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Sugar thiourea catalyzed highly enantioselective Michael addition of 2-hydroxy-1,4-naphthoquinone to β-nitroalkenes†

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A highly enantioselective Michael addition of 2-hydroxy-1,4-naphthoquinone to β-nitrostyrenes has been achieved using a novel class of sugar-*Cinchona* thiourea conjugates. The method offers significant advantages such as low catalyst loading (1 mol%), high enantioselectivity (up to 99% ee), short reaction times and ambient reaction conditions.

Introduction

Nitroolefins are important intermediates in organic synthesis since the nitro group can easily be transformed into the corresponding amine and carbonyl compounds.[1] Asymmetric Michael reaction of nitroalkenes is one of the most important methods for C–C bond formation, which provides direct access to enantiopure nitroalkanes.[2] The conjugate addition of 1,4-naphthoquinone to nitroalkenes[3] is particularly attractive as it provides easy access to nitroalkyl substituted naphthoquinones which are very useful precursors for the synthesis of various biologically active compounds.

Naphthoquinones are important structural units in many natural products. They are mainly used as dyes in industry. Many quinone containing compounds are found to exhibit potent biological activity.[4] Quinone containing antitumor drugs such as mitoxantrone, ametantrone and doxorubicin have been used as effective anticancer agents for the treatment of leukemia.[5,6]

Recently, bifunctional thiourea derivatives have been recognized as effective organocatalysts for asymmetric Michael addition reactions.[7] Therefore, the development of simple and efficient bifunctional thiourea catalysts is of great interest. In this context, carbohydrates are easily accessible chiral precursors for asymmetric synthesis.[8] In particular, glucose is very attractive because of its ready availability and well defined stereochemistry. Inspired by thiourea based organocatalysis, we attempted the synthesis of novel sugar-*Cinchona* hybrids for asymmetric Michael reaction (Fig. 1).

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In this article, we wish to report for the first synthesis and application of glucose-*Cinchona* thiourea conjugates for the enantioselective Michael addition of 2-hydroxy-1,4-naphthoquinone to β-nitrostyrenes. Accordingly, a novel class of sugar based bifunctional thiourea catalysts **II**, **IV**, **VI** and **IX** were prepared from 1-isothiocyanatoglucose and *Cinchona* amines. The starting glycosyl isothiocyanate was prepared from β-D-glucopyranose by means of sequential acetylation, bromination and isothiocyanation.[9] Addition of *Cinchona* amines to glycosyl isothiocyanate gave the bifunctional thiourea catalysts **II**, **IV**, **VI** and **IX** in good yields. These sugar-*Cinchona* based thiourea catalysts show a remarkable catalytic effect in the Michael addition of 2-hydroxy-1,4-naphthoquinone to nitroalkenes. These new catalysts furnish the Michael adducts in good yields with a high degree of enantioselectivity. Remarkably, the reaction proceeds even at very low catalyst loading (1 mol%) under ambient conditions (Table 1).

Initially, we investigated the reactivity of various catalysts in the Michael addition of 2-hydroxy-1,4-naphthoquinone (**1**) to β-nitrostyrene (**2a**) using 2 mol% of the thiourea derivatives **I**, **III**, **V** and **VIII** in toluene at room temperature. The corresponding Michael adduct **3a** was obtained with 88, 90, 80 and 87% ee respectively (Table 1, entries, 1,3,5 and 15). The same reaction was also carried out with catalysts **VII** and **X** to evaluate their efficiency. Surprisingly, these catalysts gave the product **3a** with low enantioselectivity (77 and 86% ee respectively, Table 1, entries 14 and 17).

After screening the known catalysts, we performed the above reaction with sugar-*Cinchona* based thiourea catalysts **II**, **IV**, **VI** and **IX**. Of these, thiourea catalysts **II**, **IV** and **IX** afforded the desired product **3a** with moderate enantioselectivity (86, 85 and 89% ee, Table 1, entries 2, 4 and 16). Interestingly, catalyst **VI** gave the product **3a** with a higher enantioselectivity (97% ee, Table 1, entry 6) than the others. Therefore, catalyst **VI** was shown to be superior to the others in terms of enantioselectivity. For further optimization of the reaction, we screened the

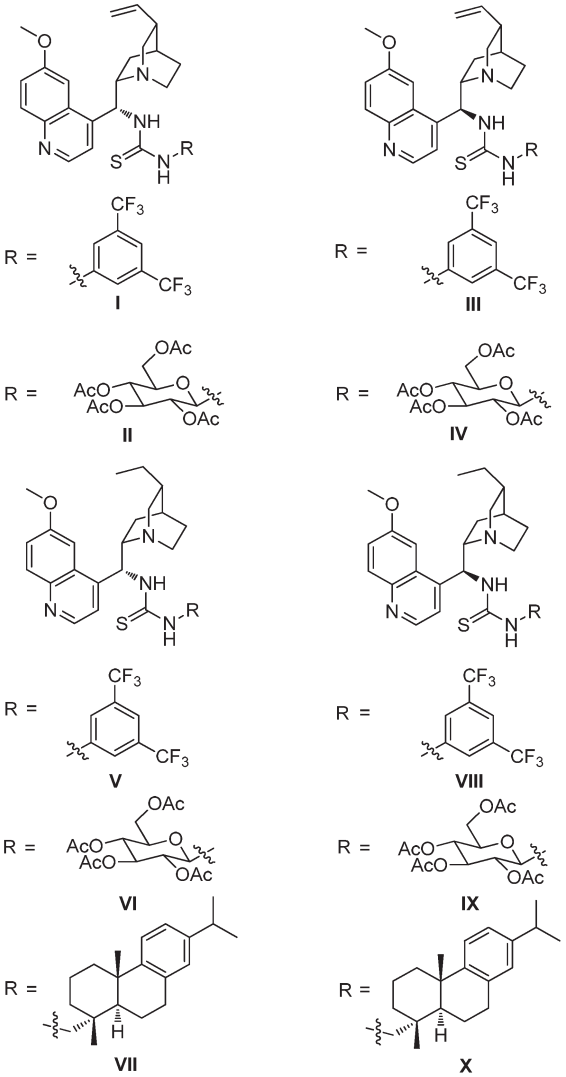
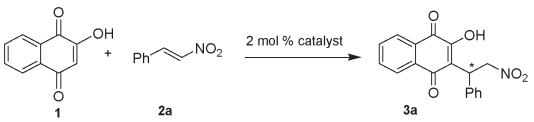


Fig. 1 Representative bifunctional thiourea catalysts.

effect of solvents, temperature and catalyst loading. Of the several solvents tested, high conversions and excellent enantioselectivities (96 and 95% ee) were achieved in CH_2Cl_2 and toluene respectively, whereas moderate enantioselectivity was observed in CH_3CN and THF. Furthermore, lower enantioselectivities and poorer yields were obtained in protic solvents like methanol. This is due to the competitive hydrogen bond interaction between methanol and either the organocatalyst or the substrate. Thus toluene was chosen as the optimal solvent for this reaction (97% ee). The yield and enantioselectivities were decreased when the reaction temperature was reduced to 0 °C. The quantity of catalyst had no significant effect on enantioselectivity and yield when the catalyst loading was reduced to 1 mol% (97% ee and 96% yield, Table 1, entry 9).

