Agricultural Waste Pulping in Nigeria: Prospects and Challenges

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Abstract
The paper industry in Nigeria has undergone serious travails as a result of the high dependence on imported inputs, most especially, long fibre pulp. Thus, Nigeria depend extensively on paper importation. As the nation is an agricultural country, it generates substantial volume of agricultural waste in all its ecological zones. The waste can be a sustainable source of raw material for the nation's pulp and paper industry. The utilisation of agricultural waste as raw material for the paper industry had been going on in a number of countries that does not have sustainable supply of wood. This practice will substantially assist the nation in eliminating the current import dependence of the paper industry to a reasonable extent.
Keywords: pulping, waste, kraft, soda, straw.

1.0 Introduction

The Nigeria paper industry has undergone serious travails. Despite the aim of the national planners to ensure sufficient production of pulp and paper products for local utilization and for export in the 60's to 1970s, the industry is still at its infancy (Ogunwusi, 2014; Onilude et al, 1998; RMRDC, 1991, 2010). Among the major problems militating against the development of the industry are its dependence on imported raw materials, most especially, long fibre pulp, chemicals, equipment, spare parts and, skilled manpower (TCPC, 1993; Makinde, 2004; Udohitinah and Oluwadare, 2011). As a result, the three pulp and paper mills that were established in the country, viz; the Nigeria Paper Mill (NPM), Jebba, the Nigeria Newsprint Manufacturing Company (NNMC), Oku Iboku and the Iwopin Pulp and Paper Company (IPPC) contributed little to pulp and paper supply in the country between 1994 to 2009 (RMRDC, 2010; 2003; Onilude and Ogunwusi, 2012; 2014). The companies remained closed throughout these period, during which they suffer a lot of bastardisation through extensively cannibalization of the process equipment. Part of the challenges that led to the closure of the NPM, Jebba and the NNMC, Oku-Iboku were operational as a total of US$85,000,000 was required, annually, to import the 85,000 metric tons of long fibre pulp if the mills were to operate at full capacity (Makinde, 2004). From all indications, the burden of long fibre pulp importation may continue to militate against optimal performance of the industry if adequate steps are not taken. To mitigate the dependence on importation of long fibre pulp supply, a strategic plan was put in place to promote plantation establishment of *Pinus species* in the country in the 1960's for long fibre pulp production. To ensure the success of the initiative, seeds of the plant species were imported and established in plantations in various locations in the savanna and forest ecologies in Nigeria (Ojo, 1971). While a modest success was recorded at the early stage of the programme, the exercise eventually turn out to be a failure (Momoh, 1970). One of the major causes of the dismal performance was the inability of the mycorrhiza fungi imported to establish in the soil as a result of high temperature. (Momoh, 1971). Thus, pine plants can currently only be found on experimental plots in Nigeria, in locations such as Afaka in Kaduna State, Miango in Jos, Plateau State, Ijaye forest reserve in Oyo State and a number of other isolated places (RMRDC, 1991). The next most important reason was the inability of government to commence the Phase 11 Petrochemical Project initiated to ensure sustainable supply of chemicals (RMRDC, 1991).

Intrinsically, paper consists of a web of pulp fibre derived from wood and other plants from which cellulose are separated from other components with pulping chemicals or mechanical force through grinding. In the final stages, on aqueous slurry of fibre components and additives are deposited on a wire screen and water is removed by gravity, pressing, suction and evaporation (Biermann, 1993). The fibre properties of the raw materials affect the quality and end use of paper produced. For fine papers, both long and short fibres are needed. The long fibres from softwoods with fibre length of about 2.8mm form a strong matrix in the paper sheet. The shorter hardwood fibres from decidous trees with fibre length ranging from 0.6 – 1.9mm (Hunter, 1988) contribute to the properties of pulp blends, most especially opacity, printability and stiffness. In fine papers, addition of short fibre length with adequate beating, contributes to printability of papers.

However, in view of the lack of long fibre pulp raw materials locally, coupled with the increasing cost of imported long fibre pulp from coniferous softwoods in most developing tropical countries in Africa, a number of researchers including King (1977) and Patil *et al,* (2011), have recommended that developing tropical countries in Africa should re-strategise and promote paper production processes that depends more on local raw materials in order to ensure the sustainability of the industry locally. One of the major options available to countries with substantial agricultural produce is to encourage the production of paper from agricultural waste. As Nigeria is an agrarian country, it is expedient that the prospects and challenges of boosting pulp and paper production locally through the establishment of pulp and paper mills that uses agricultural residues as fibrous raw material be examined in the country. This paper therefore examine the prospects and challenges of paper production from agricultural residues produced in the country. It highlights the type of waste available locally and the prospects for their use as industrial raw materials in the paper production processess.

