

Original Research Article

Physicochemical properties of Soda and Kraft lignin extracted from *Gmelina arborea* wood

Abstract

Lignin, an amorphous biopolymer is one of the major components of wood. In this study, lignin was extracted from *Gmelina arborea* wood using Soda and Kraft pulping processes. The lignin was characterized using Fourier Transformed Infrared Spectrometer (FTIR), UV/visible spectrometer, electrospray ionization mass spectrometer and scanning electron microscope (SEM). Results revealed that *G. arborea* wood lignins contained several chemical functional groups. Kraft lignin contain carboxyl and thiol group in addition to other functional groups. UV/visible spectroscopy results revealed that Soda lignin absorbed at higher wavelength than Kraft lignin. The concentrations of both conjugated and non-conjugated phenolic group were higher in Kraft lignin than Soda lignin. ESI-MS spectra revealed that the composition of the monomers was higher in Kraft lignin while dimers composition was higher in Soda lignin. The surface morphology of both lignins were heterogeneous with uneven particle size.

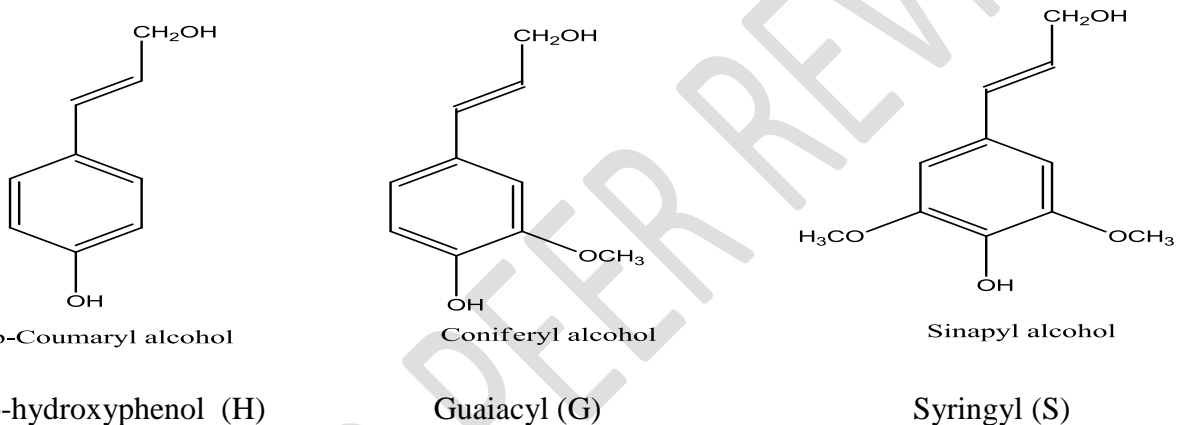
Keywords: *Gmelina arborea*, Kraft lignin, Soda lignin, physicochemical properties.

Introduction

Lignin is an abundant naturally occurring polyphenolic biopolymer present in lignocellulosic biomass cell wall and serves as binding agent for celluloses and hemicelluloses. Apart from providing mechanical support to the plant, it also plays a vital role in plant defense against various biotic and abiotic stresses as well as in seed dispersal (Boyce *et al.*, 2004; Bhuiyan, 2009). Plants contain about 15 – 30 % by weight of lignin, together with cellulose and hemicelluloses (Thakur *et al.*, 2014). Unlike most natural polymers such as cellulose, that consist of single inter monomeric linkages, lignin is a branched biopolymer consisting of many carbon-to-carbon and ether linkages. It is a heterogeneous polymer that composed of three types of

28 phenyl propane monomeric units, namely; p-coumaryl alcohol, sinapyl alcohol, and coniferyl
29 alcohol (Fig. 1) (Zakzeski *et al.*, 2016; Upton and Kasko, 2016). The structure of these
30 monomeric units differs in their degree of methoxylation of the aromatic ring at the *ortho*-, *meta*-
31 and *para*-positions (Ragauskas, 2014).

32 The composition of the monomeric units in lignin is affected by the plant species, growth
33 duration and lignin extraction method (Vanholme, *et al.*, 2008; Gosselink *et al.*, 2010). Equal
34 amounts of coniferyl and sinapyl units are present in hardwood lignin, while softwood lignin
35 contains a greater percentage of coniferyl units (92-95%).