The scope of this Michael reaction was explored under the optimized reaction conditions and the results are summarized in Table 2. By using this procedure, a wide range of

Table 1 Screening of various thiourea catalysts for enantioselective Michael addition of 2-hydroxy-1,4-naphthoquinone to β-nitrostyrene[a]



Entry	Catalyst	Solvent	T (°C)	Time (h)	Yield (%)[b]	ee (%)[c]
1	**I**	$PhCH_3$	30	4	94	88
2	**II**	$PhCH_3$	30	4	95	86
3	**III**	$PhCH_3$	30	4	94	−90
4	**IV**	$PhCH_3$	30	4	95	−85
5	**V**	$PhCH_3$	30	4	94	80
6	**VI**	$PhCH_3$	30	4	96	97
7	**VI**	$PhCH_3$	0	10	90	95
8	**VI**	$PhCH_3$	−25	18	80	82
9	**VI**	$PhCH_3$	30	6	96	97[d]
10	**VI**	CH_2Cl_2	30	4	94	95
11	**VI**	CH_3CN	30	4	96	88
12	**VI**	THF	30	4	96	90
13	**VI**	CH_3OH	30	4	87	75
14	**VII**	$PhCH_3$	30	5	92	77
15	**VIII**	$PhCH_3$	30	4	95	−87
16	**IX**	$PhCH_3$	30	4	96	−89
17	**X**	$PhCH_3$	30	5	92	−86

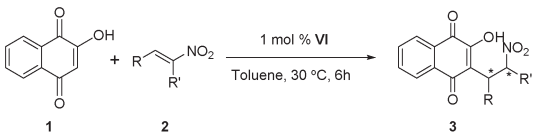
[a] Reaction was carried out with **1** (0.3 mmol), **2** (0.33 mmol) in the presence of 2 mol% of organocatalyst. [b] Isolated yield. [c] Determined by chiral HPLC. [d] 1 mol% catalyst used.

3-alkylnitro-2-hydroxynaphthoquinones (3a–3t) were prepared in good yields with excellent enantioselectivities (up to 99% ee). *ortho*-Substituted and *para*-substituted halogen containing aromatic nitroalkenes gave high ee values compared with the *meta*-substituted counterpart(Table 2, entries 2–10). 2-Naphthyl substituted and di-substituted nitroalkenes also gave high enantioselectivities (Table 2, entries 11–14). However, aliphatic and heteroaromatic nitroalkenes afforded comparatively lower enantioselectivities (Table 2, entries 15–17 and 19). *ortho*-Substituted aromatic nitroalkenes like 2-benzyloxy- and 2-methoxy derivatives gave slightly low enantioselectivities (Table 2, entry 18 and 20) due to the unfavorable interaction between the *ortho*-substituent and the nucleophile. Next we studied the diastereoselectivity of the reaction with an α-branched nitroolefin. Accordingly, treatment of (*E*)-(2-nitroprop-1-enyl)benzene with 2-hydroxy-1,4-naphthoquinone in the presence of ligand **VI** under similar reaction conditions gave the *anti*-2-hydroxy-3-((1*S*,2*R*)-2-nitro-1-phenylpropyl)-naphthalene-1,4-dione **3u** as a major isomer in 82% yield with 85% ee (entry 21, Table 2).

Based on the above results, a possible transition state model was proposed in Fig. 2. The model has no difference with the one drawn in previous reports.[3]

The nitro group likely participates in hydrogen bonding with the thiourea of the organocatalyst **VI**. The 2-hydroxy-1,4-naphthoquinone was assumed to be deprotonated by the basic nitrogen of the tertiary amine. The resulting deprotonated 2-hydroxy-1,4-naphthoquinone is then attacked by the nitroalkene from the *Re* face to afford the (***S***)-isomer. The

Table 2 Chiral thiourea **VI** catalyzed asymmetric addition of 2-hydroxy-1,4-naphthoquinone with β-nitrostyrenes[a]



Entry	*R*	R′	Product	Yield (%)[b]	ee (%)[c]
1	C_6H_5	H	**3a**	96	97
2	4–MeC_6H_4	H	**3b**	97	98
3	4–$MeOC_6H_4$	H	**3c**	96	97
4	4–FC_6H_4	H	**3d**	96	97
5	4–ClC_6H_4	H	**3e**	98	99
6	4–BrC_6H_4	H	**3f**	95	96
7	3–ClC_6H_4	H	**3g**	95	93
8	2–FC_6H_4	H	**3h**	97	96
9	2–ClC_6H_4	H	**3i**	95	97
10	2–BrC_6H_4	H	**3j**	94	95
11	2–Naphthyl	H	**3k**	93	95
12	2,4–$Cl_2C_6H_3$	H	**3l**	94	96
13	3,4–$Cl_2C_6H_3$	H	**3m**	95	98
14	3,5–$(Me)_2C_6H_3$	H	**3n**	92	94
15	Cyclohexyl	H	**3o**	93	95
16	2–Furanyl	H	**3p**	92	93
17	Butyl	H	**3q**	94	93
18	2–$BnOC_6H_4$	H	**3r**	92	93
19	2–Thienyl	H	**3s**	94	91
20	2–$MeOC_6H_4$	H	**3t**	95	90
21	C_6H_5	CH_3	**3u**	82	85

[a] Reaction was carried out with **1** (0.3 mmol), **2** (0.33 mmol), and in 0.7 mL of toluene. [b] Isolated yield. [c] Determined by chiral HPLC.

sugar moiety may help to block one of the faces of the substrate to facilitate high stereocontrol.

