufacture of pulp must contain three essential components which include:

a. Cellulose Fibers (Cellulose is described as a complex carbohydrate. A carbohydrate is defined as an organic compound that comprises of carbon, hydrogen and oxygen that function as sources of energy for living things.).

b. Lignin (Lignin is the supporting compound present on cell walls of tree which makes the wood carry the weight of the tree crown. It also gives pulp its brown colour).

c. Hemicelluloses (shorter branched carbohydrate polymers)

The major purpose of pulping is to separate cellulose fiber from wood and non-wood feed stock.

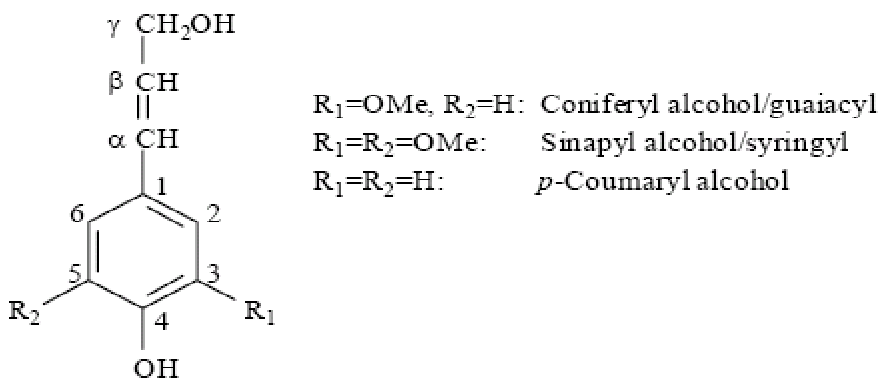


Figure 3: Structure of Monomer Unit of Lignin

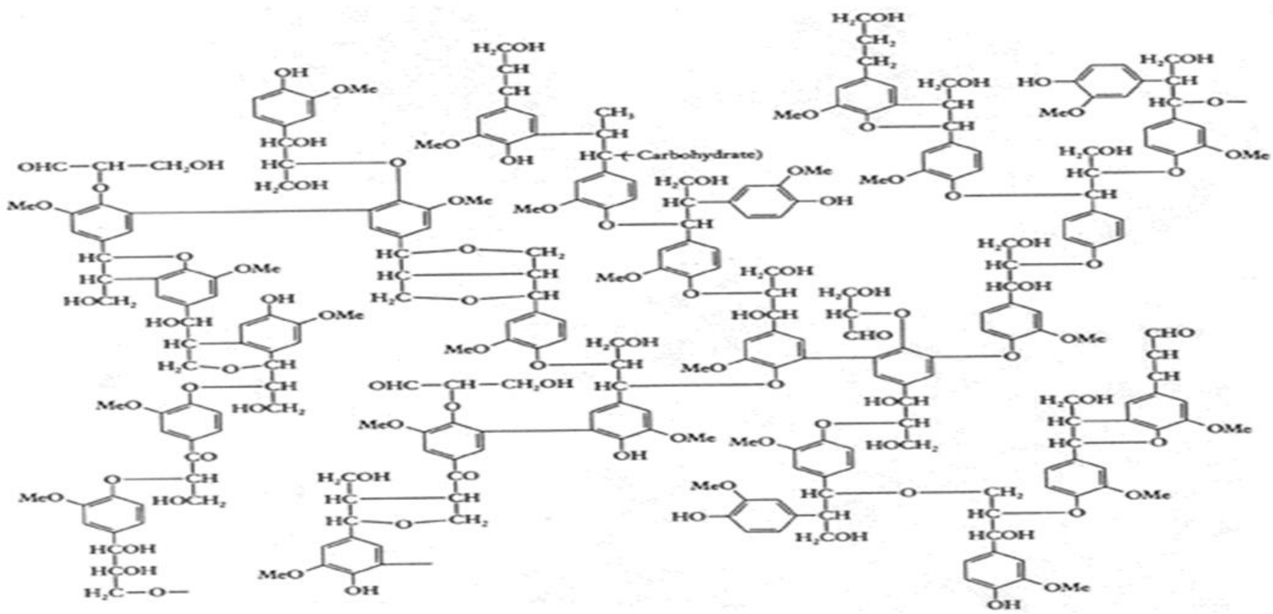


Figure 4: Structure of Lignin Precursors

2.5.1 Sources of Pulp

According to Rao (1996), pulp (which is essential for paper production) are derived from three sources

i. Wood: the hard material that the trunk and branches of a tree are made of. It is mostly obtained by afforestation (i.e. the process of planting trees in some areas of land to form a forest).

ii. Non-wood Plant: It comprises of agricultural residues which include rice straw, bamboo, okra stem, corn husk etc.

iii. Recycled Fiber paper: Waste paper is the source of recycled paper.

2.5.2 Pulping Process

The pulping process can be generally grouped into three categories which are

1. **Mechanical Pulping:** Wood or non-wood materials are open to grinding or chopping to free the cellulose fibers. This process produces high pulp yield i.e. 90-95% and the lignin is retained with the pulp in the process.
2. **Semi-Chemical pulping:** is a mechanical pulping process which involves pretreatment with chemical solution to reduce the energy requirements during processing.
3. **Chemical Pulping:** is a process in which cellulose fibers are extracted from wood or non-wood based stock by freeing the lignin content in the media of chemical solution at elevated temperature and pressure, which is referred to as cooking process. In this process, lignin which acts as a bonding agent to the cellulose fibers is dissolved in the chemical solution.

Chemical pulping can be produced by three methods namely Soda pulping, Kraft or Sulfate pulping and Sulfite pulping in which Kraft pulping is the most adopted process. In chemical pulping, the fibers are less likely to be damaged than in other pulping. Also, the extracted fibers are washed, filtered and sent to the paper making process while the filtrate separated out is referred to as black liquor.

