



## **Agricultural Residues as an Alternative Source of Fibre for the Production of Paper in Kenya-A Review**

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### **Authors' contributions**

*This work was carried out in collaboration with all the authors. All the authors approved the manuscript for submission to the journal. All the authors read and approved the final manuscript.*

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### **ABSTRACT**

The pulp and paper industry is primarily dependent on fibrous wood for pulp and paper production. However, this over-dependence on fibrous wood poses serious environmental challenges such as the diminishing of the fibrous wood stocks, deforestation, emission of greenhouse gases, and global warming. Therefore, to mitigate these environmental challenges associated with its utilization for paper and pulp production, other sustainable raw material sources can also be considered for the production of paper and pulp. There are enormous benefits associated with the utilization of non-wood fibres as an alternative and sustainable raw materials source for the production of paper and pulp. These benefits have in the recent past prompted millers in China, India, Brazil, and the USA to consider the utilization of non-wood fibres in paper and pulp production.

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In Kenya, the pulp and paper industry is very much dependent on fibrous wood for production and the industry is yet to fully embrace the utilization of nonwood fibres for paper and pulp production. Further, the dependence on fibrous wood has contributed significantly to the decline of paper pulp and paper production, deforestation, and rise in paper importations due to insufficient raw material supplies. The importation of paper and pulp products has further led to the collapse of the paper industry in Kenya. The sector stands a chance of revival and vibrancy through the utilization of the abundant agricultural residues and feedstocks lying in the agricultural fields across the country. Similar experiences elsewhere have proved that the abundance of agricultural waste can be utilized for the production of paper and pulp due to their excellent fibre content for specialty papers, and easy pulpability. The agricultural residues are therefore considered a quintessential alternative and sustainable source of raw materials for the pulp and paper industry. Moreover, their utilization will mitigate environmental impacts such as deforestation, climate change, and pollution .

*Keywords: Pulp; paper; agricultural residues; non-wood biomass; Kenya.*

## 1. INTRODUCTION

There is a high demand for pulp and paper products globally due to an increase in population, industrialization, and urbanization. This demand has led to the massive cutting down of trees as this sector is heavily reliant on fibrous wood for the production of paper and pulp which are primarily sourced from the forests [1]. There is a concern that in the coming years the demand for paper will increase tremendously and ultimately surpass the resource regeneration. The world currently produces approximately 390 million tonnes of paper and paperboard [2]. Most of the pulp and paper produced is however utilized in the packaging industry and the production of tissue papers and hygiene products. Apart from their use as stationery, newsprint among others [3].

In most countries, for example, there is heightened demand for pulp and paper for use by the hygiene and sanitary sector, stationery, publishing among other sectors. As the population continues to grow the trend for the increased demand for pulp and paper products will be sustained. Further, there is increased competition for wood supplies and a decrease in forest cover. Consequently, with the decrease of the forest cover, the cost of the wood is on the rise [4], and with the ever-rising costs for fibrous wood, an alternative raw material source will be an ideal consideration for utilization in this industry.

Agricultural residues therefore offer an alternative source of raw material in the production of pulp and paper whilst supporting the concept of a sustainable manufacturing through the use of abundant agricultural residue

resources [5]. Most of the agricultural residues are obtained from the three major sources namely; the agricultural by-products, industrial crops, and other naturally growing plants [6]. In the past, these nonwood fibres and other agricultural waste were either burnt or naturally converted into compost. Recent studies have shown that these biomasses are rich in biomass energy, and have the potential of generating energy for use at home and in the industry [7,8] Additionally, they have numerous environmental benefits such as easy palpability capacities and excellent fibre content for the production of specialty papers [9,10].

At present, the Asian countries notably China and India are the global leaders in the production and utilization of nonwood fibres. It is estimated that China alone produces 70.7 % of the pulp and paper from nonwood fibres, and India produces 8% of pulp and paper from the residues. Apart from these two countries, the other Asian countries produce 21.3% of pulp and paper from agro sources [11]. In Kenya, the pulp and paper industry is still dependent on fibrous wood for utilization in the pulp and paper industry [12], which are mainly sourced from the local forests.

The diminishing forest cover has, however, made the fibrous wood not a sustainable and ideal raw material source. It is estimated that there is only a 7.4% forest cover of the total landmass in Kenya [13]. Since Kenya is basically an agrarian-based economy, agricultural residues are abundant across the country that could therefore be utilized in the pulp and paper sector. Further, its utilization will help in the maintenance and regeneration of the forests, as healthy forests are considered as one of the solutions to the emerging climate and biodiversity crisis [14].

Moreover, the agricultural residues are considered as the alternative and sustainable sources of raw materials as they are generated from the agricultural fields after harvesting. Thus, its utilization in this sector will help in the reduction of carbon emissions and other greenhouse gases, species loss, perturbation of the water cycle, and soil erosion [15].