Conclusion

In summary, the sugar-*Cinchona* conjugates have been demonstrated as highly efficient bifunctional organocatalysts for asymmetric Michael addition. They are highly active catalysts in promoting the enantioselective Michael addition of nitroalkenes with 2-hydroxy-1,4-naphthoquinone. The reaction works well with low catalyst loading under ambient conditions and also provides the products in high yields with excellent enantioselectivity which makes it more attractive. Further investigation into the enantioselective C–C bond forming reactions using this novel catalyst is under progress in our laboratory.

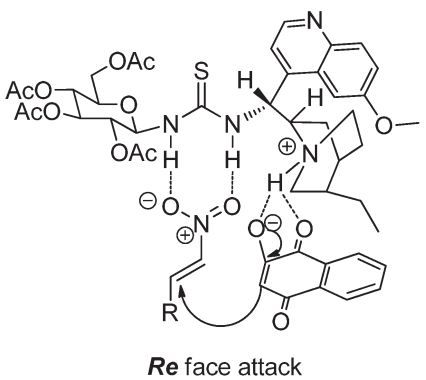


Fig. 2 A proposed transition state.

Experimental

Preparation of ligands

Catalysts **I**, **III**, **V** and were prepared according to the literature procedures.[10]

General procedure for preparing thiourea catalysts **II**, **IV**, **VI** and **IX.** To a stirred solution of the chiral amine[10] (4 mmol) in methylene chloride (10 mL) was added dropwise a solution of glycosyl isothiocyanate (4.4 mmol) in methylene chloride (15 mL) under nitrogen atmosphere. The resulting mixture was stirred at room temperature until total consumption of the isothiocyanate (monitored by TLC). After removal of the solvent, the residue was purified through column chromatography on silica gel (EtOAc/MeOH = 85/15) to give the thiourea catalyst as a white solid.

Spectral data for ligand **II**. White solid, yield 76%, m.p. = 101–103 °C, $[\alpha]_D^{28}$ = +116.8 (c = 0.5, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.17–1.32 (m, 1H), 1.40–1.52 (m, 1H), 1.75 (s, 2H), 1.79–1.94 (m, 2H), 1.96–2.14 (m, 14H), 2.65 (brs, 1H), 3.11–3.50 (m, 2H), 3.72–3.86 (m, 1H), 4.03 (s, 3H), 4.08–4.17 (m, 1H), 4.22–4.51 (m, 5H), 4.93–5.13 (m, 2H), 5.21–5.50 (m, 2H), 5.70 (brs, 1H), 5.86–6.02 (m, 1H), 7.32–7.42 (m, 1H), 7.48 (d, J = 14.5 Hz, 1H), 7.88 (brs, 1H), 7.93–8.02 (m, 1H), 8.65–8.73 (d, J = 4.5 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 20.4, 20.6, 23.2, 23.9, 24.2, 26.4, 36.9, 46.2, 48.6, 55.7, 60.2, 61.5, 68.0, 70.2, 73.2, 73.3, 82.6, 101.8, 116.7, 120.3, 122.5, 127.7, 129.3, 131.3, 137.3, 142.3, 144.5, 147.3, 158.2, 169.4, 169.8, 169.9, 170.6, 178.9, 184.1. IR (KBr): υ 2935, 1752, 1622, 1545, 1373, 1227, 1035, 912, 759 cm^{-1}; MS (ESI) m/z 714 $[M+H]^+$; HRMS (ESI): Exact mass calcd for $C_{35}H_{45}O_{10}N_4S$ 713.28509. Found: 713.28602.

Spectral data for ligand **IV**. White solid, yield 74%, m.p. = 110–112 °C, $[\alpha]_D^{28}$ −50.2 (c = 0.5, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$): δ 1.22–1.30 (m, 5H), 1.33–1.42 (m, 1H), 1.56–1.74 (m, 2H), 1.95–2.09 (m, 13H), 2.30–2.40 (brs, 1H), 2.75–2.91 (brs, 1H), 3.12–3.33 (m, 2H), 3.78–3.88 (m, 1H), 3.99 (s, 3H), 4.09–4.17 (m, 4H), 4.27–4.35 (m, 1H), 4.89–5.14 (m, 4H), 5.32 (t, J = 9.8 Hz, 1H), 5.65–5.76 (m, 1H), 7.29–7.37 (m, 1H), 7.41 (d, J = 8.9 Hz, 1H), 8.04 (d, J = 8.9 Hz, 1H), 8.75 (d, J = 3.9 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 20.5, 20.6, 23.5, 26.8, 37.2, 40.9, 53.7, 55.8, 60.8, 61.4, 68.1, 70.4, 73.2, 82.4, 102.2, 116.8, 122.2, 127.8, 131.7, 144.8, 147.7, 158.2, 169.2, 169.4, 170.3, 170.6, 180.0, 183.9. IR (KBr): υ 2944, 1753, 1622, 1544, 1371, 1231, 1037, 915, 761, 604 cm^{-1}; MS (ESI) m/z 714 $[M+H]^+$; HRMS (ESI): Exact mass calcd for $C_{35}H_{45}O_{10}N_4S$ 713.28509. Found: 713.28547.

Spectral data for ligand **VI**. White solid, yield 71%, m.p. = 116–118 °C, $[\alpha]_D^{28}$ = +128.2 (c = 0.5, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$): δ 0.85–1.01 (m, 4H), 1.26 (t, J = 7.4 Hz, 2H), 1.35–1.62 (m, 6H), 1.86–2.15 (m, 13H), 2.60 (brs, 1H), 2.86–3.21 (m, 4H), 3.78 (d, J = 9.6 Hz, 3H), 3.99 (s, 3H), 4.06–4.17 (m, 1H), 4.20–

4.32 (m, 1H), 4.84–4.95 (m, 1H), 5.02 (t, J = 9.6 Hz, 1H), 5.26–5.34 (m, 2H), 5.64–5.78 (m, 1H), 7.32–7.72 (m, 3H), 8.03 (d, J = 9.6 Hz, 1H), 8.73 (d, J = 4.2 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 11.9, 20.5, 20.6, 20.7, 24.8, 25.5, 25.8, 26.8, 36.9, 48.8, 48.9, 55.5, 61.6, 68.1, 70.9, 72.8, 73.3, 82.9, 101.5, 122.1, 128.4, 128.6, 131.8, 132.0, 132.1, 142.0, 144.7, 147.5, 157.8, 169.6, 169.8, 170.5, 171.0, 177.9, 183.7; IR (KBr): υ 2935, 1752, 1622, 1511, 1372, 1225, 1036, 910, 762, 602 cm^{-1}; MS (ESI) m/z 716 $[M+H]^+$; HRMS (ESI): Exact mass calcd for $C_{35}H_{47}O_{10}N_4S$ 715.30074. Found: 715.30103.

