Tetrahedron 69 (2013) 8422–8428

Contents lists available at SciVerse ScienceDirect

Tetrahedron

journal homepage: www.elsevier.com/locate/tet

2-Pyridylsulfinamides as effective catalysts in the asymmetric alkylation of aldehydes with diethylzinc

Kavirayani R. Prasad *, Omkar Revu

Department of Organic Chemistry, Indian Institute of Science, Bangalore 560 012, India

ARTICLE INFO

Article history:
Received 31 May 2013
Received in revised form 13 July 2013
Accepted 16 July 2013
Available online 24 July 2013

Dedicated to Dr. N.N. Joshi, National Chemical Laboratory, Pune, India

Keywords:
Chiral sulfinamides
Chiral pyridyl ligands
Asymmetric catalysis
Asymmetric alkylation

ABSTRACT

Chiral 2-pyridylsulfinamides were shown to be effective catalysts in the alkylation of aryl and alkyl aldehydes with diethylzinc providing the corresponding alcohols in excellent enantioselectivity. Sulfinamide catalysts possessing solitary chirality at the sulfur center produced the product phenethyl alcohol in good enantioselectivity. Diastereomeric sulfinamides possessing chirality at the carbon-bearing nitrogen and at the sulfur of the sulfinamide increased the enantioselectivity of the product alcohols up to >99%. However, there is no effect of the match-mismatch pair of sulfinamide diastereomers on the outcome of the chiral induction of the product phenethyl alcohols. It was conclusively proved that chirality at the sulfur center is mandatory for obtaining good enantioselectivity in the reaction.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

The advent of chiral sulfinamides such as the Davis' *p*-toluene sulfinamide and Ellman's *tert*-butanesulfinamide has given a new direction for synthesis of chiral amines and in general for asymmetric synthesis of nitrogen containing compounds.[1] Application of these sulfinamides (including the industrial application) in the synthesis of a variety of amine containing compounds of therapeutic significance is evident by a plethora of publications. However, in spite of these advances, application of the sulfinamides as ligands or catalysts in asymmetric transformations is limited. Ellmann's group reported the use of *tert*-butanesulfinamide derived ligands in enantioselective Diels–Alder reaction,[2] while a urea derivative derived from *tert*-butanesulfinamide was utilized as an organocatalyst for aza-Henry reaction[3] and in the conjugate addition of Meldrum's acid derivatives to nitrostyrenes.[4] Enantioselective hydrosilylation of imines[5] and enantioselective protonation of enol silanes[6] using sulfinamide-based catalysts were also disclosed recently. Sulfinamides in combination with rhodium catalysts were proven to be excellent catalysts for asymmetric conjugate addition of aryl boronic acids to unsaturated ketones.[7] A solitary publication on the use of sulfinamides as ligands in the enantioselective addition of diethylzinc to aryl aldehydes[8] has also surfaced in the literature.

Pyridine containing ligands in particular chiral pyridyl alcohols have attracted attention in asymmetric catalysis.[9] 2-Pyridylmethyl amines were also explored as ligands in asymmetric reactions.[10] Study of metal complexes of 2-pyridylmethylamines with metals such as copper, cobalt, and zinc has been a subject of interest for a long time in structural inorganic chemistry.[11] However, to the best of our knowledge, use of chiral pyridylsulfinamides was never studied for their efficiency as catalysts in organic reactions. We envisaged that the zinc amides derived from chiral 2-pyridyl sulfinamides can exert the dual nature of a Lewis acid and Lewis base. As a proof of this concept, we undertook examination of the enantioselective alkylation of aryl aldehydes with diethylzinc, a bench mark reaction for the efficiency of a catalyst.[12] We anticipated that the Lewis acidic metal center (zinc of the amide) would activate the carbonyl group while oxygen of the sulfinamide would act as a Lewis base to facilitate the alkyl transfer from diethylzinc and also would provide the chiral environment required for the reaction (Fig. 1).

2. Results and discussion

With the above hypothesis, a series of pyridine sulfinamides **2a**–**f** were prepared by addition of Grignard reagents to the sulfinimine **1** as described in literature.[13] Accordingly, addition of

* Corresponding author. Tel.: +91 80 2293 2524; fax: +91 80 2360 0529; e-mail addresses: kavirayaniprasad@yahoo.com, prasad@orgchem.iisc.ernet.in (K.R. Prasad).

0040-4020/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.tet.2013.07.061

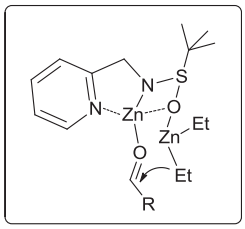


Fig. 1. Proposed TS for the addition of Et_2Zn to aldehydes with zinc amide derived from pyridylsulfinamide as catalyst.

PhMgBr to the sulfinimine **1** furnished the product sulfinamide **2a** as the major product in >95:5 diastereomeric ratio. As expected for the pyridylsulfinamides, addition of the Grignard reagent took place from a face opposite to that of the sulfinyl oxygen and with chelation to the pyridyl nitrogen. Stereochemistry of the newly formed stereogenic center of the major diastereomer **2a** was unambiguously confirmed by X-ray crystal structure analysis.[14] Similarly, addition of 2-naphthyl and 1-naphthylmagnesium bromides proceeded smoothly and the corresponding sulfinamides **2b** and **2c** were obtained in >95:5 ratio. However, addition of isopropylmagnesium chloride, *tert*-butylmagnesium chloride, as well as methylmagnesium iodide furnished an inseparable mixture of product sulfinamides in 91:9, 95:5, and 95:5 ratios, respectively. All these results are summarized in Table 1.

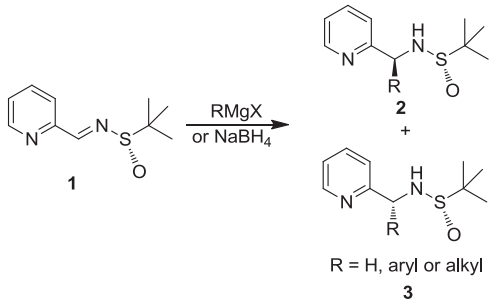


Table 1
Addition of Grignard reagents to 2-pyridylsulfinimine **1**

S. no.	Product [R]	Solvent/temp	Diastereomeric ratio **2**/**3**[a]	Yield %
1	Ph (**2a**)	THF/−78 °C	>95:5	82[b]
2	2-Naphthyl (**2b**)	THF/−78 °C	>95:5	80[b]
3	1-Naphthyl (**2c**)	THF/−78 °C	>95:5	95[b]
4	Isopropyl (**2d**)	THF/−78 °C	91:9[c]	68
5	*tert*-Butyl (**2e**)	THF/−78 °C	95:5[c]	73
6	Methyl (**2f**)	THF/−78 °C	95:5[c]	89
7[d]	H (**2g**)	MeOH/0 °C	—	81

[a] Diastereomeric ratio (dr) was estimated by ^1H NMR.
[b] Yield refers to isolated yield of the pure diastereomer after column chromatography.
[c] Non-separable mixture of diastereomers.
[d] Reaction was performed with $NaBH_4$.

