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SUPPORTING INFORMATION

Deactivation of Co-Schiff Base Catalysts in the Oxidation of *para*-Substituted Lignin Models for the Production of Benzoquinones

Ernesto C. Zuleta,[a,b] Gabriel A. Goenaga,[c] Thomas A. Zawodzinski,[b,c] Thomas Elder,[d] Joseph J. Bozell*[a,b]
[a] Center for Renewable Carbon, University of Tennessee, 2506 Jacob Drive, Knoxville, TN 37996, United States.
[b] Bredesen Center for Interdisciplinary Research and Education, 821 Volunteer Boulevard, Knoxville, TN 37996, United States
[c] Department of Chemical and Biomolecular Engineering, University of Tennessee, 1512 Middle Drive, Knoxville, TN 37996, United States
[d] USDA Forest Service, Southern Research Station, 521 Devall Drive, Auburn, AL 36849

1. Materials and instruments

All reagents and solvents were purchased from commercial sources and were used as received unless otherwise indicated. HPLC analysis employed a Waters HPLC system which consisted of a 2695 separations module, a 2996 model photodiode array detector and a 100Å, 3.5 µm, 3 mm X 150 mm SunFire C18 column. Response factor curves were prepared for **2** and **6a** (detection at 210 and 289.3 nm, respectively). The response factor F was used to quantitate the amount of analyte in each reaction (Figure S 1). For determination of **2** and **12,** the eluent was an acetonitrile/water gradient (0 min: 0.1 ml/min of 25:75 MeCN/H_2O; 15-20 min: 0.1 ml/min of 50:50 MeCN/H_2O). For determination of **6a**, an isocratic elution was performed with 50:50 MeOH/H_2O for 20 minutes at 0.2 mil/min. Infrared spectra were obtained on a PerkinElmer Spectrum One FTIR spectrometer at 4 cm^{-1} resolution and are reported in cm^{-1}.

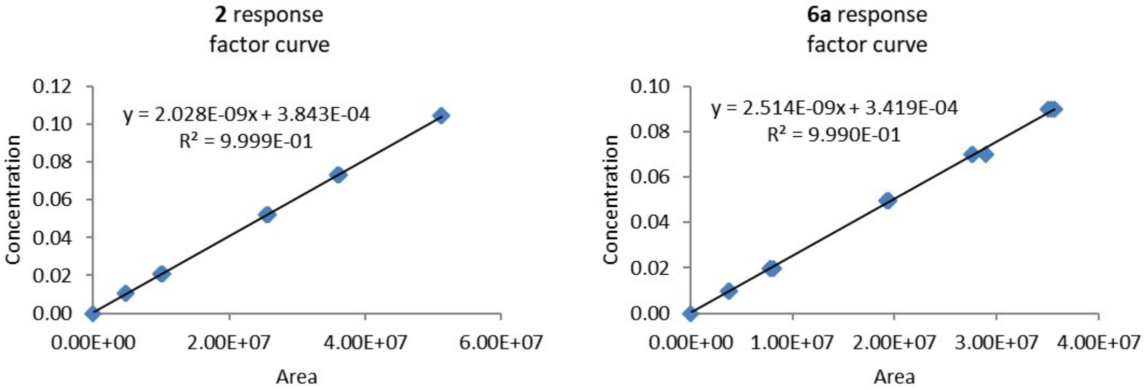

Figure S 1. Response factor curves for HPLC analysis.

2. Oxidation of *para*-substituted lignin models

CAUTION: The reactions were carried out in a 60 ml thick-walled glass Fisher-Porter bottle under oxygen pressure. While we experienced no difficulties in performing these reactions, appropriate precautions should always be used when combining organic materials and oxygen under pressure.

2.1 General procedure for the two-step oxidation of syringyl alcohol with Co-Schiff base catalysts.

In the first step, the Co-Schiff base complex (0.1 mmol) and the axial base (1 mmol, when required) were added to the bottle and mixed for 15 min. Then the quinone (0.2 mmol) and the methanol (3 ml) were added. The bottle was sealed with a pressure head and alternately evacuated under vacuum and filled three times O_2. After the final evacuation, the bottle was pressurized with O_2 to 60 psi and stirred for 48h at room temperature (rt). In the second step, **2** (1 mmol, 184.18 mg) was added to the bottle and then 2 ml of methanol. Then the filling procedure with O_2 was repeated. Each reaction was run for 40 minutes, after which the reaction mixture was transferred to a 50-ml round-bottom flask. To make sure that all the crude material was transferred to the 50-ml round-bottom flask, the walls of the reactor were washed with DCM and all the washes were transferred to the flask using a Pasteur pipette. The crude material was concentrated under vacuum using a rotary evaporator at 30 °C to remove the solvent., and then was dried overnight under vacuum. After the crude material was dried overnight, the sample was dissolved in 100 ml of acetonitrile using a volumetric flask. A 5 ml aliquot of this solution was dissolved in 100 ml of a 25:75 $MeCN/H_2O$ solution. A sample from this last solution was injected in the HLPC. Finally, using the respective equation and the dilution factor, the amount of **2** and DMBQ was determined using HPLC and their conversion and yield were calculated according to eq. S1 and S2, respectively.