38 Fig.1 : Monomeric units in lignin

39 These monomeric units undergo free radical polymerization to form lignin macro structure
40 (Khaldi-Hansen and Kamm, 2016). According to Terashima *et al.*, (2012), the phenoxy radical
41 stabilization occurs when monolignol radicals are randomly coupled to one another in any of the
42 positions of the unpaired electron within the plant cell wall, leading to the formation of lignin
43 polymer. Lignin composition and structure depend on the availability, and nature of monolignol
44 present and the type of bonds formed during the free radical polymerization of monolignols. This
45 radical polymerization led to the formation of condensed (5-5', β -5', β - β , β -1') or non-condensed
46 bonds (β -O-4', 4-O-5', α -O-4') linkages in lignin macro structure (Terashima *et al.*, 2012). The
47 most common lignin bond is the β -O-4 linkage, which constitutes about 50% in softwood and
48 60% in hardwood (Sjostrom, 1993; Henriksson, 2007). In hardwood, these β -O-4 linkages
49 consist of about 40% guaiacyl type and 60% syringyl type (Sjostrom, 1993). The carbon-carbon
50 bonds in lignin are generally more stable compared to the ether bonds and often resist to

51 processes such as chemical pulping (Henriksson, 2007). The presence of several functional
52 groups in lignin makes it possible to modify lignin into different industrial products such as
53 bioplastics, binders, adsorbent, dispersant, corrosion inhibitors, epoxy resins as well as some
54 industrial chemicals such as phenol, catechol, vanillin, benzene etc., (Thakur *et al.*, 2014; Kadla,
55 *et al.*, 2002). The utilization of lignin and its modified products is worth considering since lignin
56 is a waste material and does not compete with food (Laurichesse and Averous, 2014).

57 Cherif *et al.*, (2020) reported the physicochemical properties of Organosolv and Kraft lignins
58 from selected hard and soft woods. Fingerprint analysis by FTIR showed unique peaks
59 corresponding to lignin, such as C=C and C-O in aromatic rings, however, there was no
60 significant differences in the fingerprint result between both lignin. Corn stover, rice straw and
61 softwood Kraft lignin samples were characterized by Fox and McDonald, (2010) using pyrolysis
62 GC-MS, ¹³C CP/MAS NMR spectroscopy, and permanganate oxidation degradation. Pyrolysis
63 GC-MS showed the softwood Kraft, corn stover, and rice straw lignins to be G – type, H/G/S –
64 type, and G/S – type, respectively. The Kraft and rice straw lignins were found to have high
65 degrees of condensation. Watkins *et al.*, (2014) extracted and characterized lignin from wheat
66 straw, flax fiber, pine straw, and alfalfa. Also, Yang *et al.*, (2016) carried out the comparative
67 study of lignin from wheat straw obtained using soda-anthraquinone or kraft pretreatment and
68 reported that the main lignin linkages were β-aryl ether substructures (β-O-4), phenylcoumaran
69 (β -5) and resinol (β - β) substructures, while minor content of spirodienone (β -1),
70 dibenzodioxocin (5-50) and α, β -diaryl ether linkages were detected as well. The
71 physicochemical properties of lignin from *Chromolaena odorata* and *Tithonia diversifolia* have
72 also been reported (Nwosu and Muzakir, 2015).

73
74 Numerous reports exist on the biological activities of *G. arborea* organs. These include the
75 phytochemical constituent, antioxidant, antihelminthic, antidiabetic, antimicrobial, diuretic,
76 antipyretic and analgesic activities (Khare, 2004; Unnikrishnan, 2007; Satyanarayana, 1986;
77 Patil *et al.*, 2009; Rohith *et al.*, 2012; Ambujakshi and Thakkar, 2009; Pattanayak, *et al.*, 2011;
78 El-Mahmood *et al.*, 2010; Sravani *et al.* 2011).

79 To the best of our knowledge, reports on the physicochemical properties of *G. arborea* lignin is
80 scarce. This present study aimed at extracting lignin from *Gmelina arborea* wood using Soda
81 and Kraft pulping processes, and also evaluating the physicochemical properties of the extracted
82 lignin in order to ascertain their industrial potentials.

83

84

85 **Material and methods**

86 **2.1 Sample Collection and Preparation**

87 The sample, *Gmelina arborea* was collected from Ikot Obio Inyang, in Etinan Local Government
88 Area of Akwa Ibom State (GPS??). The tree was cut into logs and further processed into chips of
89 about 1cm by 1cm; air dried for three months, and stored in plastic bags pending pulping.

90 **2.2 Extraction of lignin**

91 Lignin was extracted from the *Gmelina arborea* wood chips using the Soda and Kraft pulping
92 processes.

93 **2.2.1 Soda pulping processes**

94 Briefly, 100g of sample chips were soaked in 1000 mL of 20 % NaOH solution in a 10 L
95 laboratory digester. The pulping was done for three hours at 30 °C. After the pulping, the pulps
96 were separated from the black liquor and beaten using mortar and pestle. It was quantitatively
97 transferred to the digester and pulped again for another three hours using the same pulping liquor
98 in order to extract greater quantity of lignin. Thereafter, the pulps were separated from black
99 liquor and washed with tap water. The black liquor was kept pending precipitation of lignin.

100 **2.2.2 Kraft pulping process**

101 In this process, wood chips (100g) were pulped with Kraft pulping liquor at 30 % sulphidity.
102 The liquor was prepared by dissolving NaOH and Na₂S at a ratio of 3:1 in 1000 mL of water.
103 The wood chips were soaked in the Kraft pulping liquor at the ratio of 1: 10 (wt/v). Pulping was
104 done using the same procedure described previously for Soda pulping.