Spectral data for ligand **IX**. White solid, yield 70%, m.p. = 114–116 °C, $[\alpha]_D^{28}$ −59.0 (c = 0.5, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ 0.78–0.94 (m, 3H), 1.14–1.44 (m, 4H), 1.53–1.70 (m, 1H), 1.75–2.22 (m, 17H), 2.66 (brs, 1H), 3.10 (brs, 1H), 3.57–4.06 (m, 6H), 4.07–4.25 (m, 1H), 4.90–5.11 (m, 2H), 5.22–5.34 (m, 1H), 5.78 (brs, 1H), 6.74 (brs, 1H), 7.23–7.74 (m, 3H), 7.94–8.12 (m, 1H), 8.77 (d, J = 4.5 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 11.3, 20.5, 22.8, 23.2, 24.6, 24.8, 25.7, 34.7, 55.4, 55.9, 59.6, 61.4, 68.0, 70.3, 73.1, 73.3, 82.3, 102.4, 120.4, 121.0, 122.4, 128.4, 129.4, 131.5, 131.9, 132.1, 144.8, 147.7, 158.4, 169.4, 170.0, 170.2, 170.7, 178.4, 183.8. IR (KBr): υ 2955, 1751, 1622, 1547, 1372, 1229, 1035, 910, 759, 608 cm^{-1}; MS (ESI) m/z 716 $[M+H]^+$; HRMS (ESI): Exact mass calcd for $C_{35}H_{47}O_{10}N_4S$ 715.30074. Found: 715.30117.

General procedure for preparing thiourea catalysts VII and X

To a stirred solution of the chiral amine (2 mmol) in methylene chloride (8 mL) was added dropwise a solution of dehydroabietic isothiocyanate[11] (2.4 mmol) in methylene chloride (12 mL) under nitrogen atmosphere. After completion of the reaction, the resulting mixture was concentrated under reduced pressure and the residue was purified through column chromatography on silica gel (hexane/EtOAc = 5/95) to give the thiourea catalyst as a white solid.

Spectral data for ligand **VII**. White solid, yield 67%, m.p. = 132–134 °C, $[\alpha]_D^{28}$ = +119.9 (c = 0.5, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$): δ 0.62–0.76 (m, 3H), 0.90–0.96 (m, 3H), 1.10 (s, 3H), 1.18–1.25 (m, 9H), 1.31–1.88 (m, 13H) 2.10–2.21 (m, 2H), 2.58–2.89 (m, 5H), 2.94–3.15 (m, 3H), 3.20–3.37 (m, 2H), 3.42–3.59 (m, 1H), 3.90 (s, 3H), 4.16 (s, 1H), 6.81 (s, 1H), 6.97 (d, J = 7.7 Hz, 1H), 7.10 (d, J = 7.7 Hz, 1H), 7.34–7.51 (m, 2H), 7.68 (t, J = 6.6 Hz, 1H), 8.01 (d, J = 8.8 Hz, 1H), 8.67 (s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 11.8, 18.1, 18.4, 18.9, 23.9, 24.4, 25.2, 25.8, 29.6, 30.1, 33.4, 36.1, 36.3, 37.2, 37.3, 38.0, 46.0, 48.8, 49.0, 55.7, 56.4, 60.8, 102.4, 120.1, 120.5, 122.6, 123.7, 124.1, 126.7, 129.3, 129.6, 131.9, 133.6, 134.6, 145.0, 145.4, 146.9, 147.6, 158.3, 178.7, 182.5. IR (KBr): υ 3258, 2928, 2865, 1735, 1620, 1547, 1374, 1231, 1031, 826, 724 cm^{-1}; MS (ESI) m/z 654 $[M+H]^+$; HRMS (ESI): Exact mass calcd for $C_{41}H_{57}ON_4S$ 653.42476. Found: 653.42689.

Spectral data for ligand **X**. White solid, yield 68%, m.p. = 128–130 °C, $[\alpha]_D^{28}$ −92.04 (c = 0.5, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$): δ 0.68–0.85 (m, 6H), 1.08 (s, 3H), 1.10–1.42 (m, 15H), 1.46–1.67 (m, 4H), 1.68–1.91 (m, 3H), 1.97 (s, 3H), 2.01–2.17 (m, 2H), 2.56–2.90 (m, 5H), 3.34–3.55 (m, 3H), 3.76–3.87 (m, 1H), 3.96 (s, 3H), 6.88 (d, J = 7.2 Hz, 1H), 6.99–7.12 (m, 1H), 7.19 (s, 1H), 7.22 (d, J = 4.3 Hz, 1H), 7.30–7.35 (m, 1H), 7.38–7.46 (m, 1H), 7.95 (d, J = 9.3 Hz, 1H), 8.70 (s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 11.2, 18.4, 19.1, 22.3, 23.2, 23.9, 24.5, 25.2, 25.7, 29.8, 33.3, 34.5, 35.8, 37.3, 37.6, 37.9, 41.5, 45.5, 55.3, 55.9, 59.9, 102.4, 120.1, 120.5, 122.6, 123.5, 124.0, 126.6, 127.9, 129.3, 131.2, 134.8, 143.1, 144.6, 145.3, 147.2, 147.4, 158.4, 177.1, 183.0. IR (KBr): υ 3251, 2926, 2867, 1731, 1621, 1549, 1376, 1230, 1030, 828, 726 cm^{-1}; MS (ESI) m/z 654 $[M+H]^+$; HRMS (ESI): Exact mass calcd for $C_{41}H_{57}ON_4S$ 653.42476. Found: 653.42559.

General procedure for the organocatalytic asymmetric addition of 2-hydroxy-1,4-naphthoquinones to nitroolefins

To a stirred solution of organocatalyst **VI** (1 mol%) and nitroolefin (**2**) (0.33 mmol) in toluene (0.7 mL) was added 2-hydroxy-1,4-naphthoqnuinone (**1**) (0.3 mmol). The resulting mixture was stirred for 6 h at room temperature. After completion of the reaction, the mixture was concentrated *in vacuo* and the resulting residue was purified by column chromatography on silica gel (hexane/EtOAc) to afford the corresponding Michael adduct (**3**).