## **2. STATUS OF GLOBAL PAPER PRODUCTION**

The pulp and paper industry is one of the largest industries globally. It is dominated by paper millers from North American, Northern European, and East Asian countries. The Latin American and Australasia paper millers also make a significant contribution to this industry [2]. Presently, the paper millers from the Asian countries notably China and India contribute to over 78% of the world's paper and paperboard production needs. Consequently, the paper millers from these two countries will continue to be major industry players now and into the future [11]. Currently, the global annual paper production is at 390 million tonnes. It is therefore estimated that annually, there is an average consumption of 55kg of paper produced per person. The countries such as China, the USA, and Japan are heavy consumers of paper due to their accelerated industrial growth, bigger population sizes, and urbanization. The industrialized European countries consume a quarter of the produced paper. The African countries consume a paltry 2% of the paper produced [2]. The consumption patterns globally are however on an upward trend due to the heightened demand for paper by the packaging industries, the demand for paper products in the hygiene and sanitation sector, the adoption of new technologies, and the enhanced production capacities by the Asian paper millers. Further, the increased economic participation of the middle class has also contributed to the high demand of pulp and paper products. In the hygiene and sanitation sector, for example, paper is used in the manufacture of paper towels, toilet paper, and disposable makeup wipes [16,17].

## **3. METHODOLOGY**

The review took a systematic approach with the keywords "agricultural residues", "agricultural residues AND Kenya", pretreatment AND non-woody biomass "Pulp and paper AND

production", Pulp and paper AND Kenya, Pulp and paper production AND global.

## **4. STATUS OF PAPER PRODUCTION IN KENYA**

The pulp and paper industry was started as a joint venture between the Kenyan government, and the International Finance Corporation (IFC). This joint venture led to the opening of Pan Paper mills Webuye in 1974. The paper mill was solely started to produce the country's paper needs. The raw material was to come from the fibrous wood. After many years in operation the mill was recently shut down due to technical challenges, and decrease of the available raw material source [18]. At the peak of its operations, Pan paper mills produced more than 80% of the country's paper needs from the fibrous wood [12].

With the collapse of Pan Paper mills, the local economy took a dip and unemployment rose to unprecedented levels. In the process, the closure forced the Kenyan government and other industry players to resort to importations so to satisfy the ever increasing high demand of pulp and paper in the country. The total pulp and paper imports into the country, for example, averages 365,371 tonnes annually. Hence, the pulp and paper importations have not only dealt a blow to the local production of pulp and paper but also forced the production levels to drop drastically. The current production level is at less than 20 percent [19].

There have been attempts by other industry players to revive and resuscitate and the sector. This is buoyed by the emergence of smaller paper mills such as Kenya paper mills, Thika, Mathu paper mills, Chandaria paper mills, Highland paper mills, Eldoret and Kibos sugar and allied industries [20]. However, even with the emergence of these paper mills, they still cannot adequately meet the high paper demands the country is experiencing due to the lack of adequate raw material source as most of these paper mills are dependent on recycled paper as a raw material source.

## **5. POTENTIAL OF NON-WOOD FIBRE IN PULP AND PAPER**

The paper industry has been heavily reliant on the fibrous wood for survival and operations. However with the depletion of the forest covers, millers have been forced to consider alternative and sustainable raw material source for their

production needs [14,21]. The fibrous wood sources have other varied uses such as the production and trade of round wood, sawn wood, wood-based panels, wood pulp, and production of wood charcoal among other uses [22]. These varied uses of the trees have resulted in the scarcity of the fibrous wood for the production of pulp and paper. Consequently, this development on the varied uses of wood has generated lot of research interests on the suitability of nonwood plants for paper and pulp production. Similar experiences in countries where the utilization of the non-wood plants have been successful, the paper millers have adopted their utilization in paper production due to their benefits [15,23].

The use of nonwood plant species for paper production has origins in Egypt where the papyrus sedge (*Cyperus papyrus, L.*), was used for paper production in 1800 BC [24]. The mass production of paper from the nonwood plants was only made possible after the USA commercialized the production of paper from non-wood plants. Further, the utilization of nonwood plants in the paper industry proved pivotal when a French Scientist Anselm Payen, isolated the cellulose in 1833. In non-wood plants, the cellulose is the primary structural component of their cell wall [25].

The non-wood fibres are obtained from the annual plants planted and harvested within one growing season and can either be agricultural residues or fibre crops. The agricultural residues are field residues after the principal crops have been harvested. Some notable examples are rice

and wheat straw, corn stalks, flax straw, sugar cane bagasse, hemp, kenaf, and bamboo [26]. The utilization of these agricultural residues in the paper and pulp industry is widespread due to their abundance and availability. For instance, the paper millers in China utilize the abundant agro wastes within their jurisdiction for pulp and paper production [23]. Similarly, the paper mills in other countries have exploited and used the residues for the same reasons [21].