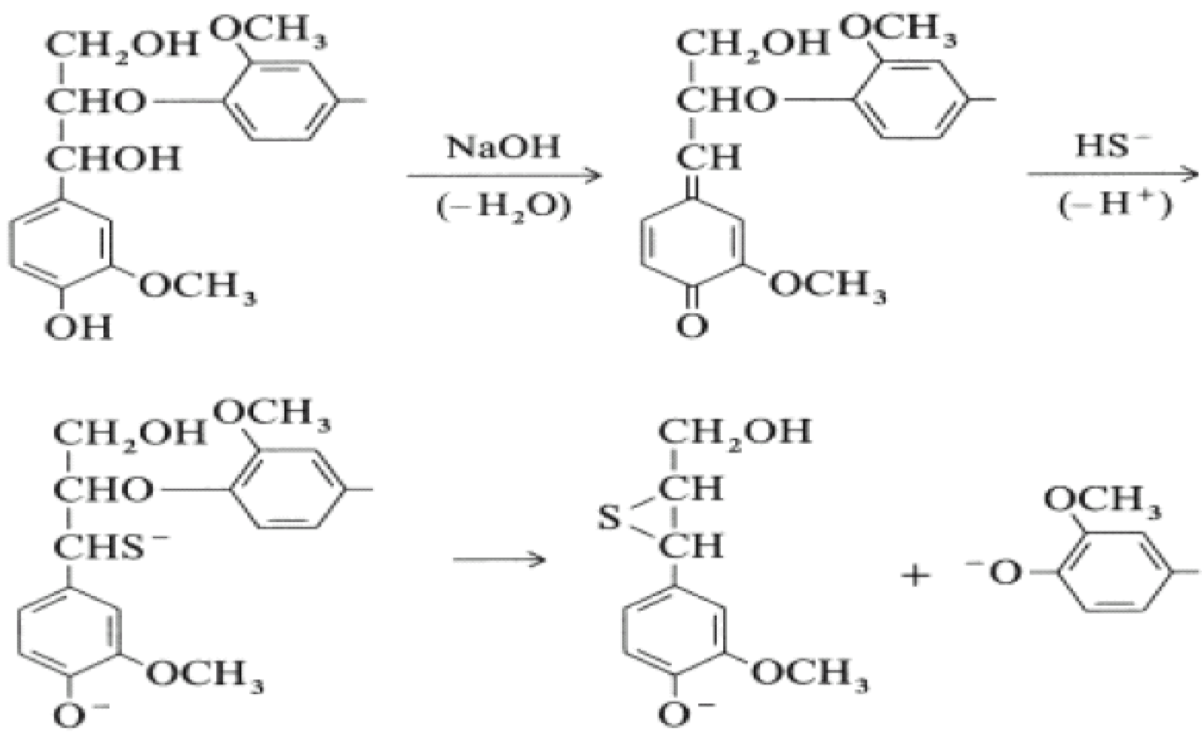


Figure 5: Lignin Degradation during Kraft Pulping Process

Table 2.1 Comparison of Different Pulping Process

Pulping Process	**Pulp yield (%)**	**Pulp strength**	**Energy requirement**	**Life/Stability**
Mechanical pulping	90-95	Poor	High	Moderate
Semi-chemical pulping	55-90	Medium	Moderate	Moderate
Chemical pulping	45-55	Excellent	Low	High

The pulp produced then undergoes the bleaching process.

2.5.3 Bleaching of Pulp

It involves removing virtually all of the lignin that still remains after cooking. Bleaching involves two processes which include: Oxygen delignification and final bleaching.

a. **Oxygen Delignification** involves treating the washed pulp with highly alkaline sodium hydroxide. The high pH ionizes phenolic grouped in the lignin, which are then attacked by molecular oxygen. The aromatic part of the lignin is partly destroyed and it is then depolymerized to lower molecular weight compounds. These are more soluble in water and can be removed from the fibers.

b. **Final Bleaching** is always carried out in several stages to improve the efficiency of the chemicals used, and to decrease the strength loss of the pulp. The chemicals used include chlorine, chlorine dioxide, sodium hypochlorite, oxygen, peroxide, ozone.

2.6 Pulp and Paper Production Pineapple Leaves (*Ananas comoscus*) and Corn Stalk (*Zea mays)*

Wood serves as a major raw material in pulp and paper production worldwide and the depletion of forest had made significant impact on the environment and human. The search for an alternative fiber in non-wood material is vital in pulp and paper production. Non wood plants offer several benefits over wood, some of which include short growth cycles, minute irrigation, fertilization and low lignin content which enhances easy alleviation of energy and chemicals used during pulping (Taiwo *et al.*, 2014). Since most agro wastes contain cellulose in form of fibers, there is abundance non-wood fibers potentially available for the paper industry which gives possible sources for pulp with minute environmental degradation risk than wood (the most broadly used lingo-cellulosic material in the manufacture of pulp, furniture, boards of disparate types and also as a source of energy (Ekhuemelo *et al.*, 2006).

It has been noted that Nigeria has abundance agro waste like pineapple and corn stalk which are yet to be utilized. Pineapple (Ananas comoscus) has been found to be a common tropical plant which comprises of coalesced berries, cellulose, holocelluloses, hemicelluloses and lignin with some extractives such as gums and resins.

According to the characterization carried out on pineapple leaves and corn stalk, it has been found that the two samples contain high cellulose content, low lignin content and low ash content (though a bit high in corn straw) and the characterization carried out on the paper produced, it has been shown that pineapple leave and corn stalk are suitable non wood raw materials for paper making and can serve as an alternative to wood source for pulp and paper making to protect and conserve our environment from deforestation and its adverse effects. (Aremu *et al.*, 2015).

2.7 Handmade Paper from Banana Stem (*Musa paradisiaca*)

Banana stem has also been regarded as a waste product which is used in domestic cooking purpose but due to continuous depletion of wood in the society, research and analysis has also been carried out which shows that banana stem is also a source of raw material for the production of paper pulp. The pulp produced is used for the manufacture of different types of paper such as tissue, bloating, tracing, grease proof paper, fiber, board, writing and printing paper.

Over the years, it has been observed in the North Eastern region of India that farmers dispose enormous amount of stems after harvesting the fruit because there is no significant use of banana stem but based on this research, it has been found out that making out tissue paper from the banana stem will be of great benefit to the farmers in such that they make money both from the fruit and the tissue made from the stem; it will also boost the interest in the cultivation of banana crops.

Several industries manufacture tissue paper using bamboo, hardwood, softwood, jute etc. as raw material because it contains a significant percentage of cellulose but banana stem serves as a very suitable alternative raw material which contains a significant amount of cellulose (Gopal *et al.,* 2011).