105 **3.4 Precipitation of lignin from black and spent liquors**

106 The filtrate obtained during Soda pulping is known as black liquor, whereas the one obtained
107 during Kraft pulping is known as spent liquor. Each of this liquor was precipitated using 3 M
108 H₂SO₄. The acid was added gradually and lignin was obtained as a precipitate at a pH of 2 (Li
109 and Ge, 2011). The obtained lignin was filtered, washed with distilled water and dried in the
110 oven at 70 °C for 24 hours.

111 The percentage yield of the lignin based on oven dry weight was calculated as follows:

$$112 \quad \text{Percentage yield (\%)} = \frac{W_2}{W_1} \times 100$$

113 Where w_1 = weight of the sample (g)

114 w_2 = weight of the lignin (g)

115 **2.2 Characterization of Lignin**

116 **2.2.1 Determination of functional groups**

117 The functional group of Soda and Kraft lignin were determined using Fourier Transform
118 Infrared spectroscopy (FTIR). KBr disks containing 1 % finely ground lignin samples were
119 used.

120 **2.2.2 Determination of wavelength of maximum absorption (λ_{max}) and absorbance**

121 The wavelength of maximum absorption (λ_{max}) and absorbance of Sand Kraft lignin
122 were determined using Ultra Violet/ visible spectroscopy in accordance with Surina *et al.*
123 (2015). Briefly, stock solutions of lignin were prepared by dissolving 4 mg of lignin in 50 ml of
124 0.2 M NaOH, the mixture was shaken in a mechanical shaker for 30 min to achieve complete
125 dissolution. UV-VIS spectrophotometer was used to determine the absorbance and λ_{max} at the
126 absorption region of 190 to 450 nm, scan speed 5 nm/s and 1nm resolution.

127 **2.2.3 Determination of types of phenolic structure present in Kraft and Soda lignin**

128 ~~UV spectroscopy offers a simple and reliable way of determining phenolic hydroxyl groups~~
129 ~~present in lignin. This technique is based on the difference in the absorption between lignin in~~
130 ~~alkaline and in neutral solution.~~ 5 mg of lignin was dissolved separately in 5 ml dioxane and 5
131 ml of 0.2 M NaOH was added. From each lignin solution, 2 ml of lignin solution in dioxane was
132 diluted to 25 ml using a buffer solution of pH 6, (citrate /NaOH) and 5 mL of lignin solution in
133 0.2 M NaOH was also diluted to 25 mL using 0.2 M NaOH (Gartner and Gellerstedt, 1999). This
134 gives each lignin solution a concentration of about 0.04 g/L. The difference UV- VIS spectra
135 were obtained using Genesys spectrophotometer in the absorption region of 200 to 450 nm, scan
136 speed 5 nm/s and 1nm resolution. The lignin solution in dioxane was used as a reference and the
137 lignin solution in 0.2 M NaOH was measured against it. From the difference spectra, the
138 absorbance values at 300 and 350 nm were recorded.

139 Concentration of each type of phenolic structure of lignin were calculated as follows:

140 a) Non conjugated phenolic structures (I and III)

$$\text{OH (I and III)} = [(0.250 \times A_{300 \text{ nm}} (\text{NaOH}) + 0.0595 \times A_{350 \text{ nm}} (\text{NaOH}))] \\ \times \frac{1}{(c \times d)} \text{ mmol/g}$$

142 b) Conjugated phenolic structures (II and IV)

$$\text{OH (II and IV)} = [0.0476 \times A_{350 \text{ nm}} (\text{NaOH})] \times \frac{1}{(c \times d)} \text{ mmol/g}$$

144 c) Total amount of phenolic hydroxyl groups

$$\text{OH (I + II + III + IV)} = [0.250 \times A_{300 \text{ nm}} (\text{NaOH}) + 0.107 \times A_{350 \text{ nm}} (\text{NaOH})] \\ \times \frac{1}{(c \times d)} \text{ mmol/g}$$

146 Where c = The concentration of lignin in g/L and

147 d = The path length through the sample in cm.

148 A= Absorbance

149

150

151 **2.2.5 Determination of surface morphology**

152 Surface morphology of lignin was determined using scanning electrons microscope
153 (SEM).

154 **2.4.6 Determination of lignin monomers and dimers**

155 The monomeric and dimeric units of the kraft degraded from kraft and soda lignin were
156 determined by Electron spray ionization - mass spectrometer (ESI-MS). The molecular formula
157 of the lignin monomers and dimers were determined using high resolution ESI-MS at the range
158 of 100 to 500 m/e.