The agricultural residues are primarily utilized in the paper industry since they contain fibres with similar and average biometrical properties to the hardwood fibres [27]. Further, these agricultural wastes can produce pulps that are easier to be drained for further processing, apart from the development of pulps and papers of denser and stiffer sheets [28]. Moreover, the pulps produced from non-wood plants can be used to develop papers of a high potential use in the packaging industry through the addition of chemicals and test liner fibres [29]. Therefore, most of the non-wood fibres used in the paper industry are ideal for utilization due to their surface and strength properties [10].

According to Fahmy et al., the global production of paper and board from agricultural residues constitutes about 8% of the estimated globally available agricultural residues [30]. Therefore, the countries with limited forest cover could reap big from the utilization of the abundant agricultural residue resources within their borders in the production of pulp and paper.

**Table 1. The top ten leading countries in non-wood pulping capacities**

Country	Non-wood pulping capacity (1000 metric tons)	Pulping capacity (%) in country from non-wood	Global pulping capacity (%) from non-wood
1.CHINA	17672	84.2	70.7
2.INDIA	2001	61.3	8.0
3.PAKISTAN	491	100	1.96
4.VENEZUELA	260	65.0	1.1
5.COLUMBIA	252	46.8	1.0
6.MEXICO	230	24.1	0.92
7.THAILAND	221	34.2	0.88
8.TURKEY	191	27.4	0.76
9.BRAZIL	182	8.0	0.73
10.GREECE	160	84.2	0.64

Source: Sayed et.al (2019)

## 6. AGRICULTURAL RESIDUES GENERATION IN KENYA

In Kenya, the agricultural sector contributes about 51 percent of the country's GDP and creates over 60 percent of employment opportunities. Generally, the foreign export earnings from the agricultural produce are 65 percent [31]. These agricultural activities are mainly undertaken for food, industrial and horticultural purposes. Some of the food crops cultivated include; maize, wheat, sorghum, rice, millet, beans, pigeon peas, cowpeas, chickpea, green grams; and roots and tuber crops such as sweet potato, Irish potato, cassava, arrowroot, and yam. The major industrial crops are tea, coffee, pyrethrum, cotton, and sugarcane, among others. The horticultural crops include cut flowers, vegetables such as tomatoes, cabbage, kales, carrots, fruits such as bananas, mangoes, nuts, herbs, and spices [32]. Owing to the economic set up, the agricultural activities in Kenya generates approximately 15.8 MMT of dry crop residues per year [33].

## 7. PROPERTIES OF NON-WOOD FIBRES

The nonwood monocots such as cereal straws, sugarcane bagasse and corn stalks have a similar fibre composition to hardwoods and are more heterogeneous. Thus, the monocots contain large proportion of the parenchymous cells, and the epidermal cells in a wide range of dimensions [9]. The dicots such as flax straw, kenaf and hemp, contain short fibres composition surrounded with layers of longer bast fibres, and the lignin [11].

## 8. CHEMICAL PROPERTIES

The nonwood biomass comprises cellulose, hemicelluloses, lignin, and lesser amounts of extractives, protein, starch, and inorganics [34]. The plant cellulose is a polysaccharide consisting of a linear chain of linked D-glucose units [35], and the hemicellulose is a heterogeneous polymer of pentoses [36]. At the same time, the

lignin is a natural phenolic polymer that forms ether or ester linkages with the hemicelluloses [37].

## 9. CELLULOSE

The cellulose  $(C_6H_{10}O_5)_n$  is a polysaccharide consisting of a linear chain of  $\beta$  (1 $\rightarrow$ 4) linked d-glucose units. Owing to its structure, it is the main component of the primary cell wall in green plants, various forms of algae, and oomycetes. The functional groups of the cellulose in its monomer structure are made up of hydroxyls and methanol groups, while those of its polymer structure are ordered. In a polymer structure, the cellulose is semi-crystalline existing in both the crystalline and amorphous phases [38]. Although cellulose is a polymer having methanol group (-CH<sub>2</sub>OH) at carbon 6 and hydroxyl groups (-OH) at carbons 2 and 3 respectively, it is, however, insoluble in most common solvents [39].

Its applications are wide and diverse. The most distinct applications are in the fields such as pulp and paper production, the production of cellophane and rayon, the textile industry, the pharmaceutical industry, veterinary foods, and the cosmetic industry [38]. This is due to the fact that cellulose is abundant, renewable, and a biodegradable resource.