With the sulfinamides in hand, we examined, at the outset, the sulfinamide **2g** prepared by simple reduction of sulfinimine **1** as the catalyst in the addition of Et_2Zn to benzaldehyde. Thus, reaction of benzaldehyde with 1.5 equiv of diethylzinc in presence of 20 mol % of **2g** afforded the product phenethyl alcohol **4** in 72% yield and with 78% ee. It is important to note that the chiral element in this catalyst resided only at the sulfur center bearing sulfinamide. Employing the sulfinamide **2f** possessing chirality at the sulfur center and also at the amine bearing carbon as catalyst afforded the product phenethyl alcohol in 86% yield and in 86% ee. Sulfinamides **2a**–**c** bearing aryl substitution such as phenyl, 2-naphthyl, and 1-naphthyl α- to the amine afforded the product alcohol in almost identical enantioselectivities (89–91% ee). All these results are summarized in Table 2.

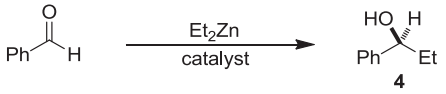
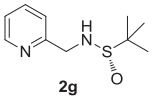
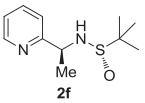
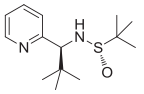
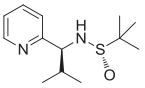
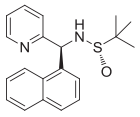
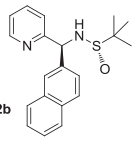
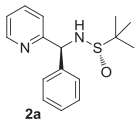


Table 2
Addition of diethylzinc to benzaldehyde catalyzed by 2-pyridylsulfinamides[a]

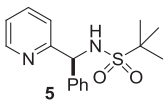
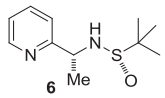
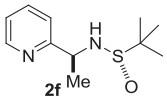
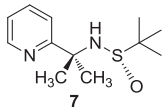
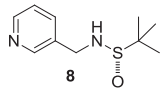
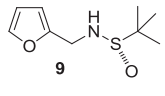
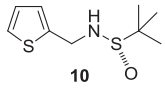
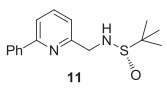
S. no.	Catalyst	Time (h)	Yield[b] (%)	er[c] (*S*:*R*)
1	 **2g**	6	72	88.8:11.2
2	 **2f**	20	86	92.9:7.1
3	 **2e**	16	87	87.3:12.7
4	 **2d**	4	70	90.4:9.6
5	 **2c**	10	71	95.1:4.9
6	 **2b**	9	80	94.9: 5.1
7	 **2a**	4	88	94.6:5.4

[a] All reactions were performed with 20 mol % of the catalyst with 1.5 equiv of Et_2Zn.
[b] Yield refers to isolated yield after column chromatography.
[c] Enantiomeric ratio (er) was estimated by HPLC analysis on a chiral column.

It was intriguing to investigate whether chirality at the sulfur center in **2a** is necessary for the enantioselectivity realized in the alkylation reaction. Accordingly, sulfinamide **2a** was oxidized to the sulfonamide **5** (which lacks chirality at the sulfur center) with *m*-CPBA, and was employed as the catalyst in alkylation of benzaldehyde. It was surprising to find that the product alcohol **4** was formed in 30% ee, comprehensively suggesting that the chirality present at the sulfinyl oxygen plays an important role in the reaction outcome. We then examined the role of *match* and *mismatch* pair of diastereomeric sulfinamides. Thus sulfinamides **2f** and **6**[15] possessing same chirality at sulfur center but epimeric at the chiral center bearing the methyl groups were employed as catalysts in the alkylation reaction. However, the corresponding alcohol was produced with the same configuration in almost identical enantiopurities, with both sulfinamides as catalysts, suggesting that

chirality at the carbon-bearing nitrogen does not play a role in the outcome of the reaction. This clearly suggested that the reaction does proceed through the TS proposed (Fig. 1). To substantiate the hypothesis that chirality at the carbon-bearing nitrogen is of no consequence, sulfinamide **7** possessing the *gem* dimethyl substitution at the carbon-bearing nitrogen was employed as the catalyst. We were pleased to find that the reaction proceeded smoothly and the product phenethyl alcohol was obtained in 90% ee. We then examined the proximity of the heteroatom by employing the 3-pyridylsulfinamide **8** as a catalyst. As expected the sulfinamide **8** produced the product alcohol **4** in 35% ee suggesting that the proximity of the heteroatom was necessary for better induction. The nature of heteroatom present in the sulfinamide was then examined for its efficiency as a catalyst in the alkylation reaction. Thus, employing the sulfinamides **9** and **10** containing furan and thiophene moieties, respectively, afforded the product alcohols with diminished enantioselectivities suggesting that the pyridine presence is pivotal for the catalysis. Also, a point of interest was that substitution on the pyridine ring also influenced the outcome of the reaction. Thus, employing sulfinamide **11**, possessing phenyl substitution at the sixth position of the pyridine ring furnished the product alcohol with diminished enantioselectivity (~63% ee). All these results are summarized in Table 3.

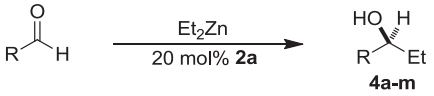
Table 3
Addition of diethylzinc to benzaldehyde catalyzed by various sulfinamides[a]

S. no.	Catalyst	Time (h)	Yield[b] (%)	er[c] (*S*:*R*)
1	 **5**	6	67	65.2:34.8
2	 **6**	4	86	91:9
3	 **2f**	16	86	92.9:7.1
4	 **7**	18	72	95.3:4.7
5	 **8**	4	75	67.4:32.6
6	 **9**	18	60	60.8:39.2
7	 **10**	4	59	62.8:37.2
8	 **11**	17	75	81.4:18.6

[a] All reactions were performed with 20 mol % of the catalyst with 1.5 equiv of Et_2Zn.
[b] Yield refer to isolated yield after column chromatography.
[c] Enantiomeric ratio (er) was estimated by HPLC analysis on a chiral column.

After optimizing the reaction conditions, we generalized the alkylation reaction of a series of aldehydes with diethylzinc with **2a** as the catalyst. Alkylation of the aryl aldehydes proceeded with excellent enantioselectivity, the highest being >99% for **4a** from the ethylation of 3-chlorobenzaldehyde. Presence of dimethylamino substitution in the aryl aldehyde, capable of strong chelation to Et_2Zn rendered the corresponding phenethyl alcohol **4l** in low enantiomeric purity. It was also noteworthy that the alkylation of cyclohexane carbaxaldehyde also furnished the corresponding alcohol **4m** with 91% ee. Very few catalysts are effective for this transformation with cyclohexane carbaxaldehyde. However, alkylation of unsaturated aldehyde such as cinammaladehyde resulted in the corresponding alcohol **4k** with poor (40%) enantioselectivity. All these results are summarized in Table 4.

