Highly Enantioselective Pd-Catalyzed Asymmetric Hydrogenation of *N*-Diphenylphosphinyl Ketimines

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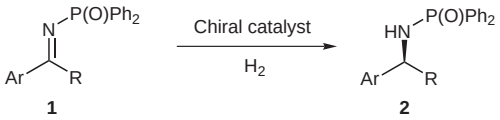
Abstract: A variety of substituted *N*-diphenylphosphinyl imines were hydrogenated using $Pd(CF_3CO_2)_2$/(*S*)-SEGPHOS as a catalyst with high enantioselectivities (86.7%–98.6% ee).

Key words: palladium, asymmetric synthesis, hydrogenation, *N*-diphenylphosphinyl imines

Transition-metal-catalyzed asymmetric synthesis is a powerful and commonly used method for preparing a wide range of enantiomerically pure compounds.[1] Among organo-transition-metal compounds, Pd complexes have become indispensable tools for both common and state-of-the art organic synthesis.[2] Although a large number of Pd-based catalytic systems have been developed for many kinds of reactions, Pd chemistry has still not achieved its full potential. So, the search for improved Pd-catalyzed reactions continues with the goal of increasing the diversity of possible substrates and reaction types.

Asymmetric hydrogenation utilizing molecular hydrogen to reduce prochiral alkenes, ketones, and imines, is one of the most powerful methods in asymmetric catalysis.[1,3] In contrast to the enantioselective hydrogenation of both alkenes and ketones, only limited success has been achieved in the enantioselective hydrogenation of imines.[4] The majority of catalysts for the asymmetric hydrogenation of imines are chiral Ir, Rh, and Ru complexes.[4] There are only a few reports on the asymmetric hydrogenation of imines using Pd complexes, although many successful examples of heterogeneous asymmetric hydrogenation reactions catalyzed by Pd(0) have been well documented in the literature.[5] In 2001, Amii et al. first reported the asymmetric hydrogenation of α-fluorinated iminoesters with a $Pd(CF_3CO_2)_2$/BINAP complex.[6] Alper et al. reported the Pd-catalyzed asymmetric double carbohydroamination of iodobenzene for the synthesis of chiral α-aminoamides with high enantioselectivity. The reaction was suggested to involve a Pd-catalyzed asymmetric hydrogenation of α-iminoamide intermediates; however, no evidence to support this claim was proffered.[7]

Recently, we have developed an enantioselective hydrogenation of α-phthalimide ketones with $Pd(CF_3CO_2)_2$/(*R*,*R*)-Me-DUPHOS system.[8] Herein, we report our results for the homogeneous asymmetric hydrogenation of *N*-diphenylphosphinyl imines **1** using Pd catalysts with up to 98.6% ee. *N*-Diphenylphosphinyl imines **1** can be conveniently prepared from the corresponding oximes.[9] Asymmetric hydrogenation of **1**[10] is one of the simple and efficient ways to synthesize chiral amines **2**,[9a,11,12] which can be readily converted to free amines under mild conditions (Scheme 1).



Scheme 1

On the basis of previous work on the Pd-catalyzed asymmetric hydrogenation of ketones[8] and imines,[6] initial studies on the influence of the reaction conditions were carried out with **1a** as a standard substrate (Table 1). The hydrogenation reaction was conducted in 2,2,2-trifluoroethanol (TFE) at 600 psi of hydrogen using $Pd(OCOCF_3)_2$/(*R*)-SYNPHOS as the catalyst. We were pleased to find an ee of 94.6%, albeit, with 85% conversion (Table 1, entry 1).

We then turned our attention to examine the effect of solvent, reaction temperature, Pd precursor, and hydrogen pressure on reactivity and enantioselectivity (Table 1). A strongly solvent-dependent phenomenon was observed (Table 1, entries 1–7); TFE is the most effective solvent, which was also the case in the Pd-catalyzed asymmetric hydrogenation of imines[6] and functionalized ketones.[8] A change in reaction temperature had no clear effect on conversion (Table 1, entry 1 vs 8), but the ee slightly decreased at a higher temperature (Table 1, entry 8). Other Pd precursors were also tested in the reaction (Table 1, entries 1, 9–11). Neutral $PdCl_2$ gave lower catalytic activity, while Pd precursors with weakly coordinating anions such as $CF_3CO_2^-$ and $CH_3CO_2^-$ provided similar results. Surprisingly, $Pd(OTf)_2$ gave worse results, which is in contrast to the asymmetric hydrogenation of α-phthalimide ketones[8] where the same result was achieved with $Pd(OCOCF_3)_2$. To our delight, an increase in the hydrogen pressure led to full conversion with the same enantioselectivity (Table 1, entry 12).