(*S*)-2-Hydroxy-3-(2-nitro-1-phenylethyl)naphthalene-1,4-dione (**3A**). (Entry 1, Table 2). Orange solid, yield 96% with 97% ee. m.p. 150–152 °C. $[\alpha]_D^{28}$ = +34.3 (c = 0.5, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 70 : 30, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 15.4 min (major) and 31.8 min (minor); ^{1}H NMR (500 MHz, $CDCl_3$): δ 5.15 (dd, J = 6.5, 13.1 Hz, 1H), 5.28–5.34 (m, 1H), 5.44–5.51 (m, 1H), 7.23–7.28 (m, 1H), 7.32 (t, J = 7.5 Hz, 2H), 7.46 (d, J = 7.5 Hz, 2H), 7.69 (t, J = 7.5 Hz, 1H), 7.73–7.80 (m, 2H), 8.07 (d, J = 7.5 Hz, 1H), 8.12 (d, J = 7.5 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$+DMSO-D_6): δ 38.8, 76.2, 120.5, 126.0, 126.8, 127.6, 128.0, 129.2, 132.0, 132.4, 134.0, 138.0, 155.4, 181.0, 183.5.

(*S*)-2-Hydroxy-3-(2-nitro-1-*p*-tolylethyl)naphthalene-1,4-dione (**3B**). (Entry 2, Table 2). Orange solid, yield 97% with 98% ee. m.p. 166–168 °C. $[\alpha]_D^{28}$ = +28.8 (c = 0.5, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 70 : 30, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 24.4 min (major) and 77.6 min (minor); ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.30 (s, 3H), 5.07–5.18 (m, 1H), 5.23–5.32 (m, 1H), 5.40–5.52 (m, 1H), 7.12 (d, J = 7.9 Hz, 2H), 7.35 (d, J = 8.1 Hz, 2H), 7.68–7.85 (m, 2H), 8.02–8.15 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 21.0, 39.3, 76.3, 121.0, 126.3, 127.2, 128.1, 129.0, 129.6, 132.6, 133.2, 134.5, 135.4, 137.6, 153.1, 181.2, 183.7.

(*S*)-2-Hydroxy-3-(1-(4-methoxyphenyl)-2-nitroethyl)naphthalene-1,4-dione (**3C**). (Entry 3, Table 2). Orange solid, yield 96% with 97% ee. m.p. 172–174 °C. $[\alpha]_D^{28}$ = +32.8 (c = 0.5, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 70 : 30, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 32.5 min (major) and 72.1 min (minor); ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.76 (s, 3H), 5.11 (dd, J = 7.0, 13.0 Hz, 1H), 5.21–5.30 (m, 1H), 5.44 (dd, J = 8.9, 13.0 Hz, 1H), 6.84 (d, J = 8.7 Hz, 2H), 7.40 (d, J = 8.7 Hz, 2H), 7.63–7.82 (m, 3H), 8.04–8.15 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$+DMSO-D_6): δ 38.3, 54.8, 76.8, 113.7, 121.1, 125.6, 126.1, 129.0, 129.5, 131.9, 132.7, 134.3, 155.3, 158.4, 181.0, 183.8.

(*S*)-2-(1-(4-Fluorophenyl)-2-nitroethyl)-3-hydroxynaphthalene-1,4-dione (**3D**). (Entry 4, Table 2). Orange solid, yield 96% with 97% ee. m.p. 160–162 °C. $[\alpha]_D^{28}$ = +32.6 (c = 0.5, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 70 : 30, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 16.2 min (major) and 30.6 min (minor); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.15 (dd, J = 6.8, 12.6 Hz, 1H), 5.30

(t, J = 6.8 Hz, 1H), 5.41 (dd, J = 8.5, 12.6 Hz, 1H), 7.00 (t, J = 8.7 Hz, 2H), 7.40–7.49 (m, 2H), 7.66–7.83 (m, 2H), 8.04–8.15 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 39.0, 76.4, 115.9 (d, J = 21.4 Hz), 120.6, 126.4, 127.2, 128.9, 129.9, 130.0, 132.6, 133.3, 133.4, 135.5, 153.1, 162.2, 181.0, 183.6.

(*S*)-2-(1-(4-Chlorophenyl)-2-nitroethyl)-3-hydroxynaphthalene-1,4-dione (**3e**). (Entry 5, Table 2). Orange solid, yield 98% with 99% ee. m.p. 204–206 °C. $[\alpha]_D^{28}$ = +20.13 (c = 0.5, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 70 : 30, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 15.5 min (major) and 36.9 min (minor);); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.16 (dd, J = 6.8, 12.5 Hz, 1H), 5.29 (t, J = 6.8, 8.1 Hz, 1H), 5.34–5.44 (m, 1H), 7.29 (d, J = 8.5 Hz, 3H), 7.41 (d, J = 8.5 Hz, 2H), 7.67–7.83 (m, 2H), 8.05–8.15 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$+DMSO-D_6): δ 38.3, 54.8, 76.8, 113.7, 121.1, 125.6, 126.1, 129.0, 129.5, 131.9, 132.7, 134.3, 155.3, 158.4, 181.0, 183.8.

(*S*)-2-(1-(4-Bromophenyl)-2-nitroethyl)-3-hydroxynaphthalene-1,4-dione (**3f**). (Entry 6, Table 2). Orange solid, yield 95% with 96% ee. m.p. 208–210 °C. $[\alpha]_D^{28}$ = +11.2 (c = 0.5, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 70 : 30, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 20.4 min (major) and 39.8 min (minor); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.10–5.21 (m, 1H), 5.27–5.36 (m, 1H), 5.43–5.56 (m, 1H), 7.22–7.39 (m, 3H), 7.47 (d, J = 7.0 Hz, 2H), 7.66–7.85 (m, 2H), 8.04–8.18 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$+DMSO-D_6): δ 38.0, 75.8,119.9, 125.3, 125.8, 129.1, 129.3, 130.9, 131.5, 132.3, 133.9, 136.9, 155.6, 180.5, 183.2.