$$SyOH\ conversion = \frac{mass\ SyOH_{initial} - mass\ SyOH_{final}}{mass\ SyOH_{initial}} \times 100 \qquad \text{(S1)}$$

$$DMBQ\ yield = \frac{mass\ DMBQ_{final} \times MW\ SyOH}{mass\ SyOH_{initial} \times MW\ DMBQ} \times 100 \qquad \text{(S2)}$$

To avoid reporting conversions higher that 100% when DMBQ was used as the inhibitor, the yield of DMBQ in those reactions was calculated on the basis of the amount of quinone generated in the reaction. This value was calculated as the final amount of DMBQ minus the amount of quinone added.

2.2 General procedure for single-step oxidation of syringyl alcohol with Co-Schiff base catalysts.

The Co-Schiff base complex (0.1 mmol) and the axial base (1 mmol, when required) were added to a Fischer-Porter bottle and mixed for 15 min. The calculated amount of quinone (0.2 mmol, when required) and **2** (1 mmol, 184.18 mg) were added to the bottle. MeOH (5 ml) was added to the bottle which was sealed with a pressure head and alternately evacuated under vacuum and filled three times with O_2. After the final evacuation, the bottle was pressurized with O_2 (60 psi) and stirred at rt. Each reaction was run for 40 min, after which the reaction mixture was transferred to a 50-ml round-bottom flask and processed as described in section 2.1. The amount of **2** and DMBQ was determined by HPLC as described in section 2.1.

2.3 Effect of the quinones 6b and 6c incubation time on the deactivation of catalyst 8

To evaluate the effect of the quinones **6b** and **6c** incubation time on the deactivation of catalyst **8**, the oxidation of **2** was evaluated at 48 and 0 hours of incubation time. The oxidation of the lignin model was done as described in 2.2., using 0.1 mmol of Co-Salen, 1 mmol of pyridine and 0.2 mmol of quinone. The yields of DMBQ with and without incubation time are presented in Table S 1.

Table S 1. Time-dependent inhibition effect of quinones.

Time (h)	**DMBQ yield (%)**[a]	**Standard Deviation**
	6b	
0	64	1.50444
48	44	1.73615
	6c	
0	33	2.12132

48	30	4.97217

[a]Average of three replicates

Using the software JMP®, a one-way analysis of variance (ANOVA) was performed to evaluate the statistical effect of the quinone incubation time. For quinone **6b**, there is a statistically significant difference between the two incubation times (p-value < 0.05, Table S 2). For quinone **6c**, there is not a statistically significant difference between the two incubation times (p-value > 0.05, Table S 3).

Table S 2. One-Way ANOVA test for incubation time with quinone **6b**.

Source	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**
Between groups	560.667	1	560.667	210.25	0.0001
Within groups	10.6667	4	2.66667		
Total	571.333	5			

Table S 3. One-Way ANOVA test for incubation time with quinone **6c**.

Source	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**
Between groups	17.6333	1	17.6333	0.98	0.3946
Within groups	53.8267	3	17.9422		
Total	71.46	4			

2.4 Effect of the concentration of quinones 6b and 6c on the deactivation of catalyst 8

To evaluate the effect of the concentration of quinone **6b** and **6c** on the deactivation of catalyst **8**, different concentrations of quinone (% mol/mol of catalyst) were evaluated. The reactions were carried out in as described in section 2.2. For each quinone, the inhibitory concentration IC50 (the concentration that reduced the yield by 50%) was estimated using a 4-parameter logistic model 4PL described in the literature.[1] The statistical software JMP® was used to estimate the parameters of the 4PL model in eq. S3 using nonlinear regression to fit the data, were Y is the yield of DMBQ and X is the quinone concentration.

$$Y = \frac{a - d}{1 + \left(\frac{X}{c}\right)^{b}} + d \qquad \text{(S3)}$$

The parameters a (the upper asymptote), d (the lower asymptote), b (the gradient of the linear portion of the model) and c (the average concentration between a and d) for the 4PL models for quinone **6b** and **6c** are shown in the Table S 4 and the Table S 5, respectively. To calculate the IC50 for each quinone, inverse regression was used to solve eq. S3 for X, establishing Y equal to 50%.