It has been discovered according to the research that among the recent developments in paper industry for the manufacture of tissue paper, banana stem acts as a superior material and it yields easily manufacturable and good strength tissue paper (Bridle & Kirkpatrick, 2004). In the aspect of economy, banana stem as a raw material is cheaper than wood and this can also solve the environmental issues caused by the falling of wood.

(Lakhan *et al.,* 2013)

2.9 Development and Evaluation of Paper from Corn Husks (*Zea mays L.*) and Snake Plant Fibers (*Sansevieria zeylanica*)

For the production of paper products, there has been constant depletion of forests. According to Martin S. (2011), over 35% of the world's trees are felled and used in the manufacture of paper products; United Nations Food and Agriculture Organization (FAOSTAT, 2010) estimated that 18million acres of forest are lost every year due to the rapid consumption of timber trees for the production of paper which also had effect on the environment in the form of deforestation. Despite the environmental situation, there is constant increase in the use of paper products daily and the quest to solve the environmental issues gave rise to the demand for alternative material for paper products.

The corn husk and snake plant fibers contain cellulosic materials which can be utilized for the paper production. The two non-timber resources (i.e. corn husk and snake plant fiber) were mixed in the 3:1, 1:1, 1:3 respectively to determine the most acceptable in terms of texture, colour and thickness. After the research, it was observed that the mixture of corn husk and snake fibers in the ratio 3:1 is the most acceptable according to the standard measurements by the TAPPI 220 sp-06.

It is hereby concluded that corn husk and snake fibers is a very good raw material for pulp and paper production and can also serve as an alternative to the use of wood for paper products.

(Rainer *et al.*, 2016).

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Research Design

This study shows the development, evaluation and analysis of wood, pulp and paper from okra stem using TAPPI methods and standards.

3.2 Research Method

The research method shows the various analyses carried out on the wood, pulp and characterization of paper.

3.3 Determination of Moisture Content

Moisture content is the amount of water present in a material such as soil, rock, ceramics, crops or wood.

Apparatus

- Petri dish
- Dessicator
- Oven
- Weighing balance

Procedure.

The petri dish was dried in an oven at 150 ^{0}C and cooled in a dessicator. The empty dried petri dish was weighed and recorded as W_1. 10 g of the okra stem was added to the petri dish; weighed and recorded as W_2. The sample was dried in the oven at 150 ^{0}C for 60 minutes and cooled in a dessicator. The dried sample was record as W_3.

Calculation

% moisture = [(c - d)/c] × 100

Where: c = as-received weight of chips/ meal, g,

d = oven-dry weight of chips/ meal, g

3.4 Determination of Sodium Hydroxide Soluble Component of the sample

Apparatus & Reagents

- 1 % NaOH
- Distilled water
- 10% acetic acid
- Weighing Balance
- Beaker
- Measuring Cylinder
- Glass rod
- Watch Glass
- Water bath
- Buchner Funnel
- Filter paper
- Oven
- Volumetric flask

Procedure

2 g of oven dried sample was weighed into a beaker. 100 ± 1 mL of 1 % NaOH solution was added and stirred with a glass rod. It was covered with a watch glass and placed in a water bath maintained at 97 °C to 100 °C for a period of 60 min, making sure the water in the bath was boiling and its level was above that of the alkali solution in the beaker. The mixture was stirred with a rod for about 5 s at 10, 15, and 25 min after placing in the bath. At the end of 60 minutes, the sample was transferred into a tarred filtering crucible and washed with 100 mL of hot water. 25 mL of 10% acetic acid was added and allowed to stand for 1 min before removal. The process was repeated with a second 25-mL portion of 10% acetic acid and then washed with hot water until acid free. The crucible and its content was dried in an oven at 105° ± 3 °C to a constant weight, cooled in a desiccator, and weighed. The percent solubility was calculated as follows:

Calculation

$S = [(A - B)/A] \times 100$

Where: A = weight of oven-dry test specimen before extraction, g

B = weight of oven-dry test specimen after extraction, g

3.5 Determination of the Water Solubility of *Abelmoschus esculentus*

The Water solubility of okra stem was carried out via 2 methods: cold water procedure and hot water procedure.

3.5.1 Determination of Cold Water Solubility

Reagents & Apparatus

- Distilled water

- Erlemeyer flask
- Measuring cylinder
- Water bath
- Round bottom flask
- Reflux condenser
- Hot plate stirrer
- Buchner funnel
- Filter paper
- Weighing balance

Procedure

2 g of oven- dried Okra stem was weighed in a 400 mL beaker and 300 mL of distilled water was added slowly while making sure the wood was well wetted initially to avoid tendency to float. The extraction was carried out at 23 °C with constant stirring for 48 hours. After the given period, the solution was then transferred into a filter paper in the Buchner funnel. It was then washed with 200 mL of cold distilled water and dried to constant weight at 105 °C.

3.5.2 Determination of Hot Water Solubility

Apparatus & Reagents

- Distilled water
- Erlemeyer flask
- Measuring cylinder
- Water bath
- Round bottom flask

- Reflux condenser
- Hot plate stirrer
- Buchner funnel
- Filter paper
- Weighing balance

Procedure

2 g of the Okra stem was weighed into a 250 mL round bottom flask, 100 mL of hot distilled water was added and placed on a heating mantle. A reflux condenser was attached and digested for 3 hours. The contents of the flask was then transferred into a filter paper in a Buchner funnel, washed with 200 mL of hot water and dried to constant weight at 105 ^{0}C.

Calculation

Hot or cold water solubility, % = [(A-B) / A] × 100

Where: A = initial weight of the test specimen, g

B = weight of the test specimen after extraction, g

3.6 Determination of the Chemical Composition of *Abelmoschus esculentus*

The chemical composition of *Abelmoschus **e**sculentus* refers to the major constituents (i.e. Cellulose, Hemicellulose, Lignin) and the minor constituents (i.e. Ash and Extractives).

3.6.1 Ash content

The ash content determination is a measure of the amount of inorganic element present in wood as components of the extractives. Ash in wood can be composed of alkaline earth metals e.g. calcium.