2.0 Agricultural Waste Generation in Nigeria

There is growing interest in the pulping of non wood plants most especially, agricultural residues globally (Sridach, 2010). Presently, non wood raw materials account for 10% of the total pulp and paper produced world wide (El-Sakhawy et al., 1996). This is mostly made up of 18% baggase, 14% bamboo and 11% others. The need to promote the use of agricultural residues is being influenced by increasing agricultural production and productivity globally as man continually sought to improve the quality of life by transforming nature to provide more food, better living conditions and long life (Hall *et al*, 2009). Agricultural mechanisation and technology has helped to accomplish this transformation. It has however left a progression of environmental problems at its wake. The problems associated with farm waste management are numerous and can escalate into disastrous situations, resulting from improper waste management. Lack of adequate information on quantity of waste generated, handling, treatment and disposal have been constraining industrial utilization of agricultural waste in Nigeria where farmers in most parts of the country have concentrated on intensive production of field crops which annually leads to generation of large quantities of vegetal waste. The type of waste generated, their quantity and characteristics have not been studied in detail in Nigeria. However, based on the distribution of the country into ecological zones through climatic considerations, coupled with the distinct characteristics of each zone, the major types of agricultural waste generated that can be of use in the paper industry locally are presented in Table 1. From the table, it can be observed that many types of straws are available in Nigeria as by-products of agriculture and thus can be potentially used as sources of raw material for the pulp and paper industry. In view of the pulpability of straws, agrowaste pulping facilities can be established in states shown in Table 2. In most cases, the by-products are cheaper than wood. As most of the straws produced locally are by-products of agricultural produce, the total cost of production will be shared with the main crop. In most cases, the cost of agricultural residues to the paper mills will be the cost of transporting the residues to the mill.

3.0 Pulping of Agriculture Waste

The earliest information on the use of any non wood plant species as surfaces for writing dated back to 3000 BC in Egypt. The pressed pitch tissue of papyrus sedge (*Cyperus papyrus,* L.), a non-wood plant, was for the first time used for paper production in 1800. In 1827, the first commercial pulp mill to use straw began operation in the USA (Atchison and McGovern, 1987). In the 1830's, Anselm Payen a paper mill, found a resistant fibrous material that existed in most plant tissues. This was termed cellulose by the French Academy in 1839 (Hon, 1994), although, after the invention of the chemical process, wood became the dominant raw material for paper production as a result of its wide availability and ubiquity (Rowel, 1983; Young, 1986; Casey, 1980). However, in many countries, wood is not available in sufficient quantities to meet the rising demand for pulp and paper (Atchison, 1987a; Judt, 1993). Consequently, studies were undertaken in Europe and North America to find new sources of non-wood raw material for pulp and paper production. Two reasons were mainly responsible for the search for new raw materials. These are the shortage of short fibre raw material (hardwood in Nordic countries) and substantial availability of agricultural residues. China produces 77% of the world's non wood pulp (Paavilainen *et al* 1996b; Paavilainen 1998). In China and India, over 70% of the raw material used by the pulp industries comes from non woody plants which are mostly agricultural residues that consists mostly of straw and baggasse. In India where the pulping of agro waste is combined with waste paper, agricultural residues are used at both small, medium and large scales pulp and paper mills.

4.0 Agricultural Waste Pulp Production Process

Among the advantages of agricultural residues pulping are the simplicity of the process and the lower requirements of pulping and bleaching chemicals. Several authorities have outlined the processes for pulping agricultural waste. However, according to Winner et al., (1991), the process of pulp and paper making from agro-based residues consists of the following stages:

i. Raw material preparation: Dedusting, depithing, leaf removal
ii. Pulping section: Cooking, beating, pulp washing, refining, bleaching, cleaning and, thickening
iii. Stock preparation: Blending and pulp conditioning
iv. Paper machine: Refining, centricleaning, dewatering, drying of paper

4.1 Raw Material Preparation

The agro residue based raw material (RM) can be procured by the mills from nearby farms. In some mills raw materials are screened at the site. The dust from the screening section is disposed of as solid waste along with municipal waste. In very small mills, bagasse is not depithed. The prepared agro raw material is then conveyed to spherical digesters. There are two types of digestion processes employed. These are the batch and continuous process. Unlike wood pulping, two different chemical pulping processes are employed, namely the kraft and soda processes (Winner et al, 1991).