(*S*)-2-(1-(3-Chlorophenyl)-2-nitroethyl)-3-hydroxynaphthalene-1,4-dione (**3g**). (Entry 7, Table 2). Orange solid, yield 95% with 93% ee. m.p. 64–66 °C. $[\alpha]_D^{28}$ = +18.9 (c = 0.5, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 80 : 20, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 23.8 min (major) and 28.3 min (minor); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.11–5.21 (m, 1H), 5.25–5.34 (m, 1H), 5.36–5.46 (m, 1H), 7.20–7.30 (m, 2H), 7.32–7.41 (m, 1H), 7.45 (s, 1H), 7.67–7.87 (m, 2H), 8.05–8.17 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 39.2, 75.9, 120.1, 126.3, 126.4, 127.2, 128.4, 128.9, 130.1, 132.4, 133.4, 134.6, 135.5, 139.4, 153.3, 180.9, 183.5; IR (KBr): υ 3376, 1645, 1590, 1551, 1471, 1373, 1276, 1055, 725 cm^{-1}; MS (ESI) m/z 380 [M+Na]$^+$; HRMS (ESI): Exact mass calcd for $C_{18}H_{12}O_5NClNa$ 380.02962. Found: 380. 03127.

(*S*)-2-(1-(2-Fluorophenyl)-2-nitroethyl)-3-hydroxynaphthalene-1,4-dione (**3h**). (Entry 8, Table 2). Orange solid, yield 97% with 96% ee. m.p. 82–84 °C. $[\alpha]_D^{28}$ = +49.9 (c = 0.5, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 70 : 30, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 16.8 min (major) and 40.7 min (minor); ^{1}H NMR (300 MHz, $CDCl_3$+DMSO-D_6): δ 5.14 (dd, J = 7.0, 13.1 Hz, 1H), 5.48–5.57 (m, 1H), 5.64–5.71 (m, 1H), 6.92–7.02 (m, 2H), 7.09–7.19 (m, 1H), 7.52–7.74 (m, 3H), 7.98 (d, J = 7.0 Hz, 1H), 8.09 (d, J = 8.1 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 33.3, 75.3, 115.7, 116.0, 119.3, 124.4, 126.4, 127.2, 128.9, 129.6, 132.6, 133.3, 135.5, 153.8, 158.8, 180.9, 183.5; IR (KBr): υ 3415, 1662, 1589, 1516, 1379, 1287, 1228, 1160, 1101, 746, 695 cm^{-1}; MS (ESI) m/z 342 [M+H]$^+$; HRMS (ESI): Exact mass calcd for $C_{18}H_{12}O_5NFNa$ 364.05917. Found: 364.06039.

(*S*)-2-(1-(2-Chlorophenyl)-2-nitroethyl)-3-hydroxynaphthalene-?1,4-dione (**3i**). (Entry 9, Table 2). Orange solid, yield 95% with 97% ee. m.p. 52–54 °C. $[\alpha]_D^{28}$ = +96.3 (c = 0.5, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 70 : 30, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 15.2 min (major) and 21.9 min (minor); ^{1}H NMR (300 MHz, $CDCl_3$+DMSO-D_6): δ 4.96 (dd, J = 6.0, 13.8 Hz, 1H), 5.34–5.50 (m, 1H), 5.73 (dd, J = 6.0, 10.0 Hz, 1H), 7.15–7.28 (m, 2H), 7.36–7.50 (m, 2H), 7.65–7.84 (m, 2H), 8.10 (t, J = 6.0 Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 34.8, 73.6, 116.7, 123.9, 124.2, 125.2, 126.8, 127.6, 128.1, 130.4, 131.0, 131.4, 132.4,133.9, 156.8, 179.7, 181.3.

(*S*)-2-(1-(2-Bromophenyl)-2-nitroethyl)-3-hydroxynaphthalene-1,4-dione (**3j**). (Entry 10, Table 2). Orange solid, yield 94% with 95% ee. m.p. 60–62 °C. $[\alpha]_D^{28}$ = +151.4 (c = 0.25, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 80 : 20, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 22.1 min (major) and 27.2 min (minor); ^{1}H NMR (300 MHz, $CDCl_3$): δ 4.85–4.96 (m, 1H), 5.37–5.49 (m, 1H), 5.70 (dd, J = 5.8, 10.4 Hz, 1H), 7.09–7.19 (m, 1H), 7.21–7.31 (m, 2H), 7.42 (dd, J = 1.1, 7.7 Hz, 1H), 7.61 (d, J = 7.9 Hz, 1H), 7.67–7.84 (m, 2H), 8.07–8.17 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$+DMSO-D_6): δ 39.1, 74.5, 118.9, 123.7, 125.4, 125.9, 127.2, 128.4, 129.2, 131.2, 132.3, 134.1,136.3, 156.9, 180.8, 183.4.

(*S*)-2-Hydroxy-3-(1-(naphthalen-2-yl)-2-nitroethyl)naphthalene-1,4-dione (**3k**). (Entry 11, Table 2). Orange solid, yield 93% with 95% ee. m.p. 152–154 °C. $[\alpha]_D^{28}$ = +11.8 (c = 0.5, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 70 : 30, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 27.1 min (major) and 61.3 min (minor); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.27 (dd, J = 6.0, 12.1 Hz, 1H), 5.44–5.60 (m, 2H), 7.55–7.61 (m, 1H), 7.65–7.87 (m, 5H), 7.91 (s, 1H), 8.10 (dd, J = 7.5, 15.9 Hz, 2H). ^{13}C NMR (125 MHz, $CDCl_3$+DMSO-D_6): δ 37.9, 75.5, 124.5, 124.6, 124.8, 124.9, 125.0, 125.3, 126.1, 126.4, 126.9, 128.6, 130.8, 130.9, 131.6, 131.7, 133.3, 134.7, 155.3, 179.9, 182.5; IR (KBr): υ 3343, 1667, 1647, 1593, 1551, 1460, 1373, 1279, 1217, 1060, 1004, 861, 819, 755, 726, 664 cm^{-1}; MS (ESI) m/z 396 [M+Na]$^+$; HRMS (ESI): Exact mass calcd for $C_{22}H_{15}O_5NNa$ 396.08424. Found: 396.08545.