Apparatus

- Carbolite furnace
- Crucible
- Oven
- Dessicator
- Weighing balance

Procedure

The empty crucible was carefully cleaned and ignited in a carbolite furnace at 525 °C for 30-60 minutes. After ignition, the crucible was cooled slightly and then placed in a desiccator. When cooled to room temperature, the crucible was weighted on the analytical balance and recorded as W_1. 10 g of the Okra stem was added and placed in the oven for 60 minutes, cooled in the desiccator, weighed and recorded as W_2. The crucible was transferred to the carbolite oven at 700 ^{0}C until ash colour was observed and then place in a desiccator and cooled to room temperature. The crucible with ash was weighed and recorded as W_3.

Calculation

% Ash content (%) = $\frac{\boldsymbol{W1}}{\boldsymbol{W2}} \times \mathbf{100}\%$

Where: W_1=weight of ash (grams).

W_2=weight of oven-dried sample (grams).

3.6.2 Determination of Extractive Content

Apparatus & Reagents

- Extraction thimble
- Ethanol

- Acetone
- Soxhlet extraction apparatus
- Condenser
- Round bottom flask
- Buchner funnel
- Filter paper

Procedure

4 g of air-dried okra stem was weighed and placed into the extraction thimble and covered with cotton wool to avoid loss of specimen. The solvents ethanol and acetone was measures in the ratio 1:2 (50ml and 100ml) into a 500 mL flat bottom flask and connected to the soxhlet extraction apparatus uprightly allowing water to flow through the condenser section. The heater was adjusted to provide boiling rates and allowed to cycle the specimens for not less than 24 times within the period of 6 hours. The flask was removed from the apparatus and then the solvents and the extract were separated using the rotary evaporator to a volume of 20 to 25 mL. The extract was transferred into the filter paper in the Buchner funnel and washed with fresh solvents. The filter paper and its content was dried in an oven for 1 hour at 105 ℃, and cooled in a desiccator, weighed to the nearest 0.1 mg. A blank determination with the solvent used in the test was carried out, evaporated to dryness, and the residue weighed to the nearest 0.1 mg. The extractive was calculated as follows:

Calculation

Extractable, % = [(We - Wb)/Wp] x 100

Where: We = weight of oven-dry extract, g

Wp = weight of oven-dry wood or pulp, g

Wb = weight of oven-dry blank residue, g

NB: The extraction should be carried out three times, so as to get enough extractive free okra stem for lignin and holocellulose determination.

3.6.3 Determination of Lignin Content

Apparatus & Reagents

- Beaker
- Sulphuric acid (72 %)
- Water bath
- Stirring rod
- Round bottom flask
- Reflux condenser
- Hot plate stirrer
- Buhner funnel
- Filter paper
- Analytical balance

Procedure

1g of oven-dried sample of extractive-free okra stem was weighed into 150 mL beaker. 15 mL of cold sulfuric acid (72 %) was slowly added while stirring and mixed well. The beaker was placed in a water bath at 20 ℃ for 2 hours. After 2 hours, the specimen was transferred into a round bottom flask by washing it with 560 mL of distilled water into a 1000 mL flask, diluting the concentration of the sulfuric acid to three per cent. A reflux condenser was attached and placed on hot plate stirrer and allowed to reflux for 4hours. The flask was removed and the insoluble material was allowed to settle. The content of the flask was filtered by vacuum suction in a Buchner funnel and the residue was washed free of acid with 500 mL of hot tap water and then oven-dried at 103 ℃. The filter paper was cooled in the desiccator and weighed until a constant weight was obtained (Li, 2004).

Calculation

Klason lignin content in Okra (%) = $\frac{W4 - W3}{100 \times W2} \times (100 - W1)$

Where: W_1=ethanol-acetone extractive content (percent).

W_2=weight of oven-dried extractive-free sample (grams).

W_3=weight of oven-dried crucible (grams).

W_4=weight of oven-dried residue and crucible (grams)

3.6.4 Holocellulose content

The holocellulose includes alpha-cellulose and hemicellulose.

Apparatus & Reagents

- Analytical balance
- Erlemeyer flask
- Glacial acetic acid
- Watch glass
- Sodium chlorite
- Water bath

Procedure

2 g sample of oven-dried okra stem was weighed and placed into a 250 mL flask with a small watch glass cover. 150 mL of distilled water, 0.2 mL of cold glacial acetic acid, and one gram of

$NaClO_2$ was added and placed into a water bath maintained between 70 ℃ - 80 ℃. Every hour for five hours, 0.2 mL of cold glacial acetic acid and one gram of $NaClO_2$ was added and stirred constantly. At the end of five hours, the flask was placed in an ice water bath until the temperature of the flask was reduced to 10 ℃. The content of the flask in a Buchner funnel was filtered and washed free of ClO_2 residue using 500 mL of cold distilled water until the residue changes colour from yellow to white. The filter was dried in the oven at 103 ℃, cooled in a desiccator and weighed until a constant weight was reached (Li, 2004).

Calculation

Holocellulose content in Okra (%) = $\frac{\boldsymbol{W4 - W3}}{\boldsymbol{100 \times W2}} \times (\boldsymbol{100 - W1})$

Where: W_1=ethanol-acetone extractive content (percent).

W_2=weight of oven-dried extractive-free sample (grams).

W_3=weight of oven-dried crucible (grams).

W_4=weight of oven-dried residue and crucible (grams).

3.6.5 Determination of Alpha cellulose

The alpha cellulose determination gives the percentage of cellulose (sugar monomer) present in the bamboo specie, values of alpha cellulose ranges from 45 to 60 % of the dry wood mass.

Apparatus & Reagents

- Analytical balance
- Erlenmeyer flask
- Watch glass
- Water bath
- NaOH (17.5% & 8.3%)

- Acetic acid (10%)

Procedure

3 g of oven-dried sample of holocellulose was weighed into a 250 mL Erlenmeyer flask and covered with a small watch glass. The flask was placed in a water bath that was maintained at 20 ℃. The sample was treated with 50 mL of 17.5 percent NaOH and mixed thoroughly for one minute. The specimen was allowed to react with the solution for 29 minutes and 50 mL of distilled water was added and mixed well for another one minute. The reaction was allowed to continue for five more minutes. The contents of the flask was transferred into a Buchner funnel and filtered by aid of vacuum suction. The residue was washed with 50 mL of 8.3 percent NaOH, then with 40 mL of 10 percent acetic acid. The residue was washed free of acid with 1000 mL of hot tap water. The filter paper was dried in an oven at 103 ℃, cooled in a desiccator and weighed until a constant weight was reached (Li, 2004).