Table 4
Addition of diethylzinc to aldehydes catalyzed by sulfinamide **2a**[a]



Aldehyde (R)	Product	Time (h)	Yield[b] (%)	er[c] (*S*:*R*)
3-Chlorophenyl	**4a**	11	80	99.8:0.2
4-Chlorophenyl	**4b**	13	60	95.3:4.7
4-Fluorophenyl	**4c**	12	84	94.7:5.3
3-Bromophenyl	**4d**	18	89	94.4:5.6
4-Bromophenyl	**4e**	5	83	93.2:6.8
4-Methoxyphenyl	**4f**	7	81	91.9:8.1
3-Phenoxyphenyl	**4g**	16	80	95:5
3,4,5-Trimethoxyphenyl	**4h**	16	35	89:11
1-Naphthyl	**4i**	2	95	94:6
4-Nitrophenyl	**4j**	12	50	92.3:7.7
Cinnamyl	**4k**	18	70	70.4:29.6
4-Dimethylamino phenyl	**4l**	17	33	69.4:30.6
Cyclohexyl	**4m**	15	77	95.7:4.3

[a] All reactions were performed with 20 mol % of the catalyst with 1.5 equiv of Et_2Zn.
[b] Yield refers to isolated yield after column chromatography purification.
[c] Enantiomeric ratio (er) was estimated by HPLC analysis on a chiral column.

As for the mechanism, we believe that the reaction is proceeding through the TS (Fig. 1) proposed. Lewis acidic metal center (zinc of the amide) activates the carbonyl group, and oxygen of the sulfinamide facilitates the alkyl transfer reaction. It was essential to have the chirality at the sulfur center in the sulfinamide catalyst for an exclusive chelation and transfer of diethylzinc from *Si* face of the aldehyde, rendering *S*-phenethyl alcohol.

3. Conclusion

In conclusion, a series of 2-pyridylsulfinamides were prepared by the addition of Grignard reagents to the sulfinimine. It was found that these sulfinamides were effective catalysts in the alkylation of aromatic aldehydes. It was also found that the chirality at the sulfur center in the catalyst is essential for higher enantioselectivity of the product alcohols. Other heteroatom substituted sulfinamides were found to be ineffective catalysts in the alkylation reaction. Further applications of these catalysts in other asymmetric transformations are underway.

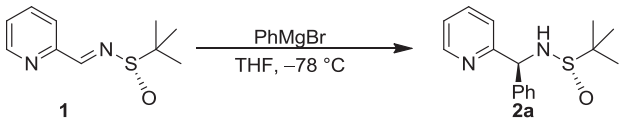
4. Experimental section

4.1. General

Column chromatography was performed on silica gel, Acme grade 100–200 mesh and neutral alumina, SD-Fine grade. TLC

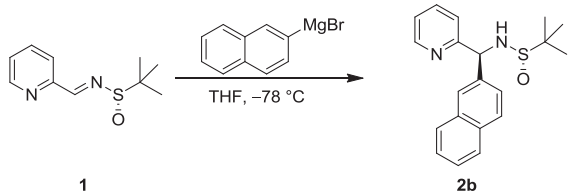
plates were visualized either with UV, in an iodine chamber, or with phosphomolybdic acid spray. All reagents were purchased from commercial sources and were used without additional purification. THF was freshly distilled over Na-benzophenone ketyl. Melting points were uncorrected. ^{1}H NMR and ^{13}C NMR spectra were recorded on a 400 MHz machine in $CDCl_3$ or $(CD_3)_2SO$ as solvent with TMS as reference unless otherwise indicated. Unless stated otherwise, all reactions were performed under inert atmosphere. All specific rotations were determined at 24 °C. HRMS was obtained using a micromass-QTOF spectrometer using electrospray ionization (ESI).

*4.1.1. Representative procedure for the addition of Grignard reagents to sulfinimine: preparation of (S)-2-methyl-N-((S)-phenyl (pyridin-2-yl)methyl) propane-2-sulfinamide (**2a**).*



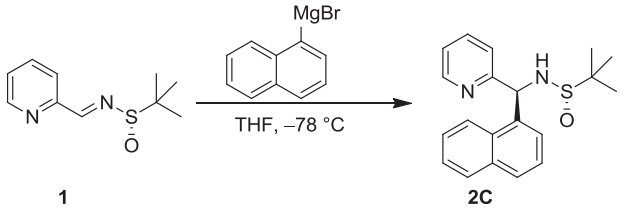
In a two-necked 50 mL round-bottomed flask equipped with a magnetic stirbar, rubber septum, and argon inlet was placed pyridylsulfinimine **1** (0.10 g, 0.48 mmol). This was dissolved in dry THF (3 mL) and the solution was cooled to −78 °C. A THF solution of phenylmagnesium bromide (1 mL of 0.7 M solution in THF, 0.71 mmol) was added dropwise at the same temperature. Progress of the reaction was monitored by TLC and after the reaction was complete (~1.0 h), it was cautiously quenched by the addition of satd NH_4Cl solution (10 mL) and extracted with EtOAc (3×10 mL). The combined organic extracts were washed with brine (15 mL) and dried over anhydrous Na_2SO_4. Evaporation of the solvent followed by silica gel column chromatography of the residue with petroleum ether/EtOAC (2:8) as eluent afforded **2a** as a white solid in 82% yield. R_f 0.50 (100% EtOAc); mp: 109–111 °C; $[\alpha]_D^{24}$ +194.2 (*c* 1.0, $CHCl_3$); IR (KBr) 3218, 2976, 2964, 2952, 2860, 1589, 1430, 1066, 1042 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ_H 8.56 (d, *J*=4.6 Hz, 1H), 7.57 (t, *J*=7.7 Hz, 1H), 7.41–7.21 (m, 5H), 7.22–7.09 (m, 1H), 7.04 (d, *J*=7.9 Hz, 1H), 5.78 (br s, 1H), 5.65 (d, *J*=2.7 Hz, 1H), 1.26 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 159.8, 148.5, 141.7, 136.6, 128.6 (2C), 128.3 (2C), 127.8, 122.4, 122.3, 61.9, 55.8, 22.7 (3C); HRMS: [M+Na] found 311.1194. $C_{16}H_{20}N_2OS$+Na requires 311.1194.

*4.1.2. Preparation of (S)-2-methyl-N-((S)-naphthalen-2-yl (pyridin-2-yl)methyl) propane-2-sulfinamide (**2b**).*



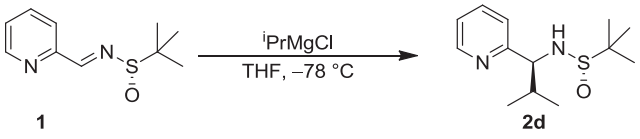
Following the general procedure mentioned above, addition of 2-naphthylmagnesium bromide to sulfinimine **1** afforded **2b** as a white solid in 80% yield. R_f 0.60 (100% EtOAc); mp: 122–125 °C; $[\alpha]_D^{24}$ +218.7 (*c* 1.0, $CHCl_3$); IR (KBr) 3435, 3195, 2974, 2959, 1591, 1568, 1470, 1088, 1063 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ_H 8.59 (d, *J*=4.8 Hz, 1H), 7.94–7.74 (m, 4H), 7.60–7.33 (m, 4H), 7.23–7.10 (m, 1H), 7.05 (d, *J*=7.9 Hz, 1H), 5.93 (s, 1H), 5.81 (d, *J*=2.0 Hz, 1H), 1.27 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 159.5, 148.5, 138.9, 136.7, 133.2, 133.0, 128.7, 128.0, 127.8, 127.7, 126.3, 126.2, 125.8, 122.6, 122.4, 62.0, 55.8, 22.8 (3C); HRMS: [M+H] found 339.1534. $C_{20}H_{22}N_2OS$+H requires 339.1531.