The agro residue is chemically digested in a digester at 150 – 160^{o}C and 6 – 7 atm pressure for about six hours (Winner *et al*, 1991). Charging and discharging takes 1.5 hours and 0.5 hours respectively. The cooking in small agro-based mills is done with caustic soda (N_aOH) and steam. The quantity of NaOH charged, varies from 6 to 134 percent of raw material, depending on the type of agro residue (Bublitz,1980). For every ton of agro residue, about 1-5 – 2.0 tons of steam is used, depending on the type of pulp required. During digestion, solid to liquid (bath ratio) in the range of 1.3 to 1.4, is usually maintained (Winner et al, 1991).

4.2 Blow Tank

After cooking, the content of the digester is discharged under pressure, either into a blow tank where the pressure is released or directly into pitchers. Water is added to reduce the pulp consistency from an inlet of 12 – 14 percent, to about 3 – 4 percent, so that it can be pumped to the washing and cleaning section.

4.3 Washing

The pulp is then pumped to the washers for washing with fresh water in the final stage and backwater in the previous stages. The washing operation takes about four to six hours. The black liquor which has total solids content of around 7 – 10% is mostly discharged to drains as chemical recovery has so far been economically unviable.

4.4 Screening

The washed pulp contains sand and uncooked agro residue as impurities. The impurities are removed through screening and centricleaning. The rejects from the screening are drained out and the pulp thickened to about 4% for bleaching. The pulp for making unbleached kraft paper (for packaging purpose) is not bleached and is taken directly for stock preparation.

4.5 Bleaching

The bleaching in small mills is carried out using calcium hypochlorite (hypo). This is added in two stages in order to provide sufficient retention time for the hypo and to minimize fibre degradation. Fifty percent of the hypo is added at the screened pulp storage chest and the rest is added in the bleacher. A retention time of about two hours is provided in the storage chest. After bleaching, the pulp is washed.

4.6 Stock Preparation

The bleached pulp is mixed with the long fibre pulp, comprising mainly rags and waste paper pulp. The mix ratio depends upon the agro residue being processed and the type of paper to be manufactured. The mix pulp is blended with additives and fillers in the blending chest.

4.7 Paper Machine

The blended pulp is again centricleaned to remove impurities and finally fed to the paper machine through a head box. From the dewatering and paper making angle, the machine has three principal stages:

i. The gravitational and vacuum dewatering stage (wire part)
ii. The mechanical dewatering stage (press rolls part)
iii. The thermal drying stage (indirect steam dryers)

On the wire part of the paper machine, the dewatering of pulp takes place by gravity and vacuum. The water from the wire mesh is collected in a pit and is continuously recycled to dilute the pulp fed into the paper machine centricleaner. In some mills, the wire is continuously washed with fresh water showers. The water is collected and fibre is recovered.

After the wire part, the edge cutting operation is carried out to obtain paper of a definite width. The edge cuts of the pulp web falls in the couch pit and are recycled. Towards the end of the wire part of the machine, the consistency of pulp rises to about 20 per cent. Further dewatering is carried out by press rolls to raise the consistency to about 55%. The paper is finally dried through an indirect steam dryer to about 94% solids and is collected in rolls as the final product.

5.0 Prospects for Utilisation of Agricultural Residues for Pulp and Paper Production in Nigeria

While theoretically, any fibrous plant can be pulped to provide cellulosic fibres for paper manufacture, technically, however, and more often, economic constraints limit the number of usable plants. The most important agricultural residues used in the pulp and paper industry are straw, baggase and more recently, sorghum (Ogunwusi, 2012; Bublitz, 1980). In Nigeria, straws are available as by-products of agriculture, and thus can be potentially cheaper than wood. In most cases, after harvest, the straws are dried and burnt off. Any programme designed to use straw as raw material in the paper industry will earn extra income for the farmers and provide employment in terms of bailing and transportation to the mills.

