

## Supplementary Information

### Structure elucidation of prot, alkali and dealkaline lignin(s) by NMR, FT-IR and Py-GC/MS: Effect of solid acid and base catalysts

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**Table S1:** Distribution of GC-MS compounds obtained from the flash pyrolysis of prot lignin

RT, Minute	Compound Name, Prot lignin	Compound types	Thermal	MgO	CaO	ZSM-5	Y-zeolite
7.20	Phenol	H-type	1.4	-	1.2	3.1	3.4
8.43	Phenol, 2-methyl	H-type	-	-	-	1.4	2.0
8.80	Phenol, 3-ethyl	H-type	2.4	-	-	-	-
8.81	p-Cresol	H-type	1.0	-	1.1	2.0	-
10.24	Phenol, 4-ethyl	H-type	-	2.0	2.3	5.4	4.8
10.66	Creosol	H-type	-	-	-	-	7.7
11.29	Phenol, 2-ethyl-4-methyl	H-type	-	-	-	2.7	-
12.41	Ethanone, 1-(2-hydroxy-5-methylphenyl)-	H-type	17.2	15.2	14.3	10.7	10.5
<b>Total</b>		<b>(H-type)</b>	<b>22.0</b>	<b>17.2</b>	<b>18.9</b>	<b>25.3</b>	<b>28.4</b>
9.04	Mequinol/Phenol, 4-methoxy	G-type	6.1	4.0	7.0	8.3	8.2
10.62	2-Methoxy-5-methylphenol	G-type	7.0	4.8	6.5	8.3	-
11.61	1,2-Benzenediol, 3-methoxy	G-type	3.3	-	2.9	3.4	-
11.89	Phenol, 4-ethyl-2-methoxy	G-type	7.3	6.1	5.8	7.0	4.8
12.49	3-Methoxy-5-methylphenol	G-type	0.3	-	-	-	-
12.96	3-Allyl-6-methoxyphenol	G-type	1.4	2.9	2.3	1.3	-
13.11	Phenol, 2-methoxy-4-propyl	G-type	0.8	-	0.9	-	-
13.59	Vanillin	G-type	2.0	3.2	2.9	-	-
14.23	Eugenol	G-type	6.9	5.3	4.4	-	-
14.25	trans-Isoeugenol	G-type	2.2	1.5	-	3.1	-
14.67	Ethanone, 1-(3-hydroxy-4-	G-type	-	2.2	2.0	1.5	-

	methoxyphenyl)							
13.02	Ethanone, 1-(2-hydroxy-6-methoxyphenyl)	G-type	0.3	-	-	-	-	-
15.17	2-Propanone, 1-(4-hydroxy-3-methoxyphenyl)	G-type	-	1.7	1.3	-	-	-
<b>Total</b>			<b>G-type</b>	<b>37.6</b>	<b>31.7</b>	<b>36.0</b>	<b>32.9</b>	<b>13.0</b>
11.3	2,3-Dimethoxytoluene	S-type	0.4	-	-	-	-	-
12.88	Phenol, 2,6-dimethoxy	S-type	10.3	6.3	7.6	9.0	6.7	-
14.13	3,5-Dimethoxy-4-hydroxytoluene	S-type	7.8	6.1	6.0	7.0	5.8	-
15.61	Ethanone, 1-(3,4-dimethoxyphenyl)	S-type	-	-	5.4	-	-	-
16.60	(E)-2,6-Dimethoxy-4-(prop-1-en-1-yl) phenol	S-type	-	1.6	1.0	2.4	-	-
16.90	Ethanone, 1-(3,4,5-trimethoxyphenyl)	S-type	-	0.9	-	-	-	-
17.20	Phenol, 2,6-dimethoxy-4-(2-propenyl)	S-type	0.6	6.6	5.6	-	-	-
17.53	Acetosyringone	S-type	-	3.9	2.5	1.4	-	-
<b>Total</b>			<b>S-type</b>	<b>19.1</b>	<b>25.4</b>	<b>28.1</b>	<b>19.8</b>	<b>12.5</b>
<b>4.67</b>	Furfural	Hetero cyclic	0.5	-	-	-	-	-
<b>7.55</b>	Oxazolidine, 2,2-diethyl-3-methyl	Hetero cyclic	0.1	-	-	-	-	-
<b>11.02</b>	Benzofuran, 2,3-dihydro	Hetero cyclic	10.1	7.6	9.0	6.8	3.3	-
<b>12.25</b>	Benzofuran, 2,3-dihydro-2-methyl	Hetero cyclic	0.4	-	-	-	-	-
<b>Total</b>			<b>Hetero cyclic</b>	<b>11.1</b>	<b>7.6</b>	<b>9.0</b>	<b>6.8</b>	<b>3.3</b>
3.63	Toluene	Aromatic hydrocarbon	-	-	-	2.3	5.0	-
5.63	o-Xylene	Aromatic hydrocarbon	-	-	-	-	9.2	-
5.73	Benzene, 1,3-dimethyl	Aromatic hydrocarbon	-	-	-	4.6	-	-
7.49	Benzene, 1,2,3-trimethyl	Aromatic hydrocarbon	-	-	-	-	6.5	-