159 **3.0 Results and Discussion**

160 **3.1 Functional groups present in Soda and Kraft lignin**

161 FTIR spectra (Table 1) showed a broad intense absorption band at $3000 - 3500 \text{ cm}^{-1}$ in both
162 Soda and Kraft lignin corresponding to the stretching vibration of the free aliphatic and aromatic
163 hydroxyl group and bonded hydroxyl of carboxylic acids ((Faix, 1992; Namasivayam and
164 Kavith, 2006). The peaks around $1595 - 1510 \text{ cm}^{-1}$ found in both samples are attributed to the
165 presence of the C-C stretching of aromatic ring (Han *et al.*, 2010). The absorption peak occurring
166 at 1595 cm^{-1} and 1599 cm^{-1} in Kraft and Soda respectively are characteristics of aromatic C-O
167 stretching of phenolic hydroxyl groups. There was aliphatic OH bending vibrations at 1036 and
168 1077 cm^{-1} in **KL** and 1036 and 1088 cm^{-1} in **SL**. There were C-O vibration band of phenol
169 around $1200 - 1215 \text{ cm}^{-1}$, in both lignin samples. The band at 1300 cm^{-1} and 1200 cm^{-1} indicate
170 presence of both syringyl and guaiacyl groups in lignin (Chen, 2014). At 1600 and 1510 cm^{-1} ,
171 aromatic skeletal vibration bands were seen for both **Soda** and **Kraft lignins**. Symmetric aryl
172 stretching was found at 1595.3 cm^{-1} and 1599.0 cm^{-1} in Kraft and Soda lignin respectively,

173 while asymmetric aryl stretching was found at 1513 cm⁻¹ and 1509 cm⁻¹ in Kraft and Soda lignin
174 respectively. Stark et al., reported 1594 cm⁻¹ (Symmetric aryl stretching) and 1512 cm⁻¹
175 (asymmetric aryl stretching) for softwood (*P. ponderosa*).

176 The major structural difference between Soda lignin and Kraft lignin is the presence of C-S
177 vibration peak at 2650 -2600 cm⁻¹ found in Kraft lignin (Fig. 2 and 3). This is as a result of the
178 presence of sulphur in Kraft pulping liquor which reacts with lignin to form lignosulphate and
179 lignothiols (Sjostrom, 1993). Also, there was no carbonyl absorption band in Soda lignin. The
180 C=O absorption band (1703 cm⁻¹) present in Kraft lignin, may be due to oxidation reaction that
181 takes place during Kraft pulping.

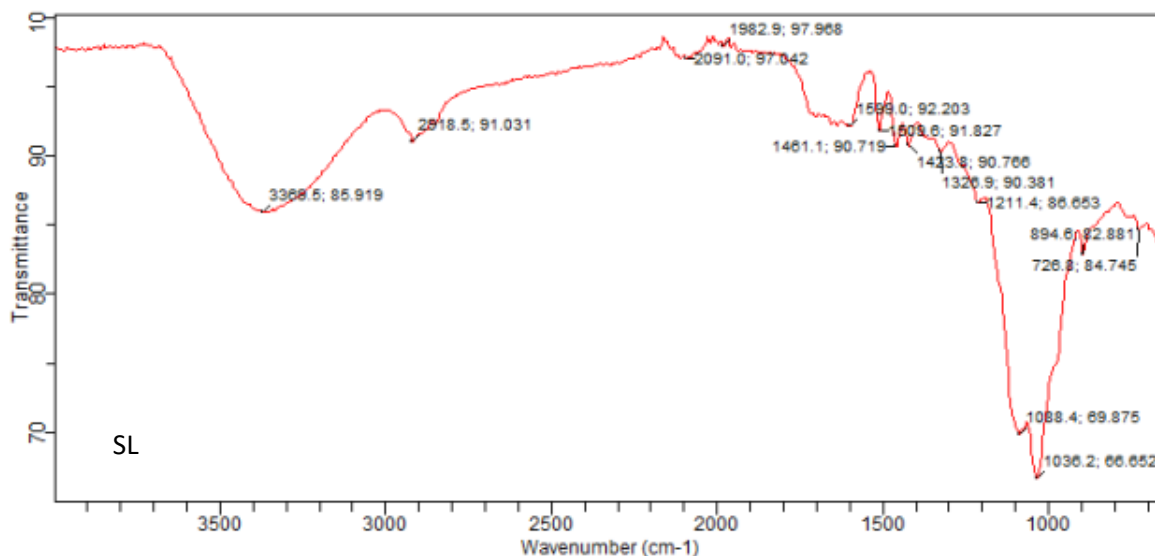
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183 Table 1: FTIR Spectra of Soda and Kraft lignin

Band (cm ⁻¹)	Assignment	Sample present
3700 - 3000	O-H stretching alcohol	All samples
3000 – 2840	C-H stretching alkane	All samples
2850 – 2815	C-H stretch (methoxy, methyl ether)	All samples
2600 – 2650	S-H stretching thiol	Kraft lignin
1982 – 1833	C-H bending aromatic	All samples
1595 – 1510	C-C stretching aromatic	All samples
1465 – 1450	C-H bending methylene and methyl group	All samples
1427 – 1423	O-H bending alcohol	All samples
1215 – 1200	C-O stretching phenol	All samples
1160 - 1085	C-O-C stretching ether	All samples