A major advantage of agricultural residues is that they are widely distributed in the country. In parts of the country that cannot support abundant growth of trees, agricultural produce are cultivated. In addition, plants of this type are frequently grown in areas that will not support trees, such as in areas with very limited rainfall and low soil quality. This makes it possible for pulp and paper mills based on agricultural produce to be establish-able in remote parts of the country. Also, the pulping of non wood fibres has been reported as ethically sound way to produce pulp and paper, compared to clear cutting of rain or premevial forests. According to Sridach (2010), the benefits of non wood plants as fibre sources are their fast annual growth rate and smaller amounts of lignin compared to wood. Also, non wood fibres such as agricultural raw materials can be pulped with lower chemical charges. Likewise, non wood pulping can make small size mills economically viable, given the simplified process and their non polluting nature (Sridach, 2010). Additinally, non wood fibres can give another income to farmers (Rousu et al, 2002; Kissinger et al. 2007).

Bublitz (1980) estimated that agricultural crops generally produce an annual crop with straw tonages varying from a low 2.2 t/ha to 4.4t/ha to a maximum of 18 to 22 t/ha. This upper range surpasses the annual growth of any species of tree. Table 3 shows the yields of straw from major agricultural commodities and their pulp yields. From the table it can be observed that the yield of straw from agricultural produce has increased considerably as a result of improvement in crop production practices. Wheat straw yields in excess of 2.5 t/ha. Apart from improved yield, agricultural residues are mostly products of annual plants compared 10 to 20 years needed for trees to become large enough for commercial harvesting. Consequently, the planning and take off stage for the establishment of pulp and paper mills based on agricultural residues will not be as long and as difficult compared with mills based on wood (Ogunwusi, 2012).

Straw fields can also be easily harvested as specialized equipment are not required except in extensive farmlands. As straws are by-products of the main crop, total cost of production is shared with the main crop and cost of straw to the pulp mill should not be excessive (Bublitz, 1980). Pulping of straws does not require high volume of chemicals as most straws are readily pulped and bleached since they are not heavily lignified. They also require short processing time compared to wood. In addition, most pulp from straws need little refining before paper making and are well suited for papers where high strength is not needed. Bleached straw pulp is generally excellent as a filler in fine papers to improve smoothness, formation, printing or writing characteristics, whereas semi-chemical straw pulps make high quality corrugating medium (Bublitz, 1980).

It has been estimated that about 40 different processes are suitable for pulping agricultural residues (Ranua *et al,* 1977). The most used method is the alkaline process which includes sulphate (kraft), soda and sulphate methods (Table 4). The most commonly used commercial method is the soda method (Sadawarte, 1995).

More recently in a work reported by Patil *et al* (2011), high biomass sorghum was reported to be a very good agricultural residue in India. Sorghum leaves and stalks were observed as suitable raw material for pulp and paper production. The pulp from the raw material was used to manufacture writing paper, wrapping paper and other paper products. Chemical analysis of sorghum justified its suitability as a potential paper making raw material where all parameters are comparable to other agro residual raw materials such as baggase and wheat (Table 5). Compared to other raw materials, sorghum leaves and stalks are easier to convert to pulp. They require smaller volume of chemicals during pulping and produce smooth and mallable pulp from sorghum stalks and leaves and show strong transparency and brightness plus better folding and bursting qualities. In Nigeria, sorghum is grown in copious quantities in all the states in the North West, North East and North Central parts of country, including Abuja. This, in addition to baggasse, rice and wheat straws can form the basis of a virile agripulp industry locally. According to Onilude and Ogunwusi (2012), non wood fibres are used for major types of papers. This reflects substantially in the increased use of non wood fibres from 2000 tons in 2003 to 850,000 tons in 2006 (FAO, 2009; Lopex, 2009). In Nigeria, the three integrated pulp and paper mills are large scale mills going by the definition of UNIDO (1978). Going by the UNIDO (1978) definition, any mill with more tha 100 tons daily capacity are large scale mills. In the Nigerian environment where there is inadequate infrastructure, raw materials and absence of skilled manpower coupled with low capital base, the establishment of only large scale mills cannot be regarded as optimal (Ogunwusi, 2014). Thus establishment of small and medium scale mills pulping agricultural waste may be a way forward in solving the persistent pulp and paper supply problems locally (Ogunwusi, 2012; 1996a; 1996b; 2014).