9.56	Benzene, 1,2,3,4-tetramethyl	Aromatic hydro-carbon	-	-	-	-	6.9
11.96	Benzene, pentamethyl	Aromatic hydro-carbon	-	-	-	-	6.5
14.29	Benzene, hexamethyl	Aromatic hydro-carbon	-	-	-	-	2.2
<b>Total</b>		<b>Aromatic hydro-carbon</b>				<b>6.9</b>	<b>36.3</b>
10.07	Benzene, 1-ethenyl-4-methoxy	Other-type	-	1.6	-	-	-
13.48	Benzene, 4-ethenyl-1,2-dimethoxy	Other-type	2.0	-	-	-	-
		Other-type					
15.10	Benzene, 1,2,3-trimethoxy-5-methyl	Other-type	2.8	3.1	2.5	2.7	-
15.29	o-Isopropylphenetole	Other-type	-	-	-	-	2.1
15.59	2,5-Dimethoxy-4-ethylamphetamine	Other-type	-	-	-	-	4.4
15.60	2-(tert-Butyl)-4-methoxyphenyl acetate	Other-type	4.8	6.2	-	4.2	-
15.93	Phthalic acid, ethyl neopentyl ester	Other-type	0.2	-	-	-	-
19.57	Hexadecanoic acid, methyl ester	Other-type	-	3.8	0.9	1.4	-
19.89	Dibutyl phthalate	Other-type	-	2.2	4.6	-	-
21.25	9-Octadecenoic acid, methyl ester	Other-type	-	1.2	-	-	-
<b>Total</b>		<b>Other-type</b>	<b>9.8</b>	<b>18.1</b>	<b>8.0</b>	<b>8.3</b>	<b>6.5</b>