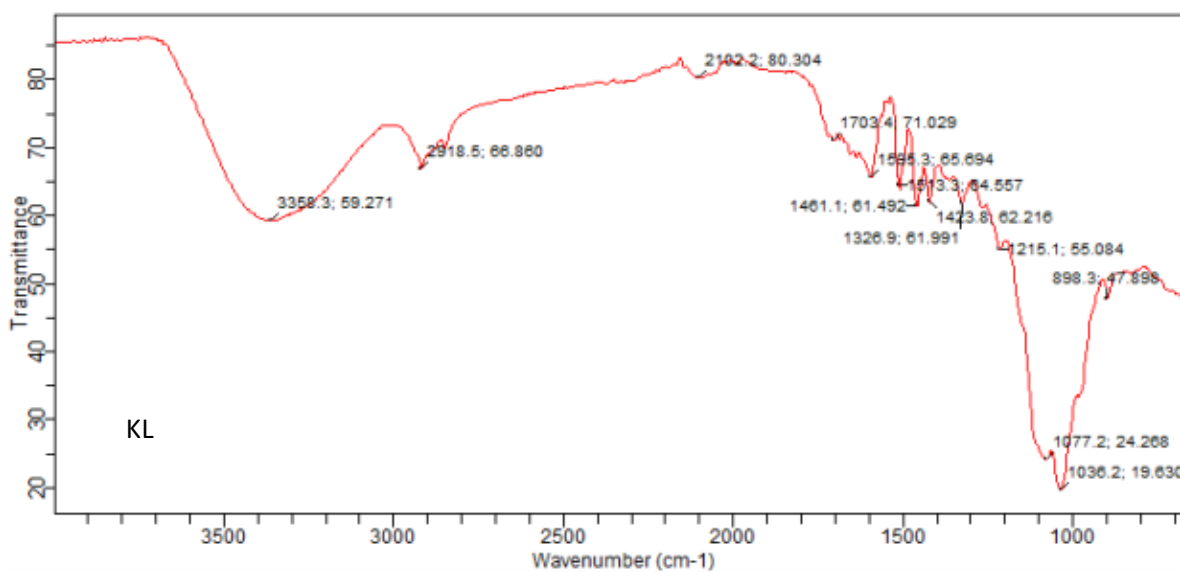
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187 Fig. 2: FTIR spectrum of Soda lignin



188

189 Fig. 3: FTIR spectrum of Kraft lignin

190 **4.2 Absorbance and wavelength of maximum absorption**

191 The wavelength of maximum absorption (λ_{\max}) and absorbance of lignin are presented in Table

192 2. Wavelength of maximum absorption (λ_{\max}) of Kraft lignin was 266 nm at absorbance of 4.538,

193 while that of Soda lignin was 280 nm at absorbance of 3.758. The increase in the absorbance of

194 Kraft lignin is due to the presence of carbonyl functional group on the lignin moiety. The

195 increase in λ_{\max} of Soda lignin is as a result of degradation of lignin that usually occurs during
 196 Soda pulping, which results in the formation of greater amount of lignin monomers and dimers.
 197 This also causes a decrease in absorbance (Sjostrom, 1993). The decrease in the λ_{\max} of Kraft
 198 lignin implies that it contains greater percentage of S-type monomeric unit, and G-type lignin or
 199 H-type lignin was probably degraded to some extent during pulping (Pei and Yang, 2014).
 200 Absorption band of non-conjugated guaiacyl and 3, 4 – dimethoxy-phenyl occurred around at
 201 277 to 282 nm, and this absorption band was found in Soda lignin.

202 Table 2: Absorbance and (λ_{\max}) of lignin and lignin esters

Sample	Absorbance	λ_{\max} (nm)
Kraft lignin	4.538	266
Soda lignin	3.758	280

203

204 2.3 Types of phenolic structure present in lignin

205 UV spectroscopic technique was also used to determine the amount of the different types of
 206 phenolic hydroxyl group present in Kraft and Soda lignin. The results are presented in Table 3.

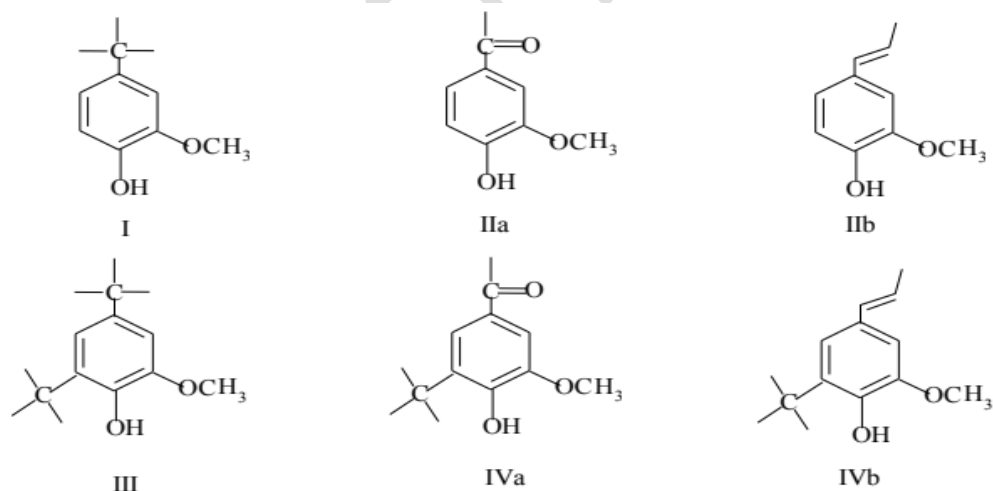
207 Table 3: Types of phenolic hydroxyl present in soda and kraft lignin