6.0 Challenges of Agricultural Residue Utilization for Pulp and Paper Production

Traditionally, agricultural residue pulp mills operate on relatively small scales (approximately 20,000 tons/year) (Patil et al., 2011). Small scale mills have more difficulties in coping with environmental legislation (Hannold, 2009). Consequently, most of the non-wood fibre pulping plants in the European Union have been closing in the past decades. This situation is also the same with China. Initially, most Chinese paper products came from domestic agricultural residues such as wheat straw and baggasse rather than wood. The capacity of the mills was very small. In addition, the quality of the paper was poor (Hannold, 2009). Although, Chinese aggregate paper production was sizeable, it was intended primarily for the domestic market. Lacking waste water treatment facilities, the mills were major contributors to the pollution of rivers and lakes (He and Barr, 2004). Within the last two decades however, major changes have occurred in the China's paper industry. The Chinese government closed thousands of state owned pulp and paper mills to reduce water pollution. Nonetheless, many of the mills remain in business and continue to account for a sizeable portion of China's aggregate paper production. Currently, the percentage share of the total fibre that is accounted for by domestically produced non-wood pulp and domestic recovered paper has fallen while the percentage share of imported wood pulp has risen sharply (Stafford, 2007).

Another major drawback to agricultural waste pulping is the seasonal availability of the raw materials. Although, harvesting is done yearly, it must be accomplished within a short period. Thus, intensive investment in heavy machinery is idle most of the year. Straw also tends to be bulky, complicating transportation and storage problems. In addition straw handling costs are higher than wood handling costs (Bublitz, 1980). Storage space must be provided for an annual supply of straw for a pulp mill, whereas, wood may be cut throughout the year and brought to the mill as needed. Also, straws are quite susceptible to microbiological degradation, particularly, when wet. This can destroy the pulping potentials in a matter of days as opposed to the weeks and months needed to degrade wood to a similar degree. The fibres of straws are generally shorter than softwoods, and hence, drain slowly. This decrease production rates during washing and dewatering operations. In addition, many straws have high silica contents. If pulped by strong alkali, the silica dissolves in the pulping liquor and re-precipitates on process equipment in the liquor recovery operations. Evaporator tubes can be plugged and lime mud setting rates seriously disturbed by silica. Also, agricultural produce require high inputs for growth, threby contributing to climate change problems. Another major problem of non wood fibre pulping is the significant variation in their chemical and physical properties compared to wood fibre (Gumuuskaya and Usta, 2002). The properties vary depending on species and local conditions such as soil and climate (Bicho et al, 1999). Short fibre length, high content of fines and low bulk density are the most important features of agricultural residues (Oinonen and Koskivirta, 1999; Paavlaiineen, 2000).

Conclusion

The need to increase paper production capacity locally cannot be over emphasized. Since the integrated pulp and paper mills cannot satisfy local pulp and paper needs, it is imperative that local production capacity be increased to reduce the drain on foreign exchange. In line with the advice by experts, one of the ways this can be achieved is to promote the pulping of tons of agricultural residues that waste away annually in the country. Although agricultural residues pulping has its drawbacks, the most important of which is environmental pollution, the development of new pulping techniques such as Arbokem patented pulping technology which is energy efficient and ecologically sound would promote the utilization of agricultural residues for pulp and paper production in the near future. Among the advantages of the technology are co-manufacturing of bioenergy with a small environmental footprint coupled with fact that the manufacturing operations are on a community-based scale. In addition, the increasing importance of the non polluting organosolv pulping method developed to eliminate lignin and hemicelluloses degradation products from black liquor, will substantially reduce the environmental problems that are associated with small scale pulping of agricultural residues.

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Table 1: Major Pulpable Agricultural Residues in Nigeria

S/N		Fibre		Ash (%)	Lignin (%)	Cellulose (%)
		Average Fibre Length (mm)	Average Diameter (μ)			
1.	+Rice	*0.5	*8.5	*14 – 20	*12 – 14	*28 – 36
2.	+Baggasse	*1.7	*20	*2	*19 – 21	*40 – 43
3.	+Sorghum	*0.8	*45	*4.2	*21 – 23	*58 – 60

*Source: Bublitz (1980)
+Source:RMRDC(1997)

Table 2: Pulpable Agricultural Residues Generated in Different Ecological Zones In Nigeria.

