

# **Sunscreen performance of lignin from different technical resources and their general synergistic effect with synthetic sunscreens**

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Table S1 Physicochemical properties of lignins from different technical resources\*

Sample descriptions	Lignin, alkali (AL370)	Lignin, alkali Low sulfonate content (AL471)	Lignin, Organosolv (OL)	Enzymatic hydrolysis lignin (EHL) **	Sodium lignosulfonate (LS)
Properties	1. Average $M_w$ : 1,140 2. Impurities: 5% moisture 3. Functional group content: carboxyl 1.39 mmol/g; phenolic hydroxyl 2.12 mmol/g; methoxyl 5.18 mmol/g 4. Solubility: H <sub>2</sub> O: insoluble NaOH: soluble 0.05%	1. Average $M_w$ : 10,000 2. Impurities: 4% sulfur 3. Functional group content carboxyl 3.9%; phenolic hydroxyl 0.51 mmol/g; methoxyl 3.48 mmol/g 4. Solubility H <sub>2</sub> O: soluble	1. Average $M_w$ : 2,900 2. Impurities: 6.5% moisture 0.2% residual sugar; 6.6% ash; Lignin content: 86.7%	1. Average $M_w$ : 3,400 2. Impurities: ~5% cellulose; ~15% ash, hemicellulose and residual enzyme; Lignin content >80%	1. Average $M_w$ : 19,000 2. Impurities: 3.7% sulfur (organically bound sulfonate group) 3. Functional group content: carboxyl 0.22 mmol/g; phenolic hydroxyl 0.57 mmol/g sulfonate group 1.13 mmol/g; methoxyl 3.93 mmol/g 4. Solubility H <sub>2</sub> O: soluble

\*Properties of different lignin mostly come from their product instructions except the molecular weight of EHL and LS and functional group contents.

\*\* The enzyme used for enzymatic hydrolysis is commercial cellulose enzyme Cellic CTec2, it is provided by Novozyme Co. Ltd (Tianjin, China)

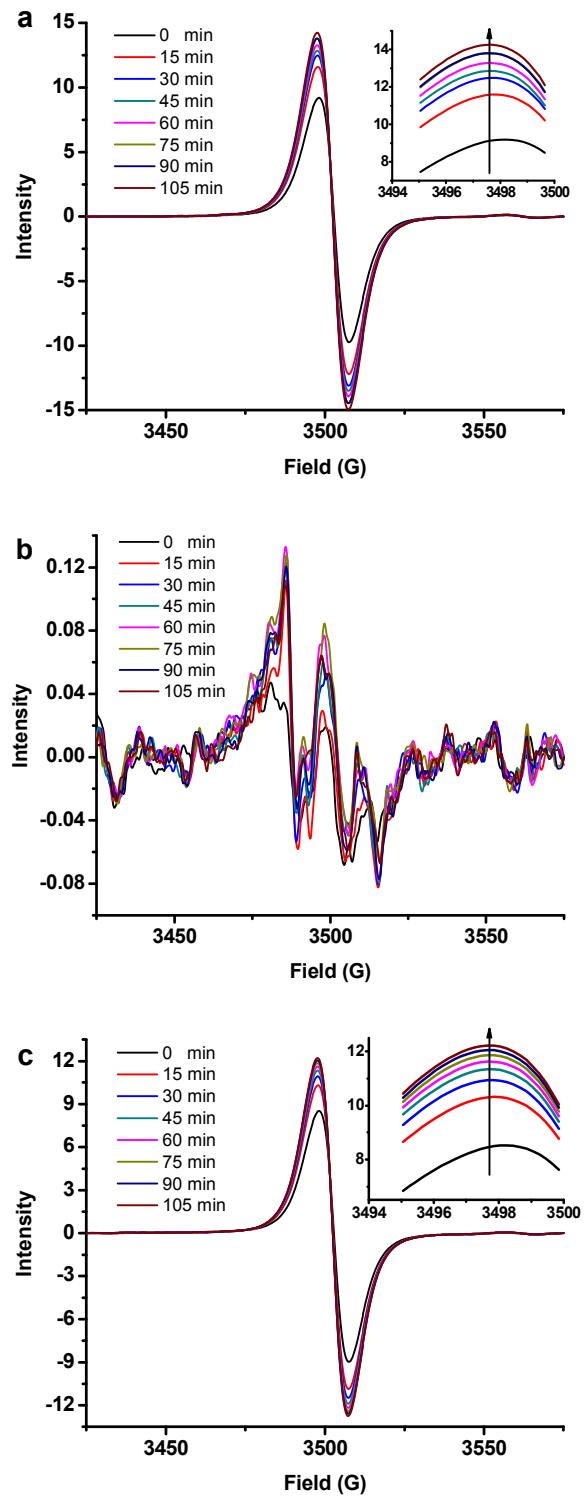
Table S2 Elemental distributions of lignin types from different technical resources.

Samples	N%	C%	H%	S%	O%*
AL370	0.52	62.8	5.74	1.145	45.985
AL471	0.03	48.13	4.871	3.815	45.186
OL	0.65	60.42	5.445	0	33.485
EHL	1.93	47.51	5.374	0	29.795
LS	0.11	43.96	5.026	4.919	43.154

\*O% = 100% - N% - C% - H% - S%.

Table S3 Active and inactive ingredients of purchased sunscreen lotion and pure cream.

<b>Lotion &amp; Cream</b>	<b>Active ingredients</b>	<b>Inactive ingredients</b>
<b>LIFE SPF15</b>	Octinoxate 7.5%, Avobenzone 4%.	<b>AQUA</b> , C12-15 Alkyl benzoate, Phenethyl benzoate, Sorbitol, Stearic acid, Sorbitan oleate, Benzyl alcohol, Isopropyl myristate, Glyceryl stearate SE, Hydrogenated soybean oil, VP/Eicosene copolymer, Triethanolamine, Imidazolidinyl urea, Methylparaben, Dimethicone, Simmondsia chinensis (jojoba) Seed oil, Aloe barbadensis leaf extract, Tocopherol, Propylparaben, Acrylates/C10-30 Alkyl acrylate crosspolymer, Carbomer, Disodium EDTA, Parfum.
<b>NIVEA Cream</b>		<b>Water</b> , Glycerin, Mineral Oil, Myristyl alcohol, Butylene glycol, Alcohol denat., Stearic acid, Myristyl myristate, Microcrystalline wax, Glyceryl stearate, Hydrogenated coco-glycerides, Simmondsia chinensis (jojoba) seed oil, Tocopheryl acetate, Lanolin alcohol (Eucerit®), Polyglyceryl-2 caprate, Dimethicone, Carbomer, Sodium hydroxide, Phenoxyethanol fragrance.



**Figure S1.** ESR spectra of OL (a), BMDM (b) and OL/BMDM mixture (c) under different UV radiation time.