	Kraft lignin	Soda lignin
Absorbance at 300	0.417	0.150
Absorbance at 350	0.345	0.241
Types of phenolic hydroxyl group		
i) Non conjugated phenolic OH (I+III) (mmol/g)	3.120	1.295
ii) Conjugated phenolic OH (II + IV) (mmol/g)	0.410	0.287
Total phenolic (mmol/g)	3.530	1.582

208

209 According to Gartner and Gellerstedt (1999), there are six types of phenolic lignin structures
 210 (Figure 4). The UV- absorption maxima at 300 nm and 350 – 360 nm were assigned to the
 211 unconjugated phenolic structures (I and III), and those at 350 to 370 nm was assigned to
 212 conjugated structures (II and IV). The absorption maxima at 360 nm was attributed only to

213 phenolic structural type IIa and IVa in lignin (Zakis, 1994). The UV results (Table 3) revealed
 214 that the concentration of non-conjugated phenolic group and conjugated phenolic group in Kraft
 215 lignin were 3.120 mmol/g and 0.410 mmol/g respectively, and the total amount of phenolic
 216 hydroxyl group was 3.530 mmol/g, while the concentration of non-conjugated phenolic hydroxyl
 217 group and conjugated phenolic hydroxyl group in Soda lignin were 1.295 mmol/g and 0.287
 218 mmol/g respectively and the total amount of phenolic hydroxyl was 1.582 mmol/g. The decrease
 219 in the amount of both conjugated and non- conjugated phenolic group in Soda lignin may be
 220 attributed to the high rate of degradation of Soda lignin during Soda pulping in which most of the
 221 lignin fragments are solubilized in the pulping liquor (Sjostrom, 1993). Surina *et al.*, 2015
 222 reported 1.621 mmol/g, 0.229 mmol/g and 1.850 mmol/g for non-conjugated phenolic hydroxyl
 223 group, conjugated phenolic hydroxyl group and total amount of phenolic hydroxyl respectively
 224 in non-wood Soda-anthraquinone lignin.

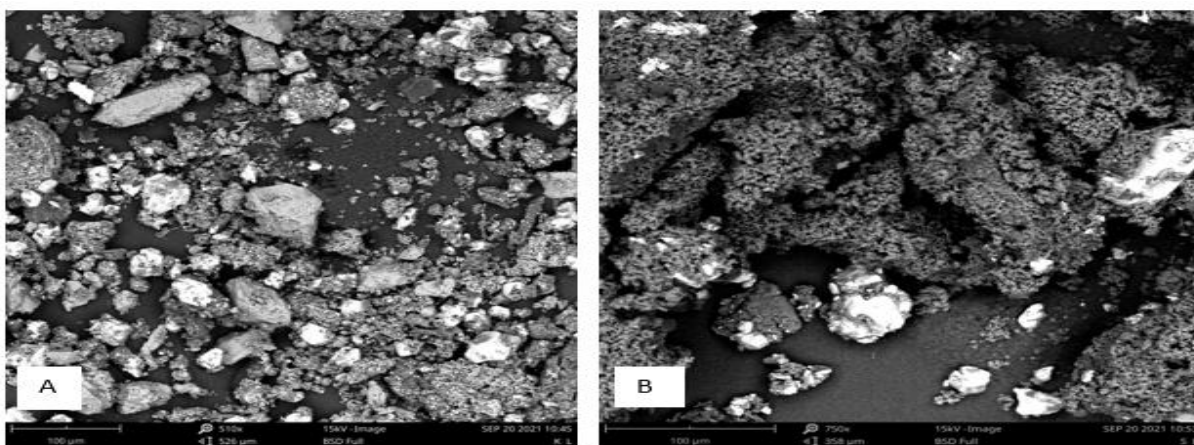


225
 226 Figure 4: Types of phenolic structures of lignin (Zakis, 1994; Gartner and Gellerstedt, 1999)

227 4.4 Surface morphology

228 Surface morphological structure of Kraft and Soda lignin are presented in Figure 5. The
 229 structure revealed that the surface of both Kraft and Soda lignin are rough heterogeneous

230 surfaces with uneven particle size and pore spaces. The particle sizes of Kraft lignin are larger
231 than that of Soda lignin.
232



233
234 Figure 5: Surface morphology of Kraft lignin (A) and Soda lignin (B)
235
236