## 10. HEMICELLULOSE

The hemicelluloses are heterogeneous polymers of pentoses (xylose, arabinose), hexoses (mannose, glucose, galactose), and acid sugars. In hardwoods, the hemicellulose mostly contains xylans, and in softwoods, the hemicelluloses contain mostly glucomannans [36]. The xylans in hardwoods are heteropolysaccharides with homopolymeric backbone chains of 1, 4-linked b-Dxylopyranose units and may contain, xylose arabinose, glucuronic acid or its 4-O-methyl ether, and acetic, ferulic, and p-coumaric acids [40]. The role of hemicellulose is primarily to fix the cell wall skeleton connecting it to the cellulose fibre network [41].

**Table 2. The chemical composition of selected non –wood biomass**

Type of biomass	Cellulose(%)	Hemicellulose (%)	Lignin (%)	Ash (%)	Extractive (%)
Oil Palm	14.3-65.2	12.5-38.7	17.3-26.5	2.0-3.5	0.9-3.0
Bamboo	20.3-61.5	19.3-21.4	11.1-32.2	1.7-5.1	1.3-2.8
Bagasse	55.6-57.4	23.9-24.5	24.35-26.3	1.5-5.3	2.65-3.25
Rattan	35.6-52.9	22.8-34.7	21.0-22.0	1.3-2.0	0.3-2.0
Bast Kenaf	44.3-57.8	15.6-19.2	22.0-23.2	2.0-5.0	0.1-0.25
Core Kenaf	37.5-49.6	15.1-21.4	18.0-24.3	2.3-4.3	0.12-0.3

Source: Dungani et al (2015)

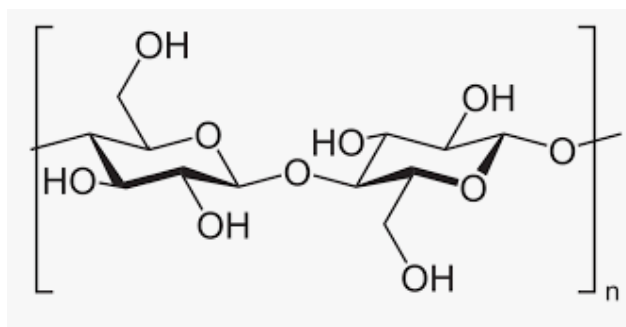


Fig. 1.The chemical structure of cellulose

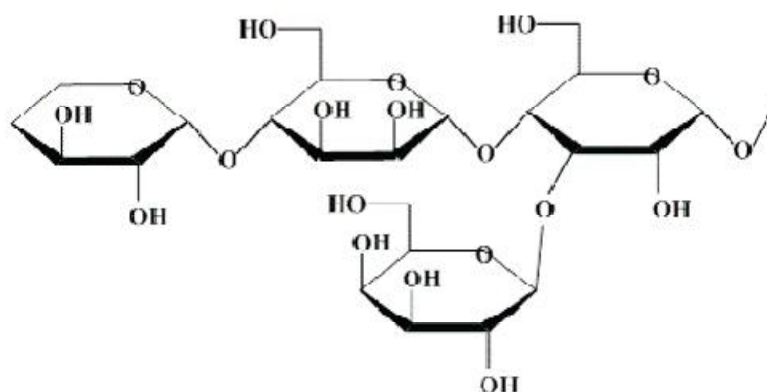


Fig. 2. The chemical structure of hemicellulose

## 11. LIGNIN

The lignin contains several functional groups such as aliphatic hydroxyl, phenolic hydroxyl and methoxyl groups. These functional groups affect the lignin reactivity and the chemical properties [42]. The most abundant hydroxyl group in a lignin polymer is the aliphatic hydroxyl [43], and the lignin polymer is usually made up of three major precursors namely, p-coumaryl alcohol, coniferyl alcohol and sinapyl alcohol [44].

Owing to the chemical composition of the lignin, the nonwood fibres have to be pretreated before their utilization in the production of paper. Thus, the pretreatment is done mainly through the chemical pulping process [45], where the tensile strength is weakened, while the tensile stiffness of the fibres remains intact [46]. The colour of the fibres during this process is, therefore, attributed to the presence of lignin [21].

## 12. PHYSICAL PROPERTIES

The physical properties of nonwood fibres are fibre length and width, crystallinity, and permeability. The fibres of non-woods are usually formed in aggregates or bundles since they are single units representing the basic building block of the fibre polymer. This fibre aggregate formation is the reason why cotton or flax are used in rope making and the textile industry [47].

## 13. PREPARATION OF NON-WOOD FOR PULPING

The agricultural residues or other nonwood fibres are sorted first before pulping. The pulping processes differs from one non-wood fibre type to the other. Overall, the development of pulp and paper involves pulping, washing and screening, oxygen delignification, bleaching, drying, and calendaring.