(*S*)-2-(1-(2,4-Dichlorophenyl)-2-nitroethyl)-3-hydroxy naphthalene-1,4-dione (**3l**). (Entry 12, Table 2). Orange solid, yield 94% with 96% ee. m.p. 118–120 °C. $[\alpha]_D^{28}$ = +31.6 (c = 0.5, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 70 : 30, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 13.2 min (major) and 21.0 min (minor); ^{1}H NMR (300 MHz, $CDCl_3$): δ 4.97 (dd, J = 6.4, 13.6 Hz, 1H), 5.35 (dd, J = 9.6, 13.8 Hz, 1H), 5.63–5.71 (m, 1H), 7.22 (dd, J = 1.9, 8.5 Hz, 1H), 7.38–7.41 (m, 2H), 7.69–7.88 (m, 2H), 8.11 (d, J = 7.7 Hz, 2H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 36.6, 74.8, 118.8, 126.5, 127.2, 127.5, 128.9, 129.8, 130.4, 132.5, 133.2, 133.4, 134.3, 134.7, 135.6, 154.2, 180.8, 183.6; IR (KBr): υ 3263, 1675, 1638, 1588, 1550, 1469, 1431, 1370, 1275, 1222, 1058, 1026, 877, 819, 728, 688 cm^{-1}; MS (ESI) m/z 392 [M+H]$^+$; HRMS (ESI): Exact mass calcd for $C_{18}H_{11}Cl_2NO_5Na$ 413.99120. Found: 413.99213.

(*S*)-2-(1-(3,4-Dichlorophenyl)-2-nitroethyl)-3-hydroxynaphthalene-1,4-dione (**3m**). (Entry 13, Table 2). Orange solid, yield 95% with 98% ee. m.p. 104–106 °C. $[\alpha]_D^{28}$ = +13.4 (c = 0.5, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 70 : 30, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 16.1 min (major) and 22.8 min (minor); ^{1}H NMR (500 MHz, $CDCl_3$+DMSO-D_6): δ 5.22–5.38 (m, 3H), 7.34–7.41 (m, 2H), 7.56–7.64 (m, 1H), 7.68–7.73 (m, 1H), 7.77 (t, J = 7.3 Hz, 1H), 8.02–8.10 (m, 2H). ^{13}C NMR (125 MHz, $CDCl_3$+DMSO-D_6): δ 36.6, 74.8, 117.9, 124.3, 124.6, 126.5, 128.4, 128.8, 130.0, 130.7, 131.3, 133.0, 136.5, 138.0, 156.7, 180.2, 181.7; IR (KBr): υ 3260, 1675, 1639, 1588, 1550, 1469, 1431, 1370, 1275, 1219, 1132, 1058, 1027, 881, 728, 687 cm^{-1}; MS

(ESI) *m/z* 414 $[M+Na]^+$; HRMS (ESI): Exact mass calcd for $C_{18}H_{11}Cl_2NO_5Na$ 413.99120. Found: 413.99281.

(*S*)-2-(1-(3,5-Dimethylphenyl)-2-nitroethyl)-3-hydroxynaphthalene-1,4-dione (**3n**). (Entry 14, Table 2). Orange solid, yield 92% with 94% ee. m.p. 108–110 °C. $[\alpha]_D^{28}$ = +16.1 (*c* = 0.5, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 70 : 30, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 22.0 min (major) and 26.0 min (minor); ^1H NMR (300 MHz, $CDCl_3$): δ 2.28 (s, 1H), 5.09 (dd, *J* = 6.6, 13.2 Hz, 1H), 5.19–5.28 (m, 1H), 5.42–5.54 (m, 1H), 6.89 (s, 1H), 7.06 (s, 2H), 7.64–7.84 (m, 2H), 8.10 (dd, *J* = 7.5, 15.5 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$+DMSO-D_6): δ 20.6, 45.1, 77.4, 117.3, 124.8, 125.3, 125.4, 127.4, 130.1, 130.2, 133.6, 134.3, 136.6, 140.6, 153.7, 180.7, 181.4; IR (KBr): υ 3419, 2921, 1661, 1592, 1577, 1516, 1374, 1282, 1038, 855, 705, 554 cm^{-1}; MS (ESI) *m/z* 352 $[M+H]^+$; HRMS (ESI): Exact mass calcd for $C_{20}H_{17}O_5NNa$ 374.09989. Found: 374.10160.

(*S*)-2-(1-Cyclohexyl-2-nitroethyl)-3-hydroxynaphthalene-1,4-dione (**3o**). (Entry 15, Table 2). Orange solid, yield 93% with 95% ee. m.p. 114–116 °C. $[\alpha]_D^{28}$ −47.9 (*c* = 0.5, in acetone). HPLC on Chiralcel AS–H column, hexane/*i*-PrOH = 95 : 5, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 26.9 min (minor) and 34.2 min (major); ^1H NMR (300 MHz, $CDCl_3$): δ 0.92–1.22 (m, 5H), 1.51–1.71 (m, 3H), 1.73–1.96 (m, 3H), 3.74–3.88 (m, 1H), 4.73–4.86 (m, 1H), 5.01–5.16 (m, 1H), 7.67–7.87 (m, 2H), 8.07–8.20 (m, 2H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 26.0, 31.0, 31.1, 38.2, 40.3, 75.8, 120.8, 125.9, 126.8, 129.2, 132.4, 132.9, 134.9, 154.3, 180.5, 183.9.

(*S*)-2-(1-(Furan-2-yl)-2-nitroethyl)-3-hydroxynaphthalene-1,4-dione (**3p**). (Entry 16, Table 2). Orange solid, yield 92% with 93% ee. m.p. 112–114 °C. $[\alpha]_D^{28}$ = +9.04 (*c* = 0.5, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 70 : 30, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 25.6 min (major) and 48.3 min (minor); ^1H NMR (300 MHz, $CDCl_3$): δ 5.17 (dd, *J* = 6.8, 13.6 Hz, 1H), 5.23–5.34 (m, 1H), 5.48 (t, *J* = 7.5 Hz, 1H), 6.24 (d, *J* = 3.0 Hz, 1H), 6.30–6.34 (m, 1H), 7.33 (s, 1H), 7.68–7.88 (m, 3H), 8.08–8.22 (m, 2H). ^{13}C NMR (75 MHz, $CDCl_3$+DMSO-D_6): δ 33.2, 75.1, 106.9, 110.6, 118.3, 126.1, 126.6, 128.9, 132.2, 133.1, 134.8, 141.7, 150.7, 156.7, 181.2, 183.6.