237 4.1.6 Lignin monomers and dimers composition

238 Macro structure of lignin degrades during pulping. The main degradation reactions of lignin in
239 alkaline medium are the cleavage of β -aryl ether bonds. (Sjostrom, 1993). The monomeric and
240 dimeric composition of lignin was determined using electrospray ionization mass spectrometry
241 (ESI-MS). The results obtained (Fig. 6 and 7) showed that Soda lignin contained a mixture of 27
242 monomers and dimers, while Kraft lignin contained a mixture of 15 monomers and dimers. High
243 resolution ESI-MS identified 2 monomeric and 18 and dimeric components in Soda lignin, while
244 5 monomeric and 15 and dimeric components were present in Kraft lignin. The high level
245 monomeric and dimeric constituent in Soda lignin was due to the fact that the Soda liquor had
246 greater tendency to attack ether linkage (β -O-4 linkages) in lignin during pulping and cause
247 cleavage of ether-lignin bond (Sjostrom, 1993). This cleavage promotes lignin solubilization by
248 decreasing the molecular weight and increasing the phenolic hydroxyl group content (Balakshin,
249 2013). The reaction of phenolic β -O-4 unit in guaiacyl structures begins with the reversible

250 formation of an unstable quinone methide (Sjostrom, 1993). The quinone methide structure may
 251 undergo several reactions depending on the severity of the alkaline medium. In the absence of
 252 hydrogen sulfide, the degradation of quinone methide proceeds mainly via elimination of
 253 formaldehyde unit, and as a result, the enol ether is formed, this led to the absence of carbonyl
 254 group in Soda lignin as already shown in FTIR spectra. In the presence of nucleophiles, lignin
 255 condensation products may be formed resulting in the formation of lignin dimers (Gilarranz,
 256 2000). The non-phenolic lignin units are difficult to degrade, however, Soda liquor effectively
 257 depolymerised both phenolic and non-phenolic fractions of lignin β -O-4 bonds resulting in
 258 greater degradation products found in soda lignin (Sjostrom, 1993, Sannigrahi and Ragauskas,
 259 2010).

260 Table 4: Degradation products of soda and kraft lignin identified by high resolution ESI

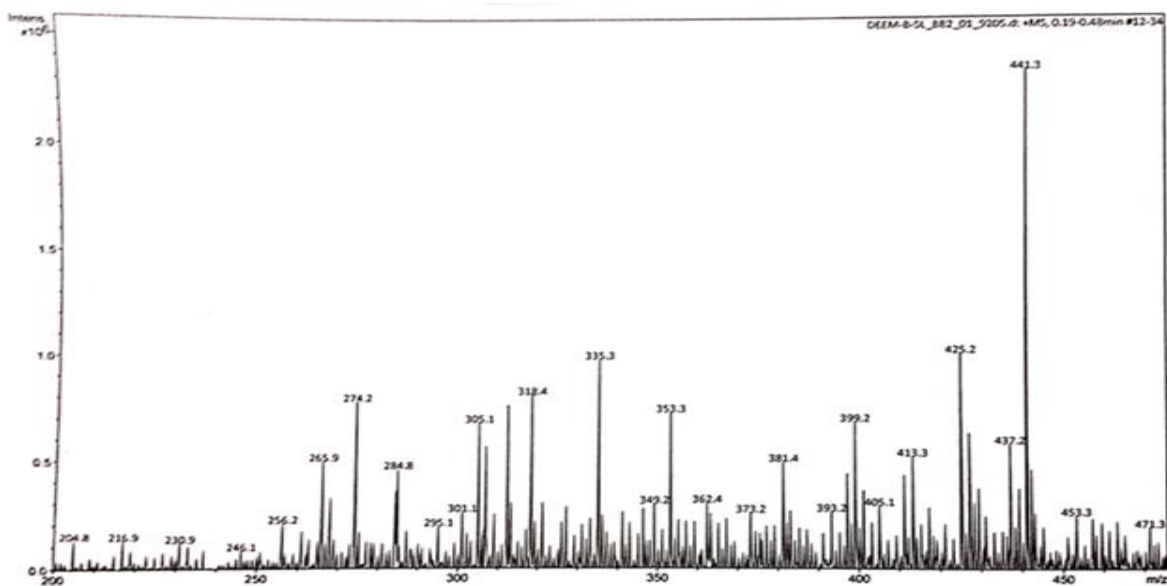
	Molecular formula	Molecular weight	Sample found	Type
1	C ₇ H ₁₀ O ₃	142	Kraft lignin	Monomer
2	C ₈ H ₁₁ O ₃	155	Kraft lignin	Monomer
3	C ₉ H ₁₂ O ₃	164	Soda lignin	Monomer
4	C ₈ H ₁₃ O ₄	173	Kraft lignin	Monomer
5	C ₁₀ H ₁₁ O ₄	195	Kraft lignin	Monomer
6	C ₁₁ H ₁₃ O ₄	209	Both samples	Monomer
7	C ₁₂ H ₁₀ O ₃	202	Soda lignin	Dimer
8	C ₁₃ H ₁₂ O ₃	216	Soda lignin	Dimer
9	C ₁₄ H ₁₄ O ₃	230	Soda lignin	Dimer
10	C ₁₃ H ₁₆ O ₃	244	Soda lignin	Dimer
11	C ₁₄ H ₁₃ O ₄	245	Both samples	Dimer
12	C ₁₆ H ₁₆ O ₃	256	Soda lignin	Dimer
13	C ₁₅ H ₁₉ O ₅	274	Both samples	Dimer
14	C ₁₇ H ₁₇ O ₅	301	Soda lignin	Dimer
15	C ₁₅ H ₁₉ O ₅	304	Kraft lignin	Dimer
16	C ₁₈ H ₁₇ O ₆	318	Soda lignin	Dimer
17	C ₁₈ H ₂₁ O ₆	334	Both samples	Dimer
18	C ₁₈ H ₁₉ O ₇	349	Soda lignin	Dimer
19	C ₂₂ H ₃₀ O ₇	352	Both samples	Dimer
20	C ₂₀ H ₂₆ O ₆	362	Soda lignin	Dimer
21	C ₂₁ H ₂₉ O ₇	381	Both samples	Dimer
22	C ₂₁ H ₂₉ O ₇	393	Soda lignin	Dimer