*4.1.3. Preparation of (S)-2-methyl-N-((S)-naphthalen-1-yl(pyridin-2-yl)methyl)propane-2-sulfinamide (**2c**).*



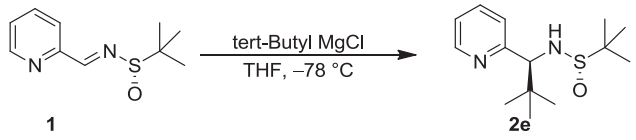
Following the general procedure mentioned above, addition of 1-naphthylmagnesium bromide to sulfinimine **1** afforded **2c** as a white solid in 95% yield. R_f 0.60 (100% EtOAc); mp: 128–129.7 °C; $[\alpha]_D^{24}$ +232.0 (*c* 0.86, $CHCl_3$); IR (KBr) 2957, 2924, 1591, 1435, 1066 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ_H 8.61 (d, *J*=4.8 Hz, 1H), 7.98 (d, *J*=8.5 Hz, 1H), 7.84 (d, *J*=8.1 Hz, 2H), 7.60 (d, *J*=6.9 Hz, 1H), 7.56–7.37 (m, 3H), 7.34 (t, *J*=7.5 Hz, 1H), 7.21–7.10 (m, 1H), 6.89 (d, *J*=7.9 Hz, 1H), 6.21 (s, 1H), 6.12 (s, 1H), 1.19 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 159.7, 148.6, 137.0, 136.5, 134.7, 131.3, 129.4, 129.0, 128.8, 126.1, 125.9, 125.5, 125.4, 122.5 (2C), 60.9, 55.9, 22.9 (3C); HRMS: [M+Na] found 361.1351. $C_{20}H_{22}N_2OS$+Na requires 361.1351.

*4.1.4. Preparation of (S)-2-methyl-N-((S)-2-methyl-1-(pyridin-2-yl) propyl)propane-2-sulfinamide (**2d**).*



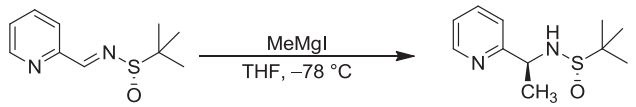
Following the general procedure mentioned above, addition of isopropylmagnesium chloride to sulfinimine **1** afforded **2d** as a colorless oil in 68% yield with 88:12 dr. R_f 0.50 (80% EtOAc/petroleum ether); $[\alpha]_D^{24}$ +82.7 (*c* 1.0, $CHCl_3$); IR (neat) 3443, 3253, 2963, 2930, 2873, 1593, 1471, 1053 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ_H 8.54 (d, *J*=4.6 Hz, 1H), 7.62 (td, *J*=7.6, 1.1 Hz, 1H), 7.25–7.08 (m, 2H), 5.06 (d, *J*=7.3 Hz, 1H), 4.14 (t, *J*=6.6 Hz, 1H), 2.05 (sextet, *J*=6.6 Hz, 1H), 1.29 (s, 9H), 0.87 (dd, *J*=5.3, 5.8 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 160.5, 148.8, 136.3, 122.4, 122.2, 65.8, 56.2, 35.3, 22.9 (3C), 19.8, 17.8; HRMS: [M+Na] found 277.1350. $C_{13}H_{22}N_2OS$+Na requires 277.1351.

*4.1.5. Preparation of (S)-N-((S)-2,2-dimethyl-1-(pyridin-2-yl)propyl)-2-methylpropane-2-sulfinamide (**2e**).*



Following the general procedure mentioned above, addition of *tert*-butylmagnesium chloride afforded **2e** as a white solid in 73% yield with 92:8 dr. R_f 0.50 (80% EtOAc/petroleum ether); mp: 132–135 °C; $[\alpha]_D^{24}$ +105.1 (*c* 0.5, $CHCl_3$); IR (KBr) 3255, 2956, 2358, 1470, 1393, 1064 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ_H 8.53 (d, *J*=4.4 Hz, 1H), 7.57 (t, *J*=7.6 Hz, 1H), 7.22–7.06 (m, 2H), 5.29 (d, *J*=7.6 Hz, 1H), 4.03 (d, *J*=7.8 Hz, 1H), 1.28 (s, 9H), 0.90 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 159.3, 148.5, 135.5, 123.8, 122.2, 68.6, 56.2, 36.5, 26.6 (3C), 23.0 (3C); HRMS: [M+Na] found 291.1507. $C_{14}H_{24}N_2OS$+Na requires 291.1507.

*4.1.6. Preparation of (S)-2-methyl-N-((S)-1-(pyridin-2-yl)ethyl)propane-2-sulfinamide (**2f**).*



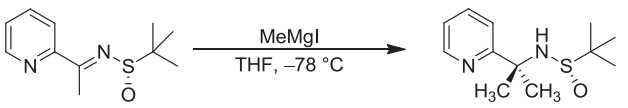
1 **2f**

Following a similar procedure mentioned above, addition of methylmagnesium iodide to sulfinimine **1** afforded **2f** (0.095 g, 89%) as a colorless oil with 95:5 dr. R_f 0.40 (100% EtOAc); $[\alpha]_D^{24}$ +80.7 (*c* 0.14, $CHCl_3$); IR (neat) 3162, 2978, 2959, 1594, 1481, 1437, 1128, 1063 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ_H 8.53 (d, *J*=4.7 Hz, 1H), 7.64 (td, *J*=7.7, 0.93 Hz, 1H), 7.27 (d, *J*=8.4 Hz, 1H), 7.16 (dd, *J*=7.4, 4.9 Hz, 1H), 4.82 (d, *J*=4.7 Hz, 1H), 4.58 (qd, *J*=12.8, 6.5 Hz, 1H), 1.49 (d, *J*=6.74 Hz, 3H), 1.24 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 161.8, 148.9, 136.8, 122.3, 121.0, 55.6, 55.2, 23.2, 22.6 (3C); HRMS: [M+Na] found 249.1040. $C_{11}H_{18}N_2OS$+Na requires 249.1038.

*4.1.7. Preparation of (S)-2-methyl-N-(phenyl(pyridin-2-yl)methyl) propane-2-sulfonamide (**5**).* To a stirred solution of **2a** (0.10 g, 0.35 mmol) in CH_2Cl_2 (3 mL) was added 3-chloroperbenzoic acid (0.12 g, 0.7 mmol) at room temperature. The reaction mixture was stirred at rt for 40 min. After the reaction was complete (TLC), it was washed with a mixture of a solution of satd $NaHSO_3$ (10 mL) and $NaHCO_3$ (10 mL). The aqueous layer was extracted with EtOAc (2×10 mL). The combined organic layers were washed with brine (10 mL), dried over anhydrous Na_2SO_4. Evaporation of solvent followed by silica gel column chromatography of the crude residue with petroleum ether/EtOAc (2:3) as eluent afforded pyridylsulfonamide **5** (0.095 g, 91%) as a white solid. R_f 0.60 (40% EtOAc/petroleum ether); mp: 139–141 °C; $[\alpha]_D^{24}$ +94.4 (*c* 0.8, $CHCl_3$); IR (KBr) 3311, 3292, 1698, 1437, 1422, 1303, 1129 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ_H 8.57 (d, *J*=4.7 Hz, 1H), 7.64 (t, *J*=7.6 Hz, 1H), 7.46–7.24 (m, 7H), 6.64 (d, *J*=7.0 Hz, 1H), 5.80 (d, *J*=6.9 Hz, 1H), 1.28 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 159.3, 149.0, 142.2, 137.5, 129.0 (2C), 128.0, 127.7 (2C), 122.9, 122.8, 61.7, 60.1, 24.4 (3C); HRMS: [M+Na] found 327.1143. $C_{16}H_{20}N_2SO_2$+Na requires 327.1143.