Calculation

Alpha-cellulose (percent) = $\frac{\boldsymbol{W4 - W3}}{\boldsymbol{100 \times W2}} \times \boldsymbol{W1}$

Where,: W_1=Holocellulose content (percent).

W_2=weight of oven-dried holocellulose sample (grams).

W_3=weight of oven-dried crucible (grams).

W_4=weight of oven-dried residue and crucible (grams).

3.6.6 Determination of Hemicellulose Content

The amount of non-sugar monomer present in the bamboo chips was determined by subtraction of the alpha cellulose content from the holocellulose content.

3.7 Extraction of Cellulose Fibres from *Abelmoschus esculentus*

3.7.1 Kraft pulping of *Abelmoschus esculentus* into cellulose

200 g of *A. esculentus* chips was weighed and subjected to Kraft pulping in a 2000 mL conical flask using a hot plate and a reflux condenser. The white liquor used in pulping was prepared by dissolving 50 g of NaOH and 25 g of Na_2S in 800 ml of distilled water. The reaction was left to run for 5 hours with an increase in temperature from 20 ℃ to 160 ℃. After 5 hours, the wood chips were mashed and the resulting brown, fluffy pulp was separated from the black liquor, washed with deionized water and then air-dried.

3.7.2 Further Bleaching of the Pulp

After drying and the yield calculated, the air dried pulp was further delignified by treating the pulp (30 g) with hydrogen peroxide (59 % hydrogen peroxide; 500 mL and 200 mL of distilled water, giving a pulp consistency of 4.3 %) at 50 ℃ to 60 ℃ for 3 hours.

3.7.3 Kappa Number Determination

Procedure

3 g of Kraft pulp was weighed and the moisture content was determined. The pulp was integrated by using a blender in 500 mL of distilled water until it was free of fibre clots and undispersed fibre bundles. The disintegrated test specimen was transferred to a 2000 mL reaction beaker and rinsed with enough distilled water to bring the total volume to 795 mL. The beaker was placed in a constant temperature bath adjusted so that the reaction temperature stays at 25.0 °C during the entire reaction with continuous stirring. 100 mL of potassium permanganate solution and 100mL of sulfuric acid solution was pipetted into a 250 mL beaker; the temperature of the solution was

brought quickly to 25 °C quickly and added immediately to the disintegrated test specimen. The beaker was rinsed out using 5 mL of distilled water, and at the end of exactly 10 minutes, the reaction was stopped by adding 20 mL of the potassium iodide solution and without filtering out the fibres, the free iodine was titrated with the sodium thiosulfate solution and few drops of starch indicator was then added towards the end of the reaction. A blank determination was carried out using the same method but without the pulp.

Calculation

The kappa number was calculated using:

$K = \frac{p \times f}{w}$ and $p = \frac{(b-a)N}{0.1}$

Where: K = kappa number

f = 50% permanganate consumption (dependent on the value of p)

w = weight of moisture-free pulp

p = amount of 0.1N permanganate actually consumed by the test specimen, mL

b = amount of the thiosulfate used in the blank determination, ml

a = amount of the thiosulfate used by the test specimen, ml

N = normality of the thiosulfate

3.7.4 Determination of the Equilibrium Moisture Content of Pulp

Procedure

3 g of pulp was weighed into a tarred weighing bottle and placed into an oven at 105 ℃ for 30 minutes without covering. After 30 minutes, the bottle was re-stoppered and allowed to cool in a desiccator. The stopper was loosened momentarily to allow air to enter and the bottle was

reweighed. The step was repeated for holding time 45 minutes, 60 minutes etc. until a persistent weight was achieved.

Calculation

The moisture content was calculated using:

% moisture content= $\frac{W2-W1}{W2-WT}(100)$

Where: W_1= weight of bottle and specimen prior to drying

W_2= weight of bottle and specimen after drying

W_T= tare weight of bottle

3.8 Production of Paper from Cellulose (Handsheet Forming of Pulps)

The production of paper was carried out by refining 10g of pulp with 5g of starch in 100ml of water. A mould and deckle was used as a sheet former and a blender was used to refine the pulp.

3.9 Characterization of the Kraft and Bleached Paper Handsheet

The paper characterization i.e. tensile and tear strength property of the Kraft paper hand sheets and hydrogen peroxide bleached paper were analyzed using the Saumya Universal Testing Machine (UTM) model UTM D2.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Characterization of Okra Stem (*Abelmoschus esculentus)*

PARAMETERS	RESULTS (%)
MOISTURE CONTENT	5.0
ASH CONTENT	6.6
NAOH SOLUBILITY	33
HOT WATER SOLUBILITY	13.26
COLD WATER SOLUBILITY	8.43
EXTRACTIVE CONTENT	48.2
LIGNIN CONTENT	6.78

4.1.1 Lignin Content

The result of the characterization of shows that Okra stem contains a very low lignin content (6.78 %). Low lignin content is an advantage to the use of non-wood materials for pulp production because lignin serves as an adhesive that binds the cellulose fibers together. Also, materials that contain low lignin will require small amount of chemical pulping since it is easier to discard it from the pulp and the paper produced will be of greater quality compared to that of other non-wood materials (Hurter & Ricco, 1998).

4.1.2 Moisture Content

The moisture content of Okra stem is low (5.0 %) which specifies its high dimensional stability as a material for papermaking and indicates the presence of a quality paper. High moisture content affects the mechanical and surface properties of paper produced which also indicates a less dimensional stability against the grain. Quality paper must have a very good dimensional stability against the grain because the strength and structure of the paper is determined by it.

4.1.3 Ash Content

Okra stem also contains low ash content (6.6 %). Ash content shows the absence or presence of other materials in combustion. Okra stem contains low presence of other materials which include: chemical, metallic and mineral matters and it indicates that Okra stem would produce good quality paper.

4.1.4 NaOH Solubility

Hot alkali solution is used to extract low molecular weight carbohydrates (which includes mostly of hemicellulose and degraded cellulose in wood) and the solubility of wood in alkali solution indicates the degree of fungus decay or of degradation by heat, light, oxidation, etc. The increase in the percentage of alkali-soluble material is a function of the extent to which the wood decays or degrades. Sodium hydroxide solubility of Okra stem is high (33 %) which indicates its capability to which it can be degraded by light and fungi easily.