(*S*)-2-Hydroxy-3-(1-nitropentan-2-yl)naphthalene-1,4-dione (**3q**). (Entry 17, Table 2). Orange solid, yield 94% with 93% ee. m.p. 92–94 °C. $[\alpha]_D^{28}$ −37.4 (*c* = 0.5, acetone). HPLC on Chiralcel AS–H column, hexane/*i*-PrOH = 95 : 5, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 22.9 min (minor) and 26.2 min (major); ^1H NMR (300 MHz, $CDCl_3$): δ 0.92 (m, 3H), 1.21–1.42 (m, 2H), 1.56–1.72 (m, 1H), 1.81–1.97 (m, 1H), 3.98–4.13 (m, 1H), 4.65–4.74 (dd, *J* = 6.0, 12.1 Hz, 1H), 4.95–5.05 (m, 1H), 7.61 (s, 1H), 7.68–7.84 (m, 2H), 8.08–8.16 (m, 2H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 13.8, 20.5, 32.4, 34.4, 77.1, 120.9, 126.3, 127.0, 129.0, 132.6, 133.2, 135.3, 153.9, 180.8, 183.9.

(*S*)-2-(1-(2-(Benzyloxy)phenyl)-2-nitroethyl)-3-hydroxynaphthalene-1,4-dione (**3r**). (Entry 18, Table 2). Orange solid, yield 92% with 93% ee. m.p. 58–60 °C. $[\alpha]_D^{28}$ = +91.2 (*c* = 0.25, in acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 90 : 10, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 72.2 min (major) and 83.1 min (minor); ^1H NMR (500 MHz, $CDCl_3$): δ 4.98 (dd, *J* = 5.3, 13.2 Hz, 1H), 5.12 (s, 2H), 5.35–5.43 (m, 1H), 5.68–5.74 (m, 1H), 6.88–6.98 (m, 2H), 7.19–7.24 (m, 1H), 7.28–7.38 (m, 3H), 7.42 (d, *J* = 7.9 Hz, 2H), 7.51 (s, 1H), 7.66–7.71 (m, 1H), 7.72–7.78 (m, 1H), 8.04–8.12 (m, 2H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 34.4, 70.3, 75.3, 112.2, 120.2, 120.9, 125.2, 126.2, 127.1, 127.4, 127.9, 128.5, 128.9, 132.7, 133.0, 135.2, 136.5, 153.8, 155.9, 181.0, 183.7; IR (KBr): υ 3370, 2924, 1661, 1591, 1548, 1491, 1451, 1379, 1329, 1240, 1156, 1105, 1052, 1030, 977, 756, 724, 693 cm^{-1} ; MS (ESI) *m/z* 452 $[M+Na]^+$; HRMS (ESI): Exact mass calcd for $C_{25}H_{19}O_6NNa$ 452.11046. Found: 452.11298.

(*S*)-2-Hydroxy-3-(2-nitro-1-(thiophen-2-yl)ethyl)naphthalene-1,4-dione (**3s**). (Entry 19, Table 2). Orange solid, yield 94% with 91% ee. m.p. 119–121 °C. $[\alpha]_D^{28}$ = +65.2 (*c* = 0.5, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 70 : 30, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 25.4 min (major) and 56.0 min (minor); ^1H NMR (500 MHz, $CDCl_3$): δ 5.14 (dd, *J* = 7.2, 13.5 Hz, 1H), 5.39–5.46 (m, 1H), 5.62 (t, *J* = 8.0 Hz, 1H), 6.94 (t, *J* = 4.0 Hz, 1H), 7.11 (d, *J* = 3.2 Hz, 1H), 7.20 (d, *J* = 5.6 Hz, 1H), 7.68–7.74 (m, 1H), 7.75–7.83 (m, 2H), 8.09 (d, *J* = 8.0 Hz, 1H), 8.15 (d, *J* = 8.0 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 34.8, 76.7, 119.9, 125.4, 126.4, 126.5, 126.9, 127.2, 129.0, 132.5, 133.4, 135.5, 138.9, 153.1, 181.0, 183.3.

(*S*)-2-Hydroxy-3-(1-(2-methoxyphenyl)-2-nitroethyl)naphthalene-1,4-dione (**3t**). (Entry 20, Table 2). Orange solid, yield 95% with 90% ee. m.p. 94–96 °C. $[\alpha]_D^{28}$ = +147.8 (*c* = 0.25, acetone). HPLC on Chiralcel OJ–H column, hexane/*i*-PrOH = 70 : 30, flow rate 1.0 mL min^{-1}, 254 nm; t_R = 16.8 min (major) and 28.1 min (minor); ^1H NMR (300 MHz, $CDCl_3$): δ 3.88 (s, 3H), 4.96 (dd, *J* = 5.5, 13.6 Hz, 1H), 5.36–5.49 (m, 1H), 5.62–5.72 (m, 1H), 6.85–6.97 (m, 2H), 7.21–7.35 (m, 2H), 7.65–7.87 (m, 3H), 8.07–8.19 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$+DMSO-D_6): δ 33.2, 54.8, 74.8, 109.9, 119.7, 119.8, 124.5, 125.2, 125.7, 127.9, 129.1, 131.7, 132.2, 133.9, 155.7, 156.0, 180.5, 183.2.

2-Hydroxy-3-((1*S*,2*R*)-2-nitro-1-phenylpropyl)naphthalene-1,4-dione (**3u**). (Entry 21, Table 2). Orange solid, yield 82% with 85% ee. m.p. 119–121 °C. $[\alpha]_D^{28}$ = +61.8 (*c* = 0.25, acetone). HPLC on Chiralcel AD–H column, hexane/*i*-PrOH = 70 : 30, flow rate 1.0 mL min^{-1}, 220 nm; t_R = 14.1 min (major) and 15.8 min (minor); ^1H NMR (300 MHz, $CDCl_3$): δ 1.53 (d, *J* = 6.8 Hz, 3H), 4.94 (d, *J* = 11.3 Hz, 1H), 6.03–6.16 (m, 1H), 7.27–7.37 (m, 3H), 7.50–7.57 (m, 2H), 7.66 (dt, *J* = 1.5, 7.5 Hz, 1H), 7.75 (dt, *J* = 1.5, 7.5 Hz, 1H), 8.03 (dd, *J* = 1.5, 7.5 Hz, 1H), 8.11(dd, *J* = 1.5, 7.5 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 19.6, 46.6, 83.4, 116.3, 121.2, 126.1, 127.8, 128.0, 129.2, 130.4, 131.0, 133.1,135.2, 137.4, 158.9, 171.1, 181.1, 183.5.

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