23	$C_{20}H_{29}O_8$	397	Both samples	Dimer
24	$C_{22}H_{29}O_9$	437	Both samples	Dimer
25	$C_{22}H_{32}O_9$	440	Both samples	Dimer

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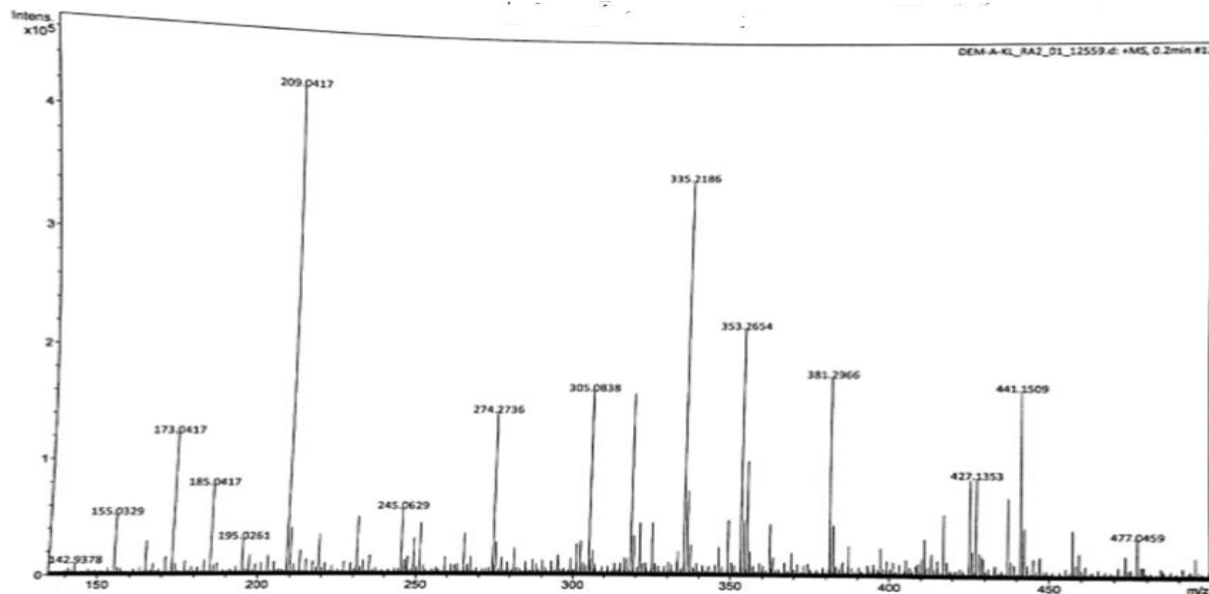


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265 Figure 6: ESI-MS Spectra of Soda lignin

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269 Figure 7: ESI-MS Spectra of Kraft lignin

270 **Conclusion**

271 Lignin was successfully extracted from *Gmelina arborea* wood. The physicochemical analysis of
 272 lignin revealed that *G. arborea* wood lignin extracted by Soda and Kraft pulping processes had
 273 several functional groups such as hydroxyl, phenolic, carboxylic, methoxy, thiols and ethers in
 274 their moiety. Kraft lignin had greater concentration of both conjugated and non-conjugated
 275 phenolic groups than Soda lignin. The monomeric composition in Kraft lignin was higher than
 276 that of the Soda lignin, while lignin dimer composition was higher in Soda lignin. The surface of
 277 both Kraft and Soda lignins was rough and heterogeneous with uneven pore sizes. Since *G.*
 278 *arborea* lignin has several functional groups, it can be modified and utilized in several industrial
 279 purposes.

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