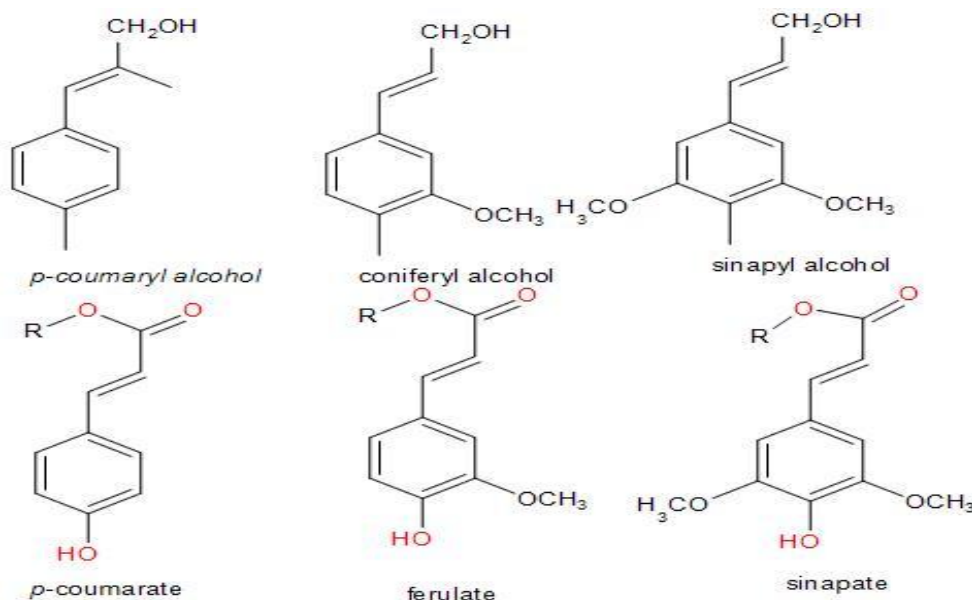


Fig. 3. The chemical structure of lignin

Table 3.The fibre dimensions of selected non- wood fibres

Source of fibres	Fibre length µm (L)		
	Max.	Min.	Average
Stalk fibres (grass fibre)			
Cereals –rice	3480	650	1140
-wheat, rye, Oats, barley, mixed	3120	680	1480
Grasses –esparto		600	1100
-sabai	1600	450	2080
Reeds –papyrus	4900	300	1500
-common reed	8000	100	1500
-bamboo	3000	375-2500	1360-4030
	3500-9000		
-sugar cane (bagasse)	2800	800	1700
Fibres flax		16000	28000
Linseed straw	55000	10000	27000
Kenaf	45000	980	2740
Jute	7600	470	1060
Hemp	4520	5000	20000
	55000		

Source: Katri Sajonkari (2001)

## A. Pulping Process

The pulping process reduces the fibrous mass of the non-wood and breaks down the interlinking bonds of the biomass hence making them more suitable for the papermaking process [48]. The most widely used pulping methods are mechanical pulping, chemical pulping, semi-chemical pulping [49,50] or bio pulping [51].

### 1. Mechanical pulping

The mechanical pulping method consists of groundwood pulping, refiner mechanical pulping (RMP), thermomechanical pulping (TMP), and chemithermo mechanical pulping (CTMP). Through this pulping method, the soaked fibre is beaten or grounded with a grindstone to produce pulp [52]. The groundwood pulping method is

majorly used during the manufacture of newsprint and magazine papers owing to the high absorbing properties of papers produced through this method and it is also an inexpensive process. Additionally, the papers produced through this method can be of excellent opacity. The only disadvantage of this process is that it produces papers with low mechanical strengths. This pulping method is thus employed for the production of folding boards, molded cartons, tissues, among other similar products [53].

The refiner mechanical pulping (RMP) method, was developed to improve and better the quality and strength of pulp and paper. The energy needs for the process are however high and the pulp produced through this method does not have similar opacity as the ones produced by the ground wood technique [52].

Thermomechanical pulping (TMP) method involves the heating of the biomass chips with steam to produce pulp. The ensuing fibres are then mechanically separated in a pressurized refiner. Through this method, stronger fibres are produced and clean steam can be recovered on completion of the process. This method, however, consumes a lot of energy to produce stronger fibres [54].

The CTMP pulping method involves the addition of catalytic chemicals to the biomass. During this pulping process, the lignin is, however, not solubilized. Thus this method is ideal for pulp whose tensile properties needs to be increased [55].

## 2. Chemical pulping

The chemical pulping method involves the addition of chemicals that eventually separates the fibres through degradation of the lignin and hemicelluloses into small water-soluble

molecules. These molecules are then washed away from the cellulose fibres without depolymerizing the cellulose fibres [56]. This method is therefore more preferred due to its ability to leave the biomass fibres intact and increasing the flexibility and conformability of the undried fibres [57]. The most commonly used chemical methods are the Kraft pulping, sulphite pulping, soda pulping, and organosolv pulping processes.

