**Supplementary materials**

Table S1 Abiotic humification reaction conditions for the 11 SHLAs

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| HA  Samples | Catechol  /mol/L | Glycine  /mol/L | Glucose  /mol/L | Temperature  /℃ | pH | MnO2 addition amount/g | Reaction time |
| SHLA 1 | 1 | 1 | - | 45 | 7 | 13.33 | 240 h |
| SHLA 2 | 1 | 1 | 1 | 45 | 7 | 13.33 |
| SHLA 3 | 0.5 | 0.5 | - | 45 | 7 | 13.33 |
| SHLA 4 | 0.25 | 025 | - | 45 | 7 | 13.33 |
| SHLA 5 | 0.5 | 1 | - | 45 | 7 | 13.33 |
| SHLA 6 | 0.25 | 1 | - | 45 | 7 | 13.33 |
| SHLA 7 | 1 | 1 | - | 25 | 7 | 13.33 |
| SHLA 8 | 1 | 1 | - | 35 | 7 | 13.33 |
| SHLA 9 | 1 | 1 | - | 45 | 6 | 13.33 |
| SHLA 10 | 1 | 1 | - | 45 | 8 | 13.33 |
| SHLA 11 | 1 | 1 | - | 45 | 7 | 25 |



(a)



(b)

Figure S1. FTIR spectra of humification precursors ((a); glycine, catechol and glucose) and 11 SHLAs (b). (n=1 for each sample; peaks at 3055 cm-1 attributed to aromatic C-H stretching; at 2925 -2950 cm-1 attributed to C-H stretching of aliphatic structures; at 1715-1722 cm-1 attributed to C=O stretching, mainly carboxylic groups; at 1572 and 1590-1598 cm-1 attributed to C=C ring stretching, symmetric C–O stretch of COO- and N-H deformation and C=N stretching (amide II band); at 1439-1480 cm-1 attributed to O-H deformation of phenols, C–H deformation and CH3 symmetric and asymmetric stretching, symmetrical stretch of COO-, at 1172-1180 cm-1 attributed to C–O stretching and C–O–H deformation of alcohols, phenols and ethers; at 749-850 cm-1 attributed to out-of-plane bending of aromatic C-H)

Table S2. Interpretation of the 13C NMR spectra of the SHLAs (Fernández-Gómez et al., 2015; Jokic et al., 2004; Nagasawa et al., 2016; Qi et al., 2012a)

|  |  |
| --- | --- |
| Chemical shift /ppm | Assignment |
| 45\* | Methyl and methylene groups in aliphatic rings and chains |
| 116-120 | Protonated aromatic carbon, and/or aromatic carbon ortho to oxygen-substituted aromatic carbon |
| 143-146 | Phenolic or aromatic amine carbon |
| 171-183 | Carboxyl carbon |

(\*SHLA 2 did not have any peak around 45 ppm)



Figure S2. Log *K* and *CC* of SHLAs (SHLA 1 and SHLA 2) produced by different precursors systems (mean values, n=3 ± standard deviation)