**Table S2:** Distribution of GC-MS compounds obtained from the flash pyrolysis of alkali lignin

Ret Time	Compound Name, Alkali lignin	Compound types	Blank	MgO	CaO	ZSM-5	Y-zeolite
7.20	Phenol	H-type	0.7	-	0.8	2.2	1.4
8.43	Phenol, 2-methyl	H-type	-	-	-	1.0	-
8.80	Phenol, 3-methyl	H-type	-	0.7	-	2.1	1.5
8.81	p-Cresol	H-type	0.8	-	1.1	-	-
10.24	Phenol, 4-ethyl	H-type	0.3	-	-	0.6	-
10.66	Creosol	H-type	13.0	-	18.4	1.6	1.4
11.59	1,2-Benzenediol, 3-methyl-	H-type	-	-	1.8	-	-
12.03	1,2-Benzenediol, 4-methyl	H-type	1.7	-	1.3	2.1	-
12.43	4-Hydroxy-2-methylacetophenone	H-type	8.9	15	13.8	-	11.5
12.80	Phenol, 4-(2-propenyl)	H-type	0.3	-	-	-	-
13.32	1,3-Benzenediol, 4-ethyl	H-type	0.9	-	-	-	-
<b>Total</b>		<b>H-type</b>	<b>26.6</b>	<b>15.7</b>	<b>37.2</b>	<b>9.6</b>	<b>15.8</b>
9.04	Phenol, 4-methoxy/ Mequinol	G-type	11.1	14.0	16.3	22.1	18.2
10.62	2-Methoxy-5-methylphenol	G-type	-	17.4	-	25.2	20.5
10.79	Phenol, 2-methoxy-3-methyl	G-type	1.0	0.9	1.3	1.9	-
11.13	m-Guaiacol	G-type	0.3	-	-	-	-
11.61	1,2-Benzenediol, 3-methoxy	G-type	1.6	-	-	-	-
11.89	Phenol, 4-ethyl-2-methoxy	G-type	5.5	7.6	7.5	8	6.8
12.39	2-Methoxy-4-vinylphenol	G-type	-	-	-	10.6	-
12.49	3-Methoxy-5-methylphenol	G-type	0.8	0.5	0.9	-	-
12.96	Phenol, 2-methoxy-3-(2-propenyl)-	G-type	-	-	-	1.2	1.2
12.96	3-Allyl-6-methoxyphenol	G-type	-	3.2	2.7	-	-
13.02	Ethanone, 1-(2-hydroxy-6-methoxyphenyl)	G-type	1.0	-	-	-	-
13.11	Phenol, 2-methoxy-4-propyl	G-type	2.9	2.2	2.1	2.1	1.2
13.59	Vanillin	G-type	11.5	8.2	5.3	1.9	-
14.14	Phenol, 4-methoxy-3-(methoxymethyl)	G-type	0.8	-	-	-	-
14.22	Phenol, 2-methoxy-4-(1-propenyl)-, (Z)-	G-type	-	-	-	3.5	-
14.23	Eugenol	G-type	4.0	9.8	8.9	-	-
14.25	trans-Isoeugenol	G-type	13.4	2.3	2.6	-	4.2
14.69	Apocynin	G-type	4.3	2.8	4.7	1.5	1.6
15.19	2-Propanone, 1-(4-hydroxy-3-methoxyphenyl)	G-type	3.7	2.5	2.2	-	1.2
15.74	4-(1-Hydroxyallyl)-2-	G-type	-	0.9	-	-	-

15.76	methoxyphenol 2-Propanone, 1-hydroxy-3-(4-hydroxy-3-methoxyphenyl)	G-type	0.4	-	0.8	1.1	-
15.87	1-(2-Hydroxy-4-methoxyphenyl) propan-1-one	G-type	1.3	-	-	-	-
16.62	Benzenepropanol, 4-hydroxy-3-methoxy	G-type	0.6	-	-	-	-
<b>Total</b>		<b>G-type</b>	<b>64.2</b>	<b>72.3</b>	<b>55.3</b>	<b>79.1</b>	<b>54.9</b>
12.88	Phenol, 2,6-dimethoxy	S-type	0.6	-	-	-	-
17.36	Ethanone, 1-(4-hydroxy-3,5-dimethoxyphenyl)	S-type	-	1.1	1.0	-	-
<b>Total</b>		<b>S-type</b>	<b>0.6</b>	<b>1.1</b>	<b>1.0</b>	<b>0</b>	<b>0</b>
11.02	Benzofuran, 2,3-dihydro	Heterocyclic	0.8	0.8	0.9	-	-
14.64	6-Methoxy-3-methylbenzofuran	Heterocyclic	0.5	-	-	-	-
16.67	Ethanone, 1-[5-(2-furanylmethyl)-2-furanyl]	Heterocyclic	0.4	-	-	-	-
<b>Total</b>		<b>Heterocyclic</b>	<b>1.7</b>	<b>0.8</b>	<b>0.9</b>	<b>-</b>	<b>-</b>
3.63	Toluene	Aromatic hydrocarbon	-	-	-	1.9	2.4
5.34	p-Xylene	Aromatic hydrocarbon	-	-	-	2.0	2.2
5.73	Benzene, 1,3-dimethyl	Aromatic hydrocarbon	-	-	-	-	4.1
6.95	Benzene, 1-ethyl-3-methyl	Aromatic hydrocarbon	-	-	-	0.8	-
7.49	Benzene, 1,2,3-trimethyl	Aromatic hydrocarbon	-	-	-	-	2.9
7.96	Benzene, 1,2,4-trimethyl	Aromatic hydrocarbon	-	-	-	-	1.2
9.75	Benzene, 1,2,4,5-tetramethyl	Aromatic hydrocarbon	-	-	-	-	1.9
11.96	Benzene, pentamethyl	Aromatic hydrocarbon	-	-	-	-	3.8
14.29	Benzene, hexamethyl	Aromatic hydrocarbon	-	-	-	-	1.8
<b>Total</b>		<b>Aromatic hydrocarbon</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>4.7</b>	<b>20.3</b>
3.30	Disulfide, dimethyl	Other-type	0.3	0.8	-	1.2	2.7
8.45	3-Cyclopentylpropionic acid, 2-methylphenyl ester	Other-type	0.3	-	-	-	-
9.28	2-Cyclopenten-1-one, 2,3,4,5-tetramethyl-	Other-type	-	-	-	0.3	-
11.28	3,4-Dimethoxytoluene	Other-type	-	1.2	-	1.7	1.5
11.30	2,3-Dimethoxytoluene	Other-type	0.8	-	1.2	-	-