Next, some commercially available chiral bidentate phosphine ligands (Figure 2) were also tested for the hydrogenation of **1a** under the same conditions (Table 2). Obviously, electron-rich ligands led to full conversions (Table 2, entries 2, 4, 6). High enantioselectivities were

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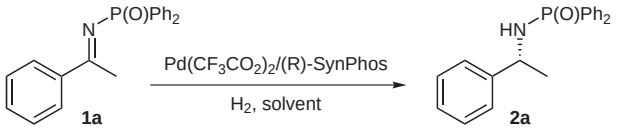
Table 1 Optimization of Reaction Conditions[a]



1a **2a**

Entry	Pd precursor	Solvent	Yield (%)[b]	ee (%)[c]
1	$Pd(CF_3CO_2)_2$	TFE	80 (85)	94.6
2	$Pd(CF_3CO_2)_2$	*i*-PrOH	<5	–
3	$Pd(CF_3CO_2)_2$	EtOH	<5	–
4	$Pd(CF_3CO_2)_2$	MeOH	<5	–
5	$Pd(CF_3CO_2)_2$	THF	<5	–
6	$Pd(CF_3CO_2)_2$	CH_2Cl_2	<5	–
7	$Pd(CF_3CO_2)_2$	toluene	<5	–
8[d]	$Pd(CF_3CO_2)_2$	TFE	79	93.5
9	$Pd(CH_3CO_2)_2$	TFE	82	94.6
10[e]	$Pd(OTf)_2$	TFE	37	91.8
11[e]	$PdCl_2$	TFE	7	–
12[f]	$Pd(CF_3CO_2)_2$	TFE	85 (>95)	94.2

[a] Unless otherwise stated, reactions were performed on a 0.2 mmol scale: Pd precursor (2 mol%), (*R*)-SYNPHOS (2.4 mol%), H_2 (600 psi), 8 h.
[b] Isolated yields; conversions are shown in parentheses.
[c] Determined by chiral HPLC analysis.
[d] The reaction was carried out in an oil bath at 50 °C.
[e] Pure complex (2 mol%) was used and no extra ligand was added.
[f] Higher H_2 pressure applied (1000 psi).

obtained using bisphosphine ligands with biphenyl and binaphthyl motifs (Table 2, entries 1–4), and the best result (96.0% ee) was achieved with (*S*)-SEGPHOS **L-5** (Table 2, entry 4). Lowering the reaction temperature to 0 °C resulted in a decreased conversion (Table 2, entry 5). With electron-rich imine **1b** as the substrate (entry 7), only a moderate conversion was obtained but an excellent

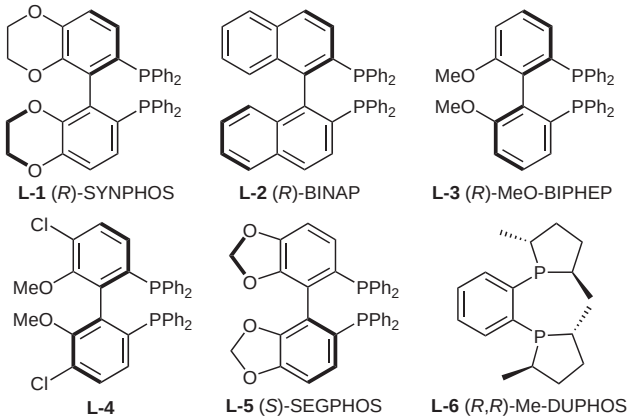
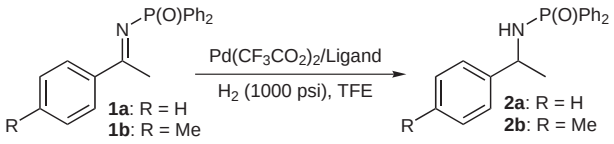


Figure 1

Table 2 Ligand Screening for the Hydrogenation of Imines **1**[a]



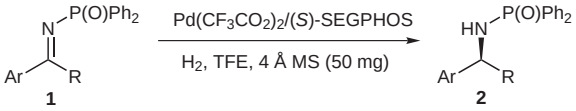
Entry	Substrate	Ligand	Yield (%)[b]	ee (%)[c]	Configuration[d]
1	**1a**	**L-2**	54	95.8	*R*
2	**1a**	**L-3**	96	95.1	*R*
3	**1a**	**L-4**	12	95.9	*R*
4	**1a**	**L-5**	98	96.0	*S*
5[e]	**1a**	**L-5**	33	93.0	*S*
6	**1a**	**L-6**	93	28.0	*R*
7	**1b**	**L-5**	35	95.4	*S*
8[f]	**1b**	**L-5**	93	96.6	*S*

[a] Unless otherwise stated, reactions were performed in TFE on a 0.2 mmol scale: $Pd(CF_3CO_2)_2$ (2 mol%), ligand (2.4 mol%), H_2 (1000 psi), r.t., 8 h.
[b] Isolated yields.
[c] Determined by chiral HPLC analysis.
[d] Determined by comparison of the sign of the optical rotation with literature data.
[e] Reaction temperature: 0 °C.
[f] 4 Å MS (50 mg) was added.

ee of 95.4% resulted. Fortunately, we found that addition of 4 Å molecular sieves gave almost complete conversion with similar ee values (Table 2, entries 7 vs 8).[13] We believe that 4 Å molecular sieves may remove traces of water, which appear to make the substrate and catalyst unstable.