### i. Kraft pulping

The Kraft pulping method employs the use of NaOH and Na<sub>2</sub>S. Thus, during the cooking process, NaOH, the S<sub>2</sub><sup>-</sup> and HS<sup>-</sup> ionizes the Na<sub>2</sub>S and hydrolyses the S<sup>2-</sup> ions. The chemical solution which is charged is then diluted to the desired liquor-to-wood ratio by the black liquor [58]. This pulping process is therefore ideal for temperatures ranging between 165 –170°C. Other determinant factors for digestion are the wood type, the extent of the delignification process desired for the wood, and the maximum digestion temperature that is usually in the range of 1 – 2 hrs.

### ii. Sulphite pulping

The sulphite pulping process employs various cooking chemicals namely calcium, magnesium, sodium, and ammonia, for the production of different types and grades of pulp suitable for specialty papers. The process is operated in a wide range of pH levels and conditions ranging from highly acidic to highly alkaline [59]. Calcium and sulphuric acid were the initial cooking agents employed for this pulping process. In recent times, however, magnesium has replaced the duo due to its chemical benefits and heat recovery systems [56].

**Table 4. The advantages and disadvantages of Kraft pulping**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>• Universal raw material basis</li> <li>• High insensitivity to bark</li> <li>• Fast pulping process</li> <li>• High yields for hardwoods</li> <li>• Good pulp strength</li> <li>• Low extract content of the pulps</li> </ul>	<ul style="list-style-type: none"> <li>• Small process flexibility</li> <li>• Low yields for soft woods</li> <li>• High residual lignin content and poor bleachability of the pulps</li> <li>• High bleaching chemicals demand</li> <li>• Indispensable use of chlorine containing bleaching agents; high water pollution</li> <li>• Offensive smell due to volatile reduced sulphur compounds</li> </ul>



The sulphite pulping process is, however, only suitable for species with low tannins, polyphenols, pigments, resins, and fats. These extractives are known to interfere with the lignin during the sulphite pulping process [56]. There are different sulphite pulping processes namely acid sulphite pulping, bisulfite pulping, neutral sulphite pulping, alkaline sulphite pulping, multistage sulphite pulping, and anthraquinone-catalyzed sulphite pulping [60].

### iii. SODA PULPING

The soda pulping process involves the cooking of the biomass with either sodium carbonate (6–8 percent solution) or a combination of sodium carbonate (50–85 percent) and sodium hydroxide (15– 50 percent) solution at a steam pressure of 1100 kPa for approximately 14 minutes at a temperature of 150-160°C [21]. On completion of the cooking process, the biomass is mechanically pressed to separate it from the black soda liquor and evaporated to a solution containing 45–55 percent solids. The solution can be alternatively evaporated until a dry powder is obtained.

This pulping process is advantageous as it produces a sulphuric-free pulp, and the quality and strength of paper can be improved through the addition of pulping additives. Anthraquinone (AQ) is considered an ideal additive since it transfers electrons from the carbohydrates of the biomass to its intermediate structures during the degradation of the lignin [61]. This transfer of the electrons thus results in a higher pulp yield, lower solid production in the black liquor solution, and a lower kappa number.

### iv. ORGANOSOLV

Organosolv pulping involves the hydrolysis and removal of the lignin through the use of organic solvent. This two-stage process uses a broad range of organic solvents such as methanol,

ethanol, propanol, butanol, isobutyl alcohol, benzyl alcohol, glycerol, glycol, ethylene glycol, triethyleneglycol, phenol, acetone, formic acid, acetic acid, propionic acid, diethyl ether, amines, ethers, esters, formaldehyde, and chloroethanol, either in their pure forms or in aqueous solutions. The ethanol organosolv pretreatment method is effective in the separation of cellulose from the lignin and hemicellulose. At the end of the process, the dissolved lignin together with other dissolved components is recovered by the distillation of the solvent [62].

The organic solvent can at times be mixed with a base. The mixture of methanol-NaOH and water, for example, dissolves about 20% of the lignin in the first stage at a temperature of 195°C. In the second stage, the mixture rids the biomass of the remaining lignin [63].

## 3. SEMI CHEMICAL PULPING

The semi-chemical pulping process involves chemical softening and the refining of the pulp in a mechanical pulper using a lower quantity of chemicals. The pulps produced through this process are always of a higher yield owing to the use of low quantities of chemicals. This method is thus mostly suitable in the production of pulp from hardwoods and sawdust for board manufacturing [64].