S/N	Ecological zone	States Involved	Pulpable agricultural Residues.
1	South West	Oyo, Ogun, Ondo, Lagos, Ekiti, Osun	Maize Straw, Rice Straw, Baggase
2	South South	Edo, Delta, Bayelsa, Rivers, Cross River, Akwa Ibom	Maize Straw
3	South East	Anambra, Enugu, Imo, Ebonyi, Abia	Maize Straw, Rice Staw
4	North Central	Plateau, Benue, Niger, Kogi, Jigawa, Zamfara	Sorghum Straw, Rice Straw, Beniseed Straw, Baggase
5	North West	Kaduna, Kano, Sokoto, Kebbi, Jigawa, Zamfara	Sorghum Straw, Millet Straw, Beniseed Straw Baggase
6	North East	Bauchi, Gombe, Taraba, Yola, Adamawa, Yobe	Baggase, Sorghum Straw, Millet Straw

Source: Ogunwusi (2014)

Table 3: Annual Dry Matter (DM) and Pulp Yields of Various Fibre Plants

Plant Species	DM yield t ha^{-1}	Pulp yield t ha^{-1}	References
Wheat straw	1)2.5	2)1.1	FAO 1995, Pahkala et al. 1994
Oat straw	1)1.6	2) 0.7	FAO 1995, Pahkala et al. 1994
Rye straw barley straw	1)2.2	2)1.1	FAO 1995, Pahkala et al. 1994
Barley straw	1)2.1	2)1.9	FAO 1995, Pahkala et al. 1994
Rice straw	3	3)1.2	Paavilainen & Torgilsson 1994
Bagasse (sugar cane waste)	9	3)4.2	Paavilainen & Torgilsson 1994
Bamboo	4	3)1.6	Paavilainen & Torgilsson 1994
Miscanthus sinensis	12	3)5.7	Paavilainen & Torgilsson 1994
Reed canary grass	6	3)3.0	Paavilainen et al. 1996b, Pahkala et al. 1996
Common reed	9	3)4.3	Pahkala et al. 1994
Kenaf	15	3)6.5	Paavilainen & Torgilsson 1994
Hemp	12	3)6.7	Paavilainen & Torgilsson 1994
Temperate hardwood (birch)	3.4	3)1.7	Paavilainen & Torgilsson 1994
Fast growing hardwood (eucalyptus)	15.0	3)7.4	Paavilainen & Torgilsson 1994
Scandinavian softwood (coniferous)	1.5	3)0.7	Paavilainen & Torgilsson 1994

1. The dry matter yield for cereal straw is estimated by using the harvest index of 0.5
2. Pulp process soda-anthraquinone

Average values, pulping method unmentioned
Source: Patil et al, (2011).

Table 4: Commercial and Potential Pulping Methods for Non-Woody Plants.

Process	Major Pulping Chemical	Commonness	References
Soda	NaOH	Commonly used	Paavilainen et al. 1996b
Kraft	$NaOH+Na_2S$	Commonly used for wood	Paavilainen 1996
Sulphite	$NaHSO_3$ and or Na_2SO_3	Commonly used	Attack et al. 1996
Phosphate	Na_3PO_4	Potential method	Janson et al. 1996
Milox	Formic acid	-	Seisto and sundquist 1996
IDE	NaOH, sodium carbonate, ethanol-water blend	-	Backman et al. 1994
Alcell	Ethanol-water blend	-	Winner et al. 1991

Source: Patil et al, (2011).

Table 5: Proximate Chemical Analysis of Sorghum

S/N	Parameters	Unit	Sorghum	Wheat Straw	Bagasse
1.	Ash content	(%)	4.195	5.7	2.5
2.	Cold water solubility	(%)	13.97	5.4	3.0
3.	Hot water solubility	(%)	18.27	0.6	5.1
4.	Alkali solubility (N/10)	(%)	48.61	36.1	35.5
5.	Pentosan content	(%)	19.73	19.8	26.0
6.	Holocellulose content	(%)	61.15	74.0	71.5
7.	Acid insoluble lignin content[1]	(%)	21.45	19.9	21.2
8.	Acid soluble lignin content [2]	(%)	1.33	1.5	2.0
9.	Alcohol benzene solubility	(%)	9.92	2.8	2.5
10.	Alpha cellulose	(%)	58.53	39.2	41.7
11.	Beta cellulose	(%)	23.27	18.6	17.7
12.	Gama cellulose	(%)	18.19	16.2	12.1

1. Total lignin corrected for ash content.
2. Holocellulose corrected for ash & lignin content.

Source: Patil *et al*, 2011