12.58	1,4-Dimethoxy-2,3-dimethylbenzene	Other-type	0.4	-	-	-	-
13.48	Benzene, 4-ethenyl-1,2-dimethoxy	Other-type	1.8	1.2	1.4	-	-
14.12	1,2,3-Trimethoxybenzene	Other-type	-	0.5	-	-	-
14.91	1,2-Dimethoxy-4-n-propylbenzene	Other-type	0.7	0.7	0.7	-	-
15.06	Benzoic acid, 4-hydroxy-3-methoxy-, methyl ester	Other-type	0.6	-	-	-	-
15.27	Benzene, 1-methoxy-4-methyl-2-(1-methylethyl)	Other-type	-	-	-	1.7	-
15.29	o-Isopropylphenetole	Other-type	-	-	-	-	1.3
15.45	2-Allyl-1,4-dimethoxybenzene	Other-type	0.3	-	-	-	-
15.87	1,6-Anhydro-. beta. -D-glucofuranose	Other-type	-	-	-	-	1.4
15.91	B-methyl cinnamic acid, methyl ester	Other-type	0.7	-	-	-	-
16.78	4-Methyl-6-methoxycoumarin	Other-type	0.3	-	-	-	-
16.89	2-Naphthalenol, 3-methoxy	Other-type	0.2	-	-	-	-
17.46	Methyl 9-methyltetradecanoate	Other-type	-	0.5	-	-	-
19.57	Hexadecenoic acid, methyl ester	Other-type	-	3.7	1.1	-	-
19.89	Dibutyl phthalate	Other-type	-	-	0.9	-	-
20.27	Methyl dehydroabietate	Other-type	-	-	-	1.7	-
21.5	Methyl stearate	Other-type	-	1.2	-	-	-
22.73	1,1'-Biphenyl, 6-hydroxy-2',3',4'-trimethoxy	Other-type	-	-	0.8	-	-
25.92	1,1'-Biphenyl-3,4,4'-trimethoxy-6'-formyl	Other-type	-	-	1.0	-	-
31.04	cis-Valerenyl acetate	Other-type	-	-	-	-	2.1
	<b>TOTAL</b>	<b>Other-type</b>	<b>6.4</b>	<b>9.8</b>	<b>5.3</b>	<b>6.6</b>	<b>9</b>