Table S 4. Parameters of the 4PL model for quinone **6b**

Parameter	**Estimate**	**Confidence limits**	
		Low	**High**
a	99.89	95.91	103.87
b	6.07	5.01	7.39
c	2.28	2.18	2.40
d	8.86	4.66	13.06

Table S 5. Parameters of the 4PL model for quinone **6c**

Parameter	**Estimate**	**Confidence limits**	
		Low	**High**
a	102.71	100.88	104.57
b	4.17	3.76	4.63
c	1.33	1.29	1.36
d	5.05	2.24	7.53

3. Synthesis of complex 13

A modified version of the method described by Floriani *et al.* was followed.[2] 1,4-BQ (1.66 mmol, 0.18 g) was placed in a 50-ml Schlenk flask fitted with a glass stopcock. The flask was capped with a rubber septum and connected to a Schlenk line and evacuated and flushed with argon three times. Co(salen) (3.32 mmol, 1.08 mg) was placed in a separate 50 ml Schlenk flask fitted with a glass stopcock. The flask was capped with a rubber septum and degassed as previously described. Dry pyridine (30 ml) was added to the Co(salen) flask and the mixture was stirred for 10 minutes. Using a cannula, the Co(salen)-pyridine solution was transferred to the 1,4-BQ flask under argon. After 5 days of stirring at room temperature, the mixture was filtered through a medium glass frit. The collected dark green solid was washed with 350 ml of cyclohexane and then dried under vacuum (25 psi) for 2 days, yielding 1.16 mg of material. The solid was analyzed without further purification. Anal. Calcd. for $C_{48}H_{46}Co_2N_6O_6$: C, 62.61; H, 5.04; N, 9.13; Co, 12.80. Found: C, 62.51; H, 4.22; N, 9,19; Co, 12.2.

4. Solubility of quinones 6a – 6c in methanol

A modification of a method from the literature was used to determine the solubility of quinones **6a – 6c** in methanol.[3,4] Approximately 370 mg of each quinone was weighed into a 20 ml glass vial. Methanol (2 ml) was added to the vial and the vial was capped. The vial samples were set in a platform shaker and vortexed for 24 hours at 200 rpm. After stirring, each quinone suspension was filtered using a 0.2 micrometer PVDF syringe filter. The filtrate was collected in another glass vial. The saturated solution (1 ml) was transferred to a weighed vial, and the methanol was allowed to evaporated overnight in a vacuum oven (25 psi and room temperature). The mass of the dry residue was calculated, and the solubility was expressed as milligrams of quinone per milliliters of methanol.

Table S 6. Solubility of studied quinones.

Quinone	**Solubility (mg/ml)[a]**	**Standard Deviation**
6a	12.9	0.2
6b	17.6	0.2
6c	73.9	0.5

[a] Average of three replicates

5. Electrochemical study of quinones and Co-Schiff base complexes

Voltammetric measurements of the quinones and the Co-Schiff base catalysts were performed using a BioLogic Science Instruments VSP3 potentiostat, equipped with EC-Lab® software V11.02. Stock solutions of quinones (0.01 M in CH_3OH or 20/80 CH_3CN/CH_3OH) and Co-Schiff base catalysts (0.005 M in CH_3OH or 20/80 CH_3CN/CH_3OH) were prepared and used for the electrochemical study. 0.1 M $LiClO_4$ in ethanol was used as the supporting electrolyte. For the oxidation potential measurement, 5 milliliters of the analyte solution plus 5 milliliters of the supporting electrolyte solution were mixed in an electrochemical cell (20 ml flask). N_2 was bubbled through the solution prior the measurements. A 3 mm diameter glassy carbon electrode was used as the working electrode, with a saturated Ag/AgCl electrode and a platinum wire for the reference and auxiliary electrodes respectively. The cyclic voltammograms were recorded with a 0.75 V/s linear potential sweep rate. The anodic potential E_{ap}, cathodic potential E_{cp}, the halfwave potential $E_{1/2}=(E_{ap}+E_{cp})/2$, and peak-to-peak separation $\Delta E=E_{pa}- E_{pc}$ of *para*-quinones and Co-Schiff base catalysts where calculated using the software EC-Lab® V11.02.

6. Computational analysis

All calculations for the study were conducted on the Alabama Supercomputer Network. An initial conformational search was done using a 1000 step Monte Carlo procedure with MMFF minimization at each step, as implemented in Spartan '16. The low energy conformation for each was refined using the M06-L density functional method. The structures were optimized, with frequency calculations for thermal corrections and to insure the identification of a stationary point and done using the SMD solvation model for ethanol. All DFT calculations were done with Gaussian 16, Revision A.03. Final renderings were carried out using Mercury 3.10 (Build 156946).

References

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