*4.1.8. Preparation of (S)-2-methyl-N-((R)-1-(pyridin-2-yl)ethyl) propane-2-sulfinamide (**6**).* To a stirred solution of the ketimine (0.10 g, 0.446 mmol) in THF (3 mL) was added K-Selectride (0.6 mL of 1 M solution in THF, 0.58 mmol) dropwise at −78 °C under argon atmosphere. The reaction mixture was stirred at −78 °C for 5 h. After completion of the reaction, it was quenched with dropwise addition of water (10 mL), and extracted with EtOAc (3×10 mL). The combined organic layer was washed with brine (10 mL), and dried over Na_2SO_4. Evaporation of the solvent followed by silica gel column chromatography of the resulting residue with petroleum ether/EtOAc (9:1) as eluent afforded **6** (0.071 g, 71%) as white solid. R_f 0.40 (100% EtOAc); mp: 101–103 °C; $[\alpha]_D^{24}$ +88.0 (*c* 0.06, $CHCl_3$); IR (KBr) 3352, 2930, 2867, 1466, 1026 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ_H 8.53 (d, *J*=4.6 Hz, 1H), 7.64 (t, *J*=7.5 Hz, 1H), 7.64 (d, *J*=7.8 Hz, 1H), 7.16 (dd, *J*=7.3, 5.0 Hz, 1H), 6.60 (q, *J*=6.6 Hz, 1H), 3.95 (d, *J*=6.0 Hz, 1H), 1.58 (d, *J*=6.7 Hz, 3H), 1.17 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 162.2, 149.2, 136.7, 122.3, 121.0, 56.6, 55.9, 24.1, 22.5 (3C); HRMS: [M+Na] found 249.1040. $C_{11}H_{18}N_2SO$+Na requires 249.1038.

*4.1.9. Preparation of (S)-2-methyl-N-(2-(pyridin-2-yl)propan-2-yl) propane-2-sulfinamide (**7**).*



7

Following the general procedure described for the addition of Grignard reagents to sulfinimines, addition of methylmagnesium iodide to ketimine afforded **7** as a colorless oil in 87% yield. R_f 0.50 (100% EtOAc); $[\alpha]_D^{24}$ +91.9 (*c* 0.9, $CHCl_3$); IR (neat) 3484, 2979, 2927, 1592, 1366, 1052 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ_H 8.54 (d, *J*=4.6 Hz, 1H), 7.67 (td, *J*=7.96, 0.96 Hz, 1H), 7.42 (d, *J*=8.0 Hz, 1H), 7.16 (dd, *J*=7.08, 5.12 Hz, 1H), 5.02 (s, 1H), 1.72 (s, 3H), 1.64 (s, 3H), 1.22 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 164.9, 148.4, 136.7, 121.9, 119.0, 58.5, 55.6, 30.3, 29.4, 22.7 (2C), 22.1; HRMS: [M+Na] found 263.1196. $C_{12}H_{20}N_2OS$+Na requires 263.1194.

4.1.10. Procedure for the reduction of sulfinimine. The following for the preparation of (*S*)-2-methyl-*N*-(pyridin-2-ylmethyl) propane-2-sulfinamide (**2g**) is representative. To a stirred solution of pyridylsulfinimine **1** (0.1 g, 0.47 mmol) in MeOH (3 mL) was added $NaBH_4$ (0.027 g, 0.714 mmol) portion wise at 0 °C and stirred at the same temperature (~30 min). After the reaction was complete (TLC), most of the solvent was removed under reduced pressure, water (10 mL) was added to the reaction mixture and extracted with EtOAc (2×20 mL). The combined organic layers were washed with brine (10 mL), dried over anhydrous Na_2SO_4. Evaporation of solvent followed by silica gel column chromatography of the crude residue with petroleum ether/EtOAc (1:9) as eluent afforded pyridylsulfinamide **2g** (0.082 g, 81%) as colorless oil. R_f 0.40 (100% EtOAc); $[\alpha]_D^{24}$ +60.0 (*c* 1.65, $CHCl_3$); IR (neat) 3469, 2980, 2960, 1599, 1440, 1048 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ_H 8.51 (d, *J*=4.8, 1H), 7.65 (t, *J*=7.7 Hz, 1H), 7.32 (d, *J*=7.8 Hz, 1H), 7.17 (t, *J*=6.1 Hz, 1H), 4.51–4.30 (m, 3H), 1.21 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 157.7, 148.8, 137.2, 122.6, 122.4, 56.3, 49.9, 22.7 (3C); HRMS: [M+Na] found 235.0882. $C_{10}H_{16}N_2OS$+Na requires 235.0881.

*4.1.11. Preparation of (S)-2-methyl-N-(pyridin-3-ylmethyl)propane-2-sulfinamide (**8**).* Following a similar procedure mentioned above, reduction of the corresponding sulfinimine with $NaBH_4$ afforded **8** as a colorless oil in 80% yield. R_f 0.40 (100% EtOAc); $[\alpha]_D^{24}$ +44.6 (*c* 1.7, $CHCl_3$); IR (neat) 3469, 3208, 1599, 1440, 1048 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ_H 8.58–8.41 (m, 2H), 7.66 (d, *J*=7.7 Hz, 1H), 7.26 (br s, 1H), 4.32 (dd, *J*=14.3, 5.1 Hz, 1H), 4.24 (dd, *J*=14.3, 7.1 Hz, 1H), 3.80 (s, 1H), 1.96 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 149.4, 149.0, 135.8, 134.0, 123.5, 56.0, 46.8, 22.5 (3C); HRMS: [M+Na] found 235.0883. $C_{10}H_{16}N_2OS$+Na requires 235.0881.

*4.1.12. Preparation of (S)-N-(furan-2-ylmethyl-2-methyl)propane-2-sulfinamide (**9**).* Following a similar procedure mentioned above, reduction of the corresponding sulfinimine with $NaBH_4$ afforded **9** as a colorless oil in 90% yield. R_f 0.50 (80% EtOAc/petroleum ether); $[\alpha]_D^{24}$ +41.8 (*c* 1.0, $CHCl_3$); IR (neat) 3208, 2959, 2926, 2869, 1149, 1057, 1013 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ_H 7.35 (s, 1H), 6.29 (d, *J*=1.0 Hz, 1H), 6.29–6.28 (m, 1H), 4.30 (dd, *J*=14.8, 5.2 Hz, 1H), 4.20 (dd, *J*=14.8, 6.8 Hz, 1H), 3.56 (br s, 1H), 1.19 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 152.2, 142.7, 110.6, 108.1, 56.3, 42.5, 22.8 (3C); HRMS: [M+Na] found 224.0725. $C_9H_{15}NO_2S$+Na requires 224.0721.