4.1.5 Extractive Content

Extractive content is used to determine the quantity of solvent-soluble and non-volatile material in wood. The percentage of extractive content is high (48.2 %) which indicates that there is a large amount of solvent-soluble and non-volatile material in wood thereby making Okra Stem a good material for pulp making.

4.1.6 Cold Water Solubility

The cold water solubility determines the amount of extraneous constituents, which includes inorganic compounds, gums, colouring matter etc. present in wood. The percentage of cold water solubility is low (8.43 %) which indicates that Okra stem is a good material for pulp making.

4.1.7 Hot Water Solubility

The hot water solubility determines the amount of extraneous constituents, which includes inorganic compounds, gums, colouring matter in addition to starch present in wood. The percentage of the hot water solubility was 13.26 %

4.2 Characterization of Pulping

4.2.1 Pulp yield

The yield of Kraft pulp and bleached pulp were 62 % and 75 % respectively which is a high and good yield. The difference in pulp yield of Kraft pulp and bleached pulp is due to the removal of the residual lignin that is achieved in the peroxide bleached pulp which accounts for the value of Kappa number (29.8) obtained for the pulp.

4.2.3 Kappa number

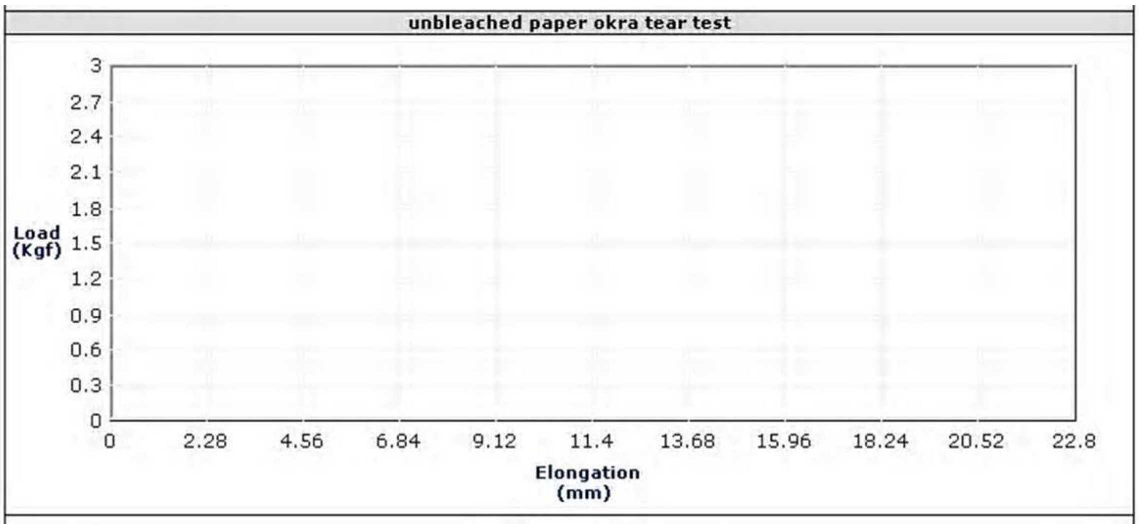
The Kappa number indicates the residual lignin content or bleachability of pulp by a standardised analysis method. The Kappa number derived from the pulp was 29.8.

4.2.2 Moisture Content

The amount of moisture in the pulp wass 11 %. This describes that the pulp degradation is low.

4.3 Okra Unbleached Paper Tear Test

Thickness (mm)	Width/Dia (mm)	Length (mm)	Area (mm^2)
0.05	20.00	40.00	0.01



Graph 1: A graph showing the unbleached paper okra tear test for 20mm by 40mm paper

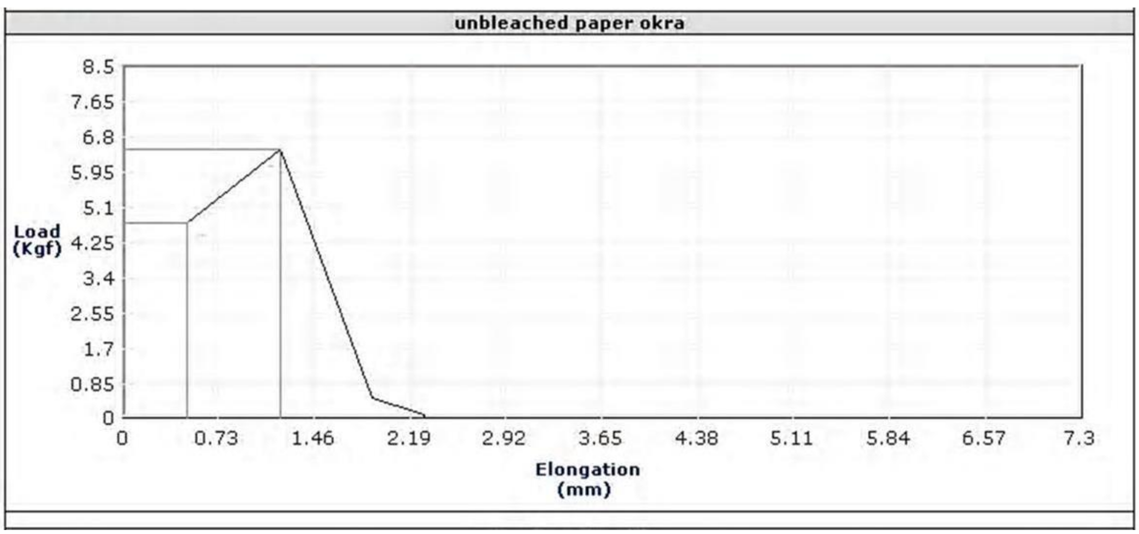
Table 4.1 Analysis Result

S/NO	SPECIFICATION	VALUE
1	Yield Load	0.00Kgf
2	Yield Elongation	3.40mm
3	Tensile Strength at Yield Load	0.00Kg/cm^2
4	Breaking Load	0.00Kgf
5	Elongation at Break Load	16.60mm
6	Tensile strength at Breaking Load	0.00Kg/cm^2
7	Tenacity at Breaking Load	0.00gms/Derier
8	Elongation % at Break	41.50%
9	Maximum Load	0.00Kgf
10	Elongation at Maximum Lad	17.80mm
11	Tensile Strength at Maximum Load	0.00Kg/cm^2
12	Tenacity at Maximum Load	0.00gms/Derier
13	Elongation % at Maximum Load	44.50%
14	Modulus Elasticity	0.00Kg/cm^2
15	0.1% Offset Yield Strength	0.00MPA

The length of the unbleached paper hand sheet obtained from this research was 40mm with a thickness of 0.05mm and a diameter of 20mm. The tear strength property of the handsheet paper shows that the yield load which was the initial load inserted on the material was 0.00Kgf and the load at which the machine used in breaking the material which is also the maximum load was 0.00Kgf thereby giving no load before the paper sheet will be distorted with an elongation of 3.40mm and a tensile strength of 0.00Kg/cm^2. Also, at the take off point of the extension, the paper handsheet had the elongation of 16.60mm and by the time it was about to break it had the elongation of 17.80mm.