## 4. BIO PULPING

The bio pulping process involves the treatment of the biomass with a lignin-degrading microorganism prior to the pulping process. These microorganisms, degrades both the biomass and the lignin resulting in the improvement of the tensile properties of the pulp. In addition, their use in biomass reduces the presence of lipophilic extractives in the pulp [51]. The most widely used microorganisms for the bio pulping process are the *Pycnoporus sanguineus* and *Polyporus arcularius*.

**Table 5. The advantages and disadvantages of sulphite pulping**

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>• High process flexibility</li> <li>• High yields for soft woods</li> <li>• Good bleachability</li> <li>• Low water pollution</li> <li>• Possible utilization of dissolved carbohydrates</li> </ul>	<ul style="list-style-type: none"> <li>• Limited raw material basis</li> <li>• High requirements on raw material quality especially it is highly sensitive to the bark of plants</li> <li>• Poor pulp strength</li> <li>• Low pulping yields for hardwoods</li> <li>• Pollutes air through the emission of SO<sub>2</sub></li> </ul>

*White rot fungi*. They are widely used because they are the most proficient biodegrader, which degrades the lignin selectively [65].

The *white rot* fungi optimizes the degradation process either by the selective or simultaneous delignification process. During the selective delignification process, the lignin is degraded earlier than the cellulose and the hemicellulose. While the simultaneous delignification process allows for both the decomposition of the hemicellulose and the lignin to occur at the same time. The decay patterns by these microorganisms are however dependent on the biomass species and the prevailing environmental conditions [66].

The bio pulping process can be carried out under normal temperature conditions as it is neither toxic nor chemically hazardous. In addition, the process requires less energy needs in the subsequent stages [67].

#### 14. WASHING AND SCREENING OF PULP

The washing of the pulp takes about four to six hours in a wash tank that generates a black liquor solution. This black liquor solution is a mixture of the chemicals used during the pulping process and constitutes about 7 – 10% of the total pulp solid contents [25]. The pulp is drained after washing, screened to remove impurities, and thickened to about 4% for bleaching. The pulp for making packaging paper is, however, not usually bleached but blended with additives and fillers in a blending chest [56,68].

##### A. Oxygen Delignification

Oxygen delignification involves the removal of the lignin before the final bleaching of the pulp and starts from the degradation of the lignin through to the formation of the phenolic radical [69]. At the end of this process, the optical properties, the tensile index, and the folding endurance of the pulp are improved. In softwoods, this process is performed from the initial kappa numbers 22–32 to a final kappa number of 8–22 [70]. This delignification process is ideal because it effectively offsets the downstream bleaching and reduces the pollution effects on the bleaching effluent. In addition, the removal of the residual lignin during this process curtails the sources of absorbable organic halides (AOX) [71].

##### B. Bleaching

The bleaching process removes about 5–10% of the residual lignin using chlorine dioxide or hypochlorite through several stages such as elemental chlorine, alkali, optional hypochlorite, chlorine dioxide, alkali, and chlorine dioxide [72]. A common sequence during the bleaching process is CEDED with individual chemical stage followed by a washing stage (where C is Chlorination, D is Chlorine Dioxide, and E is Alkali). The Sulphite bleached pulps, however, require a shorter bleaching sequence [59].

The application of the oxygen bleach significantly reduces the kappa number of the pulp owing to the less usage of chlorine dioxide in the subsequent stages [73]. Other bleaching agents such as chlorine gas, chlorine dioxide, sodium hypochlorite, and hydrogen peroxide may be applied in stages. A stronger base like NaOH is usually added in between the bleaching stages to extract the dissolved lignin from the surface of the fibres [56].

##### C. Drying

When the pulp reaches the drying stage, it is approximately 60:70% water by weight. The pulp is kept under tension to prevent distortions and shrinkage as the residual moisture is evaporated through the evaporators till dryness. At the end of the drying process, the moisture content of the web paper drops to about 2:8%. The moisture content of the paper is, however, always dependent on the end-use requirements of paper [74].

The evaporation of the moisture content is usually done through a drying machine, and the steam-heated cast iron cylinder is the most commonly used drying machine. This dryer is known to evaporate the maximum residual moisture from the paper web, as the paper web snakes through a series of cylinders to ensure consistent drying patterns on both sides of the paper [75]. Alternatively, the drying process can also be done through the application of high-velocity air cap, impinging jet tunnel dryers, air flotation dryers, the air turns, IR dryers, ultraviolet curers/dryers, or EB curers/dryers [76].

##### D. Calendering

At the end of the drying process, the web paper is passed through a calender machine to make its surface extra smooth and glossy. A

calendaring machine consists of several heat rolls that apply pressure and heat to the passing web paper [77]. The calendaring machine can either be integrated as part of the paper machine or be operated as a stand-alone installation.