*4.1.13. Preparation of (S)-2-methyl-N-(thiophen-2-ylmethyl)propane-2-sulfinamide (**10**).* Following a similar procedure mentioned above, reduction of the corresponding sulfinimine with $NaBH_4$ afforded **10** as a white solid in 95% yield. R_f 0.60 (80% EtOAc/petroleum ether); mp: 73.6–74.3 °C; $[\alpha]_D^{24}$ +26.4 (*c* 1.1, $CHCl_3$); IR (KBr) 3468, 3207, 2980, 2959, 2868, 1455, 1366, 1057 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ_H 7.24 (d, *J*=5.0 Hz, 1H), 7.03–6.88 (m, 2H), 4.55 (dd, *J*=14.5, 4.6 Hz, 1H), 4.41 (dd, *J*=14.4, 7.5 Hz, 1H), 3.64 (br s, 1H), 1.23 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 142.2, 127.1, 126.1, 125.7,

56.3, 44.6, 22.9 (3C); HRMS: [M+Na] found 240.0493. $C_9H_{15}NS_2O$+Na requires 240.0493.

*4.1.14. Preparation of (S)-2-methyl-N-((6-phenylpyridin-2-yl)methyl) propane-2-sulfinamide (**11**).* Following a similar procedure mentioned above, reduction of the corresponding sulfinimine with $NaBH_4$ afforded **11** as a white solid in 99% yield. R_f 0.60 (100% EtOAc); mp: 110–111 °C; $[\alpha]_D^{24}$ +68.0 (*c* 1.1, $CHCl_3$); IR (KBr) 3154, 2919, 2317, 1807, 1449, 1364, 1047 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ_H 8.51 (d, *J*=7.2 Hz, 2H), 8.24 (t, *J*=7.6 Hz, 1H), 8.14 (d, *J*=7.7 Hz, 1H), 8.05–7.86 (m, 3H), 7.77 (d, *J*=7.6 Hz, 1H), 5.14 (br s, 1H), 5.11–4.99 (m, 2H), 1.80 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 157.3, 156.6, 139.0, 137.4, 129.0, 128.7 (2C), 126.8 (2C), 120.2, 119.0, 56.1, 49.3, 22.7 (3C); HRMS: [M+Na] found 311.1195. $C_{16}H_{20}N_2OS$+Na requires 311.1194.

4.1.15. Representative procedure for the addition of Et_2Zn to aldehyde. To a stirred solution of pyridylsulfinamide ligand **2a** (0.057 g, 0.2 mmol) in dry toluene (2 mL) was added diethylzinc (1.1 M solution in toluene, 1.4 mL, 1.51 mmol) at 0 °C dropwise and stirred for 15 min at 0 °C. Aldehyde (0.12 mL, 1.0 mmol) was added into the reaction mixture at 0 °C and reaction mixture was warmed slowly to rt and stirred at rt until the completion of the reaction. After completion of the reaction, it was quenched by the addition of satd NH_4Cl solution (10 mL) and the mixture was extracted with EtoAc (15 mL×2). The combined organic layers were washed with brine (20 mL), dried over Na_2SO_4, and concentrated in vacuo. The residue was purified by silica gel column chromatography using EtoAc/hexane mixture as eluent to give the product alcohols.

*4.1.16. (S)-1-Phenylpropan-1-ol (**4**).* Yield 88%, er (*S*:*R*) 94.6:5.4. Enantiomeric ratio was determined by chiral HPLC analysis (CHIRALCEL OD-H, 2.5% IPA in hexane, 0.5 mL/min, 254 nm UV detector). t_R=15.19 min for (*R*) and t_R=17.13 min for (*S*). $[\alpha]_D^{24}$ −39.8 (*c* 1.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ_H 7.42–7.27 (m, 5H), 4.58 (t, *J*=6.4 Hz, 1H), 2.11 (br s, 1H), 1.91–1.66 (m, 2H), 0.92 (t, *J*=7.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 144.5, 128.3 (2C), 127.4, 125.9 (2C), 75.9, 31.8, 10.1.

*4.1.17. (S)-1-(3-Chlorophenyl)propan-1-ol (**4a**).* Yield 80%, er (*S*:*R*): 99.8:0.2. Enantiomeric ratio was determined by chiral HPLC analysis (CHIRAL CEL OD-H, 1% IPA in hexane, 0.5 mL/min, 254 nm UV detector). t_R=47.60 min for (*R*) and t_R=53.49 min for (*S*). $[\alpha]_D^{24}$ −34.1 (*c* 1.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ_H 7.32 (s, 1H), 7.33–7.18 (m, 2H), 7.18 (d, *J*=6.78 Hz, 1H), 4.54 (t, *J*=6.5 Hz, 1H), 2.35 (br s, 1H), 1.85–1.62 (m, 2H), 0.90 (t, *J*=7.4 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 146.7, 134.3, 129.7, 127.5, 126.2, 124.2, 75.3, 31.9, 10.0.

*4.1.18. (S)-1-(4-Chlorophenyl)propan-1-ol (**4b**).* Yield 60%, er (*S*:*R*) 95:5. Enantiomeric ratio was determined by chiral HPLC analysis (CHIRAL CEL OD-H, 1% IPA in hexane, 1 mL/min, 254 nm UV detector). t_R=13.97 min for (*S*) and t_R=15.75 min for (*R*). $[\alpha]_D^{24}$ −40.9 (*c* 1.7, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ_H 7.30 (d, *J*=8.4 Hz, 2H), 7.25 (d, *J*=8.2 Hz, 2H), 4.55 (t, *J*=4.2 Hz, 1H), 2.14 (br s, 1H), 1.86–1.60 (m, 2H), 0.89 (t, *J*=7.4 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 143.0, 133.1, 128.5 (2C), 127.4 (2C), 75.3, 31.9, 10.0.

*4.1.19. (S)-1-(4-Fluorophenyl)propan-1-ol (**4c**).* Yield 84%, er (*S*:*R*): 94.7:5.3. Enantiomeric ratio was determined by chiral HPLC analysis (CHIRAL CEL OJ-H, 1% IPA in hexane, 1 mL/min, 254 nm UV detector). t_R=22.88 min for (*R*) and t_R=24.86 min for (*S*). $[\alpha]_D^{24}$ −40.6 (*c* 0.76, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ_H 7.30 (dd, *J*=8.3, 5.6 Hz, 2H), 7.02 (t, *J*=8.6 Hz, 2H), 4.57 (t, *J*=5.9 Hz, 1H), 2.0 (br s, 1H), 2.06–1.62 (m, 2H), 0.89 (t, *J*=7.4 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 160.9, 140.3, 127.6, 127.5, 115.2, 115.0, 75.3, 31.9, 10.0.