Okra Unbleached Paper

Thickness (mm)	Width/Dia (mm)	Length (mm)	Area (mm^2)
0.05	30.00	80.00	0.0015



Graph 2: A graph showing the unbleached paper okra tear test for 30mm by 80mm paper

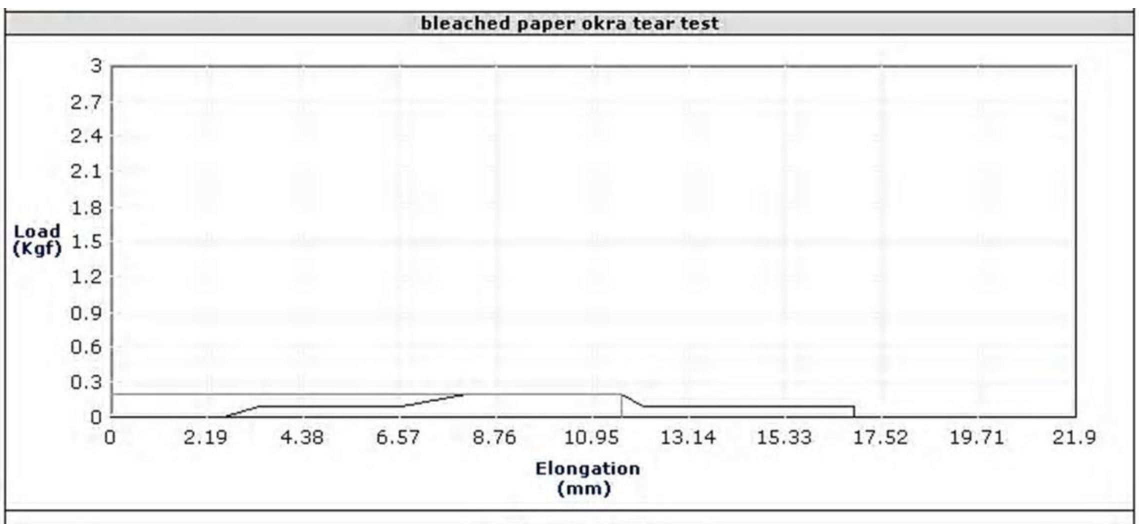
Table 4.2: Analysis Result

S/NO	SPECIFICATION	VALUE
1	Yield Load	4.70Kgf
2	Yield Elongation	0.50mm
3	Tensile Strength at Yield Load	313.33Kg/cm^2
4	Breaking Load	6.50Kgf
5	Elongation at Break Load	1.20mm
6	Tensile strength at Breaking Load	433.33Kg/cm^2
7	Tenacity at Breaking Load	6500.00gms/Derier
8	Elongation % at Break	1.50%
9	Maximum Load	6.50Kgf
10	Elongation at Maximum Lad	1.20mm
11	Tensile Strength at Maximum Load	433.33Kg/cm^2
12	Tenacity at Maximum Load	6500.00gms/Derier
13	Elongation % at Maximum Load	1.50%
14	Modulus Elasticity	50133.33Kg/cm^2
15	0.1% Offset Yield Strength	0.00MPA

The length of the unbleached paper hand sheet obtained from this research was 80mm with a thickness of 0.05mm and a diameter of 30mm. The tear strength property of the handsheet paper shows that the yield load which was the initial load inserted on the material was 4.70Kgf and the load at which the machine used in breaking the material which is also the maximum load was 6.50Kgf thereby giving an additional load of 1.80Kgf before the paper sheet will be distorted with an elongation of 0.50mm and a tensile strength of 313.33g/cm^2. Also, at the take off point of the extension, the paper handsheet had the elongation of 1.20mm and by the time it was about to break it had the same value.

4.4 Okra Bleached Paper Tear Test

Thickness (mm)	**Width/Dia (mm)**	**Length (mm)**	**Area (mm^2)**
0.05	20.00	40.00	0.01



Graph 3: A graph showing the bleached paper okra tear test for 20mm by 40mm paper