**Table S3:** Distribution of GC-MS compounds obtained from the flash pyrolysis of dealkaline lignin

Ret Time	Compound Name, Dealkaline lignin	Compound types	Blank	MgO	CaO	ZSM-5	Y-zeolite
7.20	Phenol	H-type	0.6	0.8	1.4	4.6	3.0
8.43	Phenol, 2-methyl	H-type	-	-	0.7	-	1.3
8.80	Phenol, 3-methyl	H-type	-	-	-	1.5	0.7
8.81	p-Cresol	H-type	-	-	1.1	-	-
10.66	Creosol	H-type	-	5.1	-	2.6	6.0
12.43	4-Hydroxy-2-methylacetophenone	H-type	4.0	8.3	8.4	-	-
<b>Total</b>		<b>H-type</b>	<b>4.6</b>	<b>14.2</b>	<b>11.6</b>	<b>8.7</b>	<b>11</b>
9.01	Phenol, 2-methoxy	G-type	-	25.2	31.0	17.5	-
9.04	Mequinol/Phenol, 4-methoxy	G-type	21	-	-	24.0	28.0
10.62	2-Methoxy-5-methylphenol	G-type	2.9	-	12.7	-	0.7
10.79	Phenol, 2-methoxy-3-methyl	G-type	-	-	-	1.8	-
11.89	Phenol, 4-ethyl-2-methoxy-	G-type	0.6	2.0	4.0	0.6	1.9
12.39	2-Methoxy-4-vinylphenol	G-type	-	-	-	-	3.6
12.96	Phenol, 2-methoxy-3-(2-propenyl)	G-type	-	-	0.7	-	-
13.58	Benzaldehyde, 3-hydroxy-4-methoxy	G-type	37.3	-	-	-	-
13.59	Vanillin	G-type	-	23	11.0	10.1	8.5
13.66	Phenol, 2-methoxy-5-(1-propenyl)-, (E)	G-type	-	1.1	1.4	1.5	-
14.22	Phenol, 2-methoxy-4-(1-propenyl)	G-type	-	-	-	-	1.6
14.23	Eugenol	G-type	2.2	1.0	5.6	-	-
14.25	trans-Isoeugenol	G-type	-	3.8	-	-	-
14.30	3-Methoxytyrosine	G-type	0.4	-	-	-	-
14.69	Apocynin	G-type	7.6	4.6	2.9	5.5	-
15.19	2-Propanone, 1-(4-hydroxy-3-methoxyphenyl)	G-type	-	1.7	1.9	0.6	-
15.74	4-(1-Hydroxyallyl)-2-methoxyphenol	G-type	-	1.3	-	-	-
<b>Total</b>		<b>G-type</b>	<b>72</b>	<b>63.7</b>	<b>71.2</b>	<b>61.6</b>	<b>44.3</b>
12.88	Phenol, 2,6-dimethoxy	S-type	4.6	3.5	5.1	1.0	2.9
14.13	3,5-Dimethoxy-4-hydroxytoluene	S-type	0.3	-	-	-	-
15.62	Ethanone, 1-(3,4-dimethoxyphenyl)	S-type	-	0.9	0.7	-	-
<b>Total</b>		<b>S-type</b>	<b>4.9</b>	<b>4.4</b>	<b>5.8</b>	<b>1.0</b>	<b>2.9</b>

5.99	Butyrolactone	Heterocyclic	0.9	0.7	-	-	-
6.53	2,5-Furandione, 3-methyl	Heterocyclic	0.2	-	-	-	-
7.08	2(5H)-Furanone, 3-methyl-	Heterocyclic	-	-	1.0	-	-
7.11	2(5H)-Furanone, 3-methyl	Heterocyclic	-	0.7	-	-	-
7.43	2-Hydroxy-gamma-butylolactone	Heterocyclic	6.4	1.2	1.0	-	0.4
15.91	Butyrovaniillone	Heterocyclic	0.7	-	-	-	-
	<b>Total</b>	<b>Heterocyclic</b>	<b>8.2</b>	<b>2.6</b>	<b>2.0</b>	<b>0</b>	<b>0.4</b>
3.63	Toluene	Aromatic hydrocarbon	-	-	-	2.9	4.2
5.34	p-Xylene	Aromatic hydrocarbon	-	-	-	-	5.0
5.48	Ethylbenzene	Aromatic hydrocarbon	-	-	-	1.3	-
5.63	o-Xylene	Aromatic hydrocarbon	-	-	-	7.9	-
5.73	Benzene, 1,3-dimethyl	Aromatic hydrocarbon	-	-	-	-	3.2
6.00	Styrene	Aromatic hydrocarbon	-	-	-	0.4	-
6.95	Benzene, 1-ethyl-3-methyl	Aromatic hydrocarbon	-	-	-	-	1.7
7.26	Benzene, 1-ethyl-4-methyl	Aromatic hydrocarbon	-	-	-	1.8	-
7.49	Benzene, 1,2,3-trimethyl	Aromatic hydrocarbon	-	-	-	-	4.3
7.96	Benzene, 1,2,4-trimethyl	Aromatic hydrocarbon	-	-	-	-	1.0
8.00	Benzene, 1-methyl-3-(1-methylethyl)	Aromatic hydrocarbon	0.7	-	-	-	-
8.18	Indane	Aromatic hydrocarbon	-	-	-	-	0.5
8.30	o-Cymene	Aromatic hydrocarbon	-	-	-	1.1	1.2
9.09	Benzene, 1-methyl-3-(1-methylethenyl)	Aromatic hydrocarbon	-	0.8	-	-	-
9.56	Benzene, 1,2,3,4-tetramethyl	Aromatic hydrocarbon	-	-	-	-	2.2
9.75	Benzene, 1,2,4,5-tetramethyl	Aromatic hydrocarbon	-	-	-	-	2.8
11.96	Benzene, pentamethyl	Aromatic hydrocarbon	-	-	-	-	3.3
14.29	Benzene, hexamethyl	Aromatic hydrocarbon	-	-	-	-	1.5