*4.1.20. (S)-1-(3-Bromophenyl)propan-1-ol (**4d**).* Yield 89%, er (*S*:*R*): 94.4:5.6. Enantiomeric ratio was determined by chiral HPLC analysis (CHIRAL PAK AD-H, 1% IPA in hexane, 0.5 mL/min, 254 nm UV detector). t_R=40.18 min for (*R*) and t_R=43.26 min for (*S*). $[\alpha]_D^{24}$ −25.7 (*c* 1.78, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ_H 7.49 (s, 1H), 7.39 (d, *J*=6.6 Hz, 1H), 7.31–7.13 (m, 2H), 4.54 (td, *J*=12.5, 6.2 Hz, 1H), 2.36 (br s, 1H), 1.86–1.65 (m, 2H), 0.90 (td, *J*=7.3, 2.0 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 146.9, 130.5, 129.9, 129.0, 124.6, 122.5, 75.2, 31.9, 10.0.

*4.1.21. (S)-1-(4-Bromophenyl)propan-1-ol (**4e**).* Yield 83%, er (*S*:*R*): 93.2:6.8. Enantiomeric ratio was determined by chiral HPLC analysis (CHIRAL CEL OD-H, 2.5% IPA in hexane, 0.5 mL/min, 254 nm UV detector). t_R=16.49 min for (*R*) and t_R=18.19 min for (*S*). $[\alpha]_D^{24}$ −15.94 (*c* 1.6, C_6H_6); ^1H NMR (400 MHz, $CDCl_3$) δ_H 7.47 (d, *J*=8.3 Hz, 2H), 7.20 (d, *J*=8.3 Hz, 2H), 4.55 (t, *J*=6.5 Hz, 1H), 2.1 (br s, 1H), 1.86–1.61 (m, 2H), 0.89 (t, *J*=7.4 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 143.5, 131.5 (2C), 127.7 (2C), 121.2, 75.3, 31.9, 10.0.

*4.1.22. (S)-1-(4-Methoxyphenyl)propan-1-ol (**4f**).* Yield 81%, er (*S*:*R*): 92:8. Enantiomeric ratio was determined by chiral HPLC analysis (CHIRAL CEL OD-H, 2% IPA in hexane, 0.8 mL/min, 254 nm UV detector). t_R=16.39 min for (*R*) and t_R=18.02 min for (*S*). $[\alpha]_D^{24}$ −21.3 (*c* 0.52, C_6H_6); ^1H NMR (400 MHz, $CDCl_3$) δ_H 7.26 (d, *J*=8.8 Hz, 2H), 6.88 (d, *J*=8.8 Hz, 2H), 4.53 (t, *J*=6.6 Hz, 1H), 3.80 (s, 3H), 2.0 (br s, 1H), 1.90–1.62 (m, 2H), 0.89 (t, *J*=7.4 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 158.9, 136.7, 127.1 (2C), 113.7 (2C), 75.6, 55.2, 31.7, 10.1.

*4.1.23. (S)-1-(3-Phenoxyphenyl)propan-1-ol (**4g**).* Yield 80%, er (*S*:*R*): 95:5. Enantiomeric ratio was determined by chiral HPLC analysis (CHIRAL CEL OD-H, 3% IPA in hexane, 1 mL/min, 254 nm UV detector). t_R=14.73 min for (*S*) and t_R=18.29 min for (*R*). $[\alpha]_D^{24}$ −18.6 (*c* 0.88, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ_H 7.40–7.20 (m, 3H), 7.16–7.01 (m, 2H), 7.51–6.94 (m, 3H), 6.90 (dq, *J*=2.4, 0.8 Hz, 1H), 4.57 (t, *J*=6.4 Hz, 1H), 2.0 (br s, 1H), 1.85–1.65 (m, 2H), 0.91 (t, *J*=7.4 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 157.3, 157.1, 146.7, 129.7 (2C), 129.6, 123.2, 120.7, 118.8 (2C), 117.7, 116.4, 75.6, 31.8, 10.0.

*4.1.24. (S)-1-(3,4,5-Trimethoxyphenyl)propan-1-ol (**4h**).* Yield 35%, er (*S*:*R*): 89:11. Enantiomeric ratio was determined by chiral HPLC analysis (CHIRAL CEL OD-H, 3% IPA in hexane, 1 mL/min, 254 nm UV detector). t_R=27.85 min for (*R*) and t_R=39.08 min for (*S*). $[\alpha]_D^{24}$ −15.1 (*c* 0.88, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ_H 6.57 (s, 2H), 4.52 (t, *J*=6.4 Hz, 1H), 3.86 (s, 6H), 3.83 (s, 3H), 2.10 (br s, 1H), 1.88–1.64 (m, 2H), 0.94 (t, *J*=7.4 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 153.1 (2C), 140.5, 137.0, 102.7 (2C), 76.1, 60.8, 56.0 (2C), 31.9, 10.2.

*4.1.25. (S)-1-(Naphthalen-2-yl)propan-1-ol (**4i**).* Yield 95%, er (*S*:*R*): 94:6. Enantiomeric ratio was determined by chiral HPLC analysis (CHIRAL CEL OD-H, 5% IPA in hexane, 1 mL/min, 254 nm UV detector). t_R=11.09 min for (*S*) and t_R=24.25 min for (*R*). $[\alpha]_D^{24}$ −49.8 (*c* 1.25, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ_H 8.12 (d, *J*=8.4 Hz, 1H), 7.94–7.82 (m, 1H), 7.79 (d, *J*=8.2 Hz, 1H), 7.64 (d, *J*=7.1 Hz, 1H), 7.57–7.40 (m, 3H), 5.40 (br s, 1H), 2.13–1.94 (m, 3H), 1.04 (t, *J*=7.4 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 141.6, 135.2, 131.9, 130.3, 129.3, 127.3, 126.9, 126.8, 124.7, 124.3, 74.0, 32.5, 12.0.

*4.1.26. (S)-1-(4-Nitrophenyl)propan-1-ol (**4j**).* Yield 50%, er (*S*:*R*): 92:8. Enantiomeric ratio was determined by chiral HPLC analysis (CHIRAL PAK AD-H, 5% IPA in hexane, 0.5 mL/min, 254 nm UV detector). t_R=20.94 min for (*R*) and t_R=22.48 min for (*S*). $[\alpha]_D^{24}$ −27.6 (*c* 0.3, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ_H 8.16 (d, *J*=8.5 Hz, 2H), 7.49 (d, *J*=8.5 Hz, 2H), 4.73 (t, *J*=6.4 Hz, 1H), 2.41 (br s, 1H), 1.85–1.66 (m, 2H), 0.92 (t, *J*=7.4 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 152.1, 147.1, 126.7 (2C), 123.6 (2C), 74.8, 32.1, 9.8.

*4.1.27. (S,E)-1-Phenylpent-1-en-3-ol (**4k**).* Yield 70%, er (*S*:*R*): 70:30. Enantiomeric ratio was determined by chiral HPLC analysis (CHIRAL

CEL OD-H, 5% IPA in hexane, 1 mL/min, 254 nm UV detector). t_R=7.82 min for (*R*) and t_R=12.71 min for (*S*). $[\alpha]_D^{24}$ −4.15 (*c* 3.25, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ_H 7.45–7.18 (m, 5H), 6.58 (d, *J*=15.9 Hz, 1H), 6.22 (dd, *J*=15.9, 6.7 Hz, 1H), 4.21 (td, *J*=12.9, 6.4 Hz, 1H), 1.78–1.56 (m, 3H), 0.98 (t, *J*=7.8 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 136.8, 132.3, 130.4, 128.6 (2C), 127.6, 126.5 (2C), 74.4, 30.2, 9.8.