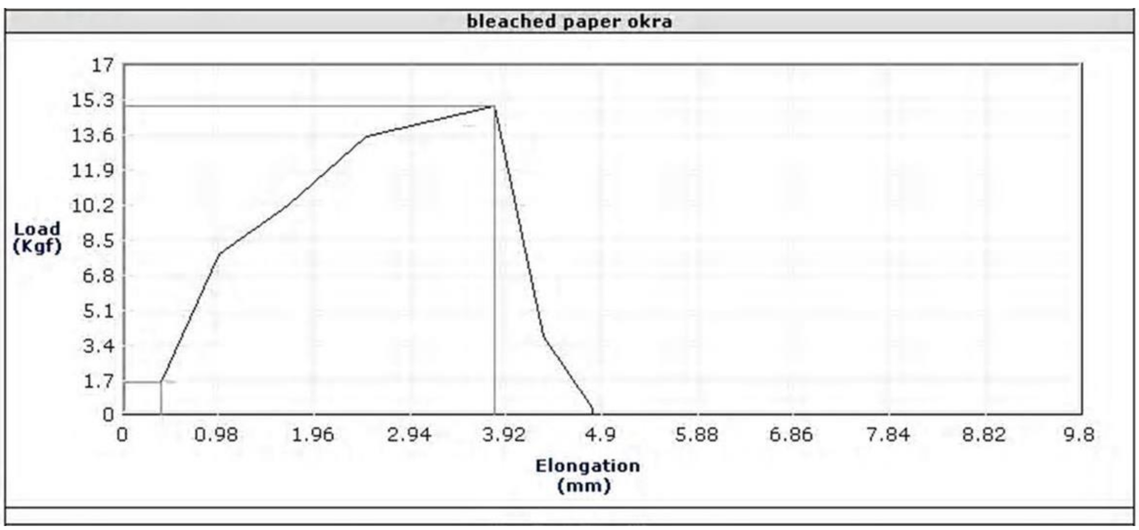
Table 4.3: Analysis Result

S/NO	SPECIFICATION	VALUE
1	Yield Load	0.00Kgf
2	Yield Elongation	1.80mm
3	Tensile Strength at Yield Load	0.00Kg/cm^2
4	Breaking Load	0.20Kgf
5	Elongation at Break Load	11.60mm
6	Tensile strength at Breaking Load	20.00Kg/cm^2
7	Tenacity at Breaking Load	200.00gms/Derier
8	Elongation % at Break	29.00%
9	Maximum Load	0.20Kgf
10	Elongation at Maximum Lad	11.60mm
11	Tensile Strength at Maximum Load	20.00Kg/cm^2
12	Tenacity at Maximum Load	200.00gms/Derier
13	Elongation % at Maximum Load	29.00%
14	Modulus Elasticity	0.00Kg/cm^2
15	0.1% Offset Yield Strength	0.00MPA

The length of the bleached paper hand sheet obtained from this research was 40mm with a thickness of 0.05mm and a diameter of 20mm. The tear strength property of the handsheet paper shows that the yield load which was the initial load inserted on the material was 0.00Kgf and the load at which the machine used in breaking the material which is also the maximum load was 0.20Kgf thereby giving an additional load of 0.20Kgf before the paper sheet will be distorted with an elongation of 1.80mm and a tensile strength of 0.00Kg/cm^2. Also, at the take off point of the extension, the paper handsheet had the elongation of 1.80mm and by the time it was about to break it had the elongation of 11.60mm.

Okra Bleached Paper

Thickness (mm)	Width/Dia (mm)	Length (mm)	Area (mm^2)
0.05	30.00	80.00	0.0015



Graph 4: A graph showing the bleached paper okra tear test for 30mm by 80mm paper

Table 4.4: Analysis Result

S/NO	SPECIFICATION	VALUE
1	Yield Load	1.60Kgf
2	Yield Elongation	0.40mm
3	Tensile Strength at Yield Load	106.67Kg/cm^2
4	Breaking Load	15.00Kgf
5	Elongation at Break Load	3.80mm
6	Tensile strength at Breaking Load	1000.00Kg/cm^2
7	Tenacity at Breaking Load	15000.00gms/Derier
8	Elongation % at Break	4.75%
9	Maximum Load	15.00Kgf
10	Elongation at Maximum Lad	3.80mm
11	Tensile Strength at Maximum Load	1000.00Kg/cm^2
12	Tenacity at Maximum Load	15000.00gms/Derier
13	Elongation % at Maximum Load	4.750%
14	Modulus Elasticity	21333.33Kg/cm^2
15	0.1% Offset Yield Strength	0.00MPA

The length of the bleached paper hand sheet obtained from this research was 80mm with a thickness of 0.05mm and a diameter of 30mm. The tear strength property of the handsheet paper shows that the yield load which was the initial load inserted on the material was 1.60Kgf and the load at which the machine used in breaking the material which is also the maximum load was 15.00Kgf thereby giving an additional load of 13.40Kgf before the paper sheet will be distorted with an elongation of 0.40mm and a tensile strength of 106.67Kg/cm^2. Also, at the take off point of the extension, the paper handsheet had the elongation of 3.80mm and by the time it was about to break it had the same value (i.e. 3.80mm).

4.5 Comparison of the Bleached and Unbleached Paper Test

The bleached and unbleached handmade paper with length of 40mm, thickness of 0.05mm and a diameter of 20mm. The results showed that there the unbleached paper contained 0.00Kgf load before the paper sheet will be distorted with an elongation of 3.40mm and tensile strength of 0.00Kg/cm^2 while the bleached paper contained 0.20Kgf load before the paper will be distorted with an elongation of 1.80mm and tensile strength of 0.00Kg/ cm^2.

The bleached and unbleached handmade paper with length of 80mm, thickness of 0.05mm and a diameter of 30mm. The results showed that there the unbleached paper contained 4.70Kgf load before the paper sheet will be distorted with an elongation of 0.50mm and tensile strength of 313.33Kg/cm^2 while the bleached paper contained 13.40Kgf load before the paper will be distorted with an elongation of 3.80mm and tensile strength of 106.67Kg/ cm^2.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In the natural world, there is no waste. The products of any process in nature are inputs to other natural processes e.g. fallen tree leaves and animal dung contain nutrients for the growth of plant, carbon dioxide (CO_2) manufactured during animal respiration is used by plants to produce oxygen and this in turn is used by animals. The activities of man (harvesting, manufacturing, packaging etc.) result in part, in outputs not considered useful by man; these are normally termed wastes and most of them are biomass wastes.

Deforestation arising from the use of forestry materials to generate wood pulp can be effectively reduced by the utilization of cellulosic waste materials as a viable alternative bioresources for production of pulp and paper products for wide range of industrial applications. Again, the conversion of cellulosic waste biomass will also reduce maize/wheat bioenergy development which has resulted in the global food shortage.

The yield of the Kraft Pulp and hydrogen peroxide bleached pulp obtained had good yields i.e. 62 % and 75 % respectively, resulting in 13 % increase in the yield of pulp. Also, the characterization of the paper showed that the paper has good tensile strength and high dimensional quality which indicates the presence of a good and quality paper.

The results of the research have shown that *Abelmoschus esculentus* (Okra stem) is a suitable and reliable non wood raw material for pulp and paper handsheet production. The study had shown the sustainability and suitability of biomass wastes as an alternative to wood source for pulp and paper production in order to curtail environmental pollution and also give rise to waste to wealth economy.

5.2 Recommendation

There should be more research efforts on conversion of lignocellulosic biomass wastes into viable raw materials for industrial applications. This will help in the conservation of environmental resources presently threatened by the rapid deforestation and environmental pollution across the globe.

Again, government at all levels should provide incentive measures to assist in more wastes recycling process to encourage effective management of forestry products.

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