## 15. CHALLENGES OF AGRICULTURAL RESIDUE UTILIZATION FOR PULP AND PAPER PRODUCTION

The utilization of nonwood biomass in the pulp and paper industry is very much feasible and an alternative to fibrous wood due to their pulping advantages, cost efficiency, pulp yield, associated environmental benefits, and the accrued income from papers produced. Their utilization is, however, inherent to some drawbacks [56]. A majority of these challenges are technological that can be improved through corrections. In other cases, the drawback results from the chemical composition of the agricultural residues. For instance, the agricultural residues with higher mineral contents require further processing before the pulping process can occur. These requirements, therefore, make the pulping process expensive, a tedious process, and at times lowers the quality of the yielded pulp. Some challenges associated with the agricultural residues are:

- i. **Availability:** The agricultural residues are bulkier, and handling them is quite challenging. Therefore, there is a need to develop efficient bailers to increase the density of the agricultural residues for efficient handling, transport, and storage. Besides, their yield per hectare is usually low, resulting in insufficient supplies and decreased production. Thus, for sustainable use of the agricultural residues in the pulp and paper industry, they need to be collected over a large area to meet the production needs of paper mills [56].
- ii. **Storage and handling:** Most of the nonwood raw materials are annual plants, and after they have been harvested, they are stored for the rest of the operating year. Their residues therefore deteriorate and limit the yield required for paper production. This deterioration of residues can be corrected by developing an efficient storage need. The residue deterioration is mostly peculiar with sugar cane bagasse owing to the action of undesirable microorganisms, which aids the biodegradation process of bagasse. In addition, the presence of residual sugar, heterogeneity of tissues, and environmental conditions facilitate the growth of microorganisms in the bagasse piles. Thus, the biodegradation process results in the chemical degradation and discoloration of the bagasse [56]. The bagasse degradation can therefore be remedied by developing an efficient depithing method during the pulping process. Generally, the straws are prone to microbial degradation and decay when stored with high moisture content.
- iii. **Pulping:** Some non-wood plants have a high silica content, which results in challenges during the washing and pulping process. The washing process of such biomass has a poor ability to drain out the moisture content and high viscosity of the black liquor solution. These pulps are therefore washed twice to reduce the content of silica. Additionally, a lime-alkali-oxygen pulping process has been developed to favour the washing process of such pulps. The addition of lime to the cooking liquor, for example, leads to the formation of calcium silicate. The calcium silicate formed is, however, insoluble in water and has a high black liquor content resulting in the formation of glassy materials, colloidal gels, and hard scales in the evaporator. This formation of glassy materials and colloidal gel can be corrected by the addition of anthraquinone, which is known to improve the pulp yield by 5% and kappa number by up to 5 [56].
- iv. **Bleaching:** The nonwood biomasses are easily discoloured during the storage period, owing to their low initial brightness. The bleaching of bagasse and other non-woody with similar parenchymous cells has therefore proved to be difficult.
- v. **Paper production:** The paper production process of nonwood biomass is usually slow as a result of the low wet strength of the fibres. This problem can be solved by blending such pulps with wood pulp in certain proportions to improve the tensile property of paper before being run through a paper machine [56].
- vi. **Chemical recovery:** The black liquors from nonwood fibre pulping process have a higher viscosity than the Kraft liquor from pine. Consequently, such non-wood are

hard to handle owing to their high solid content. The presence of high solid content challenges the chemical recovery process in evaporators, recovery boilers, causticizing equipment, and the lime kilns [56].

## 16. CONCLUSION AND FUTURE PROSPECTS

The current world paper production is approximately 390 million tonnes, and is mostly utilized in the packaging industry and the production of sanitary and hygiene products. In addition to newsprint and stationery. In the present production matrix however, most paper mills primarily depends on the fibrous wood for the production of pulp and paper leading to greenhouse gas emissions, biodiversity loss, ecosystem imbalance, and environmental pollution.

This impact caused by the production of paper from the fibrous wood could be mitigated by the utilization of the non-woody biomass. Since these non-wood biomasses are an excellent, alternative and a sustainable resource for the production of paper. These agricultural wastes can produce pulps that are easier to be drained for further processing, apart from the development of pulps and papers of denser and stiffer sheets. The pulps produced from non-wood plants can be used to develop papers of a high potential use in the packaging industry through the addition of chemicals and test liner fibres. Moreover; their fibres contain similar and average biometrical properties to the hardwood fibres. Apart from their abundance and renewability since they are spread across the county side. This review shows that pulping process of non woody biomass is ideal as it reduces their fibrous mass making them more suitable for the papermaking process, and the pulps produced through this process are always of a higher yield.

Its use can be maximized in the production of paper if the small and medium farmers are coordinated into cooperative societies. The formation and coordination of farmers' cooperative will therefore improve the reliability of the feedstock supply, and enable the societies to enjoy the economies of scale.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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