	<b>Total</b>	<b>Aromatic hydrocarbon</b>	<b>0.7</b>	<b>0.8</b>	<b>0</b>	<b>15.4</b>	<b>30.9</b>
1.92	2-Butanone	Other-type	-	-	1	-	-
2.13	3-Cyclopentene-1,2-diol, cis	Other-type	-	-	-	4	-
2.40	1-Butanol	Other-type	-	1.6	-	-	-
3.19	Propanoic acid, 2-hydroxy-, methyl ester	Other-type	0.8	-	-	-	-
3.30	Disulfide, dimethyl	Other-type	-	-	-	-	2.0
5.03	2-Cyclopenten-1-one	Other-type	-	-	-	1.4	-
5.69	Lactic acid	Other-type	0.8	-	-	-	-
6.27	1,2-Cyclopentanedione	Other-type	1.0	-	-	-	-
6.30	2-Cyclopenten-1-one, 2-methyl	Other-type	-	-	-	0.8	0.6
6.73	Camphene	Other-type	0.3	-	-	-	-
7.10	N-Hexylmethacrylamide	Other-type	0.7	-	-	-	-
7.95	Mesitylene	Other-type	-	-	-	-	2.0
8.17	1,3-Cyclohexadiene, 1-methyl-4-(1-methylethyl)	Other-type	-	-	-	1.0	-
9.09	Benzenepropanamine, alpha.-methyl	Other-type	-	-	0.8	-	-
9.11	Cyclopropyl carbinol	Other-type	2.3	-	-	-	-
9.57	Nonanal	Other-type	-	-	-	0.9	-
9.89	Benzene, 1,2-dimethoxy	Other-type	-	2.2	3.1	-	2.0
11.13	Decanal	Other-type	-	-	-	0.7	-
11.28	3,4-Dimethoxytoluene	Other-type	-	1.9	-	1.4	1.6
11.30	2,3-Dimethoxytoluene	Other-type	-	-	2.4	-	-
13.48	Benzene, 4-ethyl-1,2-dimethoxy	Other-type	-	0.6	1.0	0.3	-
13.67	Benzene, 1,2-dimethoxy-4-[[[(4-methylphenyl) sulfonyl] methyl]	Other-type	1.5	-	-	-	-
14.59	Benzaldehyde, 3,4-dimethoxy	Other-type	-	1.2	-	-	-
15.06	Benzoic acid, 4-hydroxy-3-methoxy-, methyl ester	Other-type	0.4	-	-	-	-
15.19	2-Propanone, 1-(4-hydroxy-3-methoxyphenyl)	Other-type	1.2	-	-	-	-
15.62	6-Methoxycoumaran-7-ol-3-one	Other-type	0.2	-	-	-	-
15.80	Dodecanoic acid	Other-type	-	-	-	0.3	-
18.06	Tetradecanoic acid	Other-type	-	-	-	1.3	-

18.94	1,2-Benzenedicarboxylic acid, bis(2-methylpropyl) ester	Other-type	0.2	-	-	-	-
19.12	Pentadecanoic acid	Other-type	-	-	-	0.7	-
19.57	Hexadecanoic acid, methyl ester	Other-type	-	2.8	1.0	-	1.5
19.89	Dibutyl phthalate	Other-type	0.2	1.5	-	-	-
21.50	Methyl stearate	Other-type	-	2.1	-	-	-
		Other-type					
	<b>Total</b>	<b>Other-type</b>	<b>9.6</b>	<b>13.9</b>	<b>9.3</b>	<b>12.8</b>	<b>9.7</b>