*4.1.28. (S)-1-(4-(Dimethylamino)phenyl)propan-1-ol (**4l**).* Yield 33%, er (*S*:*R*): 69.5:30.5. Enantiomeric ratio was determined by chiral HPLC analysis (CHIRAL CEL OD-H, 5% IPA in hexane, 1 mL/min, 254 nm UV detector). t_R=8.11 min for (*R*) and t_R=9.52 min for (*S*). $[\alpha]_D^{24}$ −2.83 (*c* 0.6, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ_H 7.22 (d, *J*=8.5 Hz, 2H), 6.73 (d, *J*=8.5 Hz, 2H), 4.50 (t, *J*=6.7 Hz, 1H), 2.95 (s, 6H), 1.91–1.64 (m, 3H), 0.90 (t, *J*=7.4 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 150.2, 132.5, 127.0 (2C), 112.5 (2C), 75.9, 40.7 (2C), 31.5, 10.4.

*4.1.29. (S)-1-Cyclohexylpropan-1-ol (**4m**).* Yield 77%, er (*S*:*R*): 95.7: 4.3. Enantiomeric ratio was determined by chiral HPLC analysis for benzoate derivative (CHIRAL PAK AD-H, 1% IPA in hexane, 0.3 mL/min, 254 nm UV detector). t_R=10.33 min for (*R*) and t_R=12.47 min for (*S*). $[\alpha]_D^{24}$ −4.67 (*c* 0.45, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ_H 3.28–3.26 (m, 1H), 1.82–1.01 (m, 14H), 0.95 (t, *J*=7.5 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C 77.6, 43.1, 29.3, 27.7, 26.8, 26.5, 26.3, 26.2, 10.2.

Acknowledgements

K.R.P. thanks the Department of Science and Technology (DST), New Delhi for funding of this project. K.R.P. is Swarnajayanthi fellow of DST. O.R. thanks the council of scientific and industrial research (CSIR), New Delhi for a research fellowship.

Supplementary data

Supplementary data associated with this article can be found in the online version, at http://dx.doi.org/10.1016/j.tet.2013.07.061.

References and notes

1. For a review on Davis' *p*-toluenesulfinamide as auxiliary in the synthesis of chiral nitrogen containing compounds, see: (a) Davis, F. A. *J. Org. Chem.* **2006**, *71*, 8993; (b) Zhou, P.; Chen, B.-C.; Davis, F. A. *Tetrahedron* **2004**, *60*, 8003 For a review on the use of Ellman's *tert*-butylsulfinamide as auxiliary in the synthesis of chiral nitrogen containing compounds, see: Robak, M. T.; Herbage, M. A.; Ellman, J. A. *Chem. Rev.* **2010**, *110*, 3600.
2. (a) Owens, T. D.; Souers, A. J.; Ellman, J. A. *J. Org. Chem.* **2003**, *68*, 3; (b) Owens, T. D.; Hollander, F. J.; Allen, G.; Oliver, A. G.; Ellman, J. A. *J. Am. Chem. Soc.* **2001**, *123*, 1539.
3. (a) Kimmel, K. L.; Robak, M. T.; Ellman, J. A. *J. Am. Chem. Soc.* **2009**, *131*, 8754; (b) Robak, M. T.; Trincado, M.; Ellman, J. A. *J. Am. Chem. Soc.* **2007**, *129*, 15110.
4. Kimmel, K. L.; Weaver, J. D.; Ellman, J. A. *Chem. Sci.* **2012**, *3*, 121.
5. Nielsen, L.; Skrydstrup, T. *J. Am. Chem. Soc.* **2008**, *130*, 13145.
6. Beck, E. M.; Hyde, A. M.; Jacobson, E. N. *Org. Lett.* **2011**, *13*, 4260.
7. For a recent review on Rh-catalyzed asymmetric arylation with boronic acids see: Tian, P.; Dong, H. Q.; Lin, G. Q. *ACS Catal.* **2012**, *2*, 95.
8. Huang, Z.; Lai, H.; Qin, Y. *J. Org. Chem.* **2007**, *72*, 1373.
9. (a) Eidamshaus, C.; Reissig, H. U. *Tetrahedron: Asymmetry* **2011**, *22*, 1644; (b) Chang, T. C.; Chen, C. *J. Chin. Chem. Soc.* **2008**, *55*, 606; (c) Kwong, H. L.; Yeung, H. L.; Yeung, C. T.; Lee, W. S.; Lee, C. S.; Wong, W. L. *Coord. Chem. Rev.* **2007**, *251*, 2188; (d) Bolm, C.; Zehnder, M.; Bur, D. *Angew. Chem., Int. Ed. Engl.* **1990**, *29*, 205; (e) Bolm, C.; Schlingloff, G.; Harms, K. *Chem. Ber.* **1992**, *125*, 1191.
10. (a) Banerjee, S.; Groeper, J. A.; Standard, J. M.; Hitchcock, S. R. *Tetrahedron: Asymmetry* **2009**, *20*, 2154; (b) Chelucci, G.; Baldino, S.; Chessa, S. *Tetrahedron* **2006**, *62*, 619; (c) Baratta, W.; Chelucci, G.; Gladiali, S.; Siega, K.; Toniutti, M.; Zanette, M.; Zangrando, E.; Rigo, P. *Angew. Chem., Int. Ed.* **2005**, *44*, 6214; (d) Chelucci, G.; Conti, S.; Falorni, M.; Giacomelli, G. *Tetrahedron* **1991**, *47*, 8251.
11. (a) Beitat, A.; Foxon, S. P.; Brombach, C. C.; Hausmann, H.; Heinemann, F. W.; Hampel, F.; Monkowius, U.; Hirtenlehner, C.; Knor, G.; Schindler, G. *Dalton Trans.* **2011**, *40*, 5090; (b) Mikata, Y.; Fujimoto, T.; Fujiwara, T.; Kondo, S. *Inorg. Chim. Acta* **2011**, *370*, 420; (c) Sharma, A. K.; Mukherjee, R. *Inorg. Chim. Acta* **2008**, *361*, 2768; (d) Hsua, S. C. N.; Chiena, S. S. C.; Chena, H. H. Z.; Chiang, M. Y. *J. Chin. Chem. Soc.* **2007**, *54*, 685; (e) Osako, T.; Ueno, Y.; Tachi, Y.; Itoh, S. *Inorg. Chem.* **2003**, *42*, 8087.
12. (a) Soai, K.; Niwa, S. *Chem. Rev.* **1992**, *92*, 833; (b) Pu, L.; Yu, H.-B. *Chem. Rev.* **2001**, *101*, 757.
13. Kuduk, S. D.; DiPardo, R. M.; Chang, R. K.; Ng, C.; Bock, M. G. *Tetrahedron Lett.* **2004**, *45*, 6641.
14. Crystal structure was deposited with Cambridge crystallographic data center (CCDC No. 918917). The data can be collected free of charge from CCDC www.ccdc.cam.ac.uk/data_request/cif.
15. Sulfinamide **6** was prepared according to the literature procedure by reduction of the ketimine derived from 2-acetylpyridine Chelucci, G.; Baldino, S.; Chessa, S.; Pinna, G. A.; Soccolini, F. *Tetrahedron: Asymmetry* **2006**, *17*, 3163.