Under optimized conditions [$Pd(OCOCF_3)_2$/(*S*)-SEGPHOS, 4 Å MS, TFE], a variety of substituted *N*-diphenylphosphinyl imines **1b**–**j** were subjected to asymmetric hydrogenation (Table 3).[14,15] Both electron-deficient (Table 3, entries 3 and 4) and electron-rich (Table 3, entries 2, 5–7) aryl imines can be hydrogenated with high enantioselectivities. It is noticeable that the enantioselectivity of the hydrogenation reaction for aryl imines with an electron-donating substituent is better than those with electron-withdrawing substituents (Table 3, entries 2 and 5 vs 3 and 4). For *meta*-methoxy-substituted aryl imines **1f**, a high enantioselectivity was also obtained (Table 3, entry 6). *ortho*-Methoxy-substituted aryl imines **1g** gave the highest ee of 98.6% (Table 3, entry 7). Imine **1j** bearing a furyl group gave moderate conversion with 87% ee (Table 3, entry 10). Imines **1h** and **1i** also gave good asymmetric induction (Table 3, entries 8 and 9), albeit with slightly lower activity due to steric effects. It should be noted that the enantioselectivity was comparable to that obtained with rhodium and iridium complex catalysts.[4,10]

Table 3 Asymmetric Hydrogenation of *N*-Diphenylphosphinyl Imines Catalyzed by a $Pd(OCOCF_3)_2$/(*S*)-SEGPHOS System[a]



Entry	Ar	R	Conversion (%)[b]	ee (%)[c]
1[d]	Ph	Me (**1a**)	>95 (98)	96.0
2	4-MeC_6H_4	Me (**1b**)	>95 (93)	96.6
3	4-FC_6H_4	Me (**1c**)	>95 (87)	94.0
4	4-ClC_6H_4	Me (**1d**)	94 (90)	94.2
5	4-$MeOC_6H_4$	Me (**1e**)	>95 (96)	96.0
6	3-$MeOC_6H_4$	Me (**1f**)	>95 (97)	96.0
7[e]	2-$MeOC_6H_4$	Me (**1g**)	91 (80)	98.6
8[e]	C_6H_5	Et (**1h**)	>95 (93)	86.7
9[e]	2-Naphthyl	Me (**1i**)	77 (70)	92.8
10[e]	2-Furyl	Me (**1j**)	62 (29)	87.0

[a] Reactions were performed in TFE on a 0.2-mmol scale: $Pd(CF_3CO_2)_2$ (2 mol%), ligand (2.4 mol%), H_2 (1000 psi), r.t.
[b] Conversions were determined by ^1H NMR spectroscopy; isolated yields are shown in parenthesis.
[c] Determined by chiral HPLC analysis.
[d] No MS added.
[e] Catalyst (4 mol%).

In conclusion, a highly enantioselective homogeneous hydrogenation of *N*-diphenylphosphinyl imines was developed using a chiral Pd complex in TFE; up to 98.6% ee was obtained, which provided a convenient route to chiral amines. Our ongoing experiments are focused on exploring the palladium catalyzed hydrogenation mechanism and other asymmetric hydrogenation reactions.

Acknowledgment

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(13) A series of additives were tested in the reaction of **1b**: 3 Å MS (conversion: >95%, 96.4% ee), 5 Å MS (conversion: 72%, 96.4% ee), Na_2SO_4 (conversion: 64%, 96.4% ee).

(14) **Asymmetric Hydrogenation; Typical Procedure.** (*S*)-SEGPHOS (2.9 mg, 0.0048 mmol) and $Pd(CF_3CO_2)_2$ (1.3 mg, 0.004 mmol) were placed in a dried Schlenk tube under a nitrogen atmosphere, and degassed anhydrous acetone was added. The mixture was stirred at r.t. for 1 h. The solvent was removed under vacuum to give the catalyst. This catalyst was placed in a nitrogen-filled glove box and dissolved in anhyd TFE (1 mL). To a mixture of **1a** and 4 Å MS, the catalyst solution was added, and then the mixture was transferred to an autoclave. The hydrogenation was performed at r.t. under H_2 (1000 psi) for 8–12 h. The hydrogen was carefully released and the solvents were removed. Conversion was determined by ^1H NMR spectroscopy. The ee was determined by HPLC after purification on silica gel (hexanes–EtOAc–Et_3N, 1:2:0.02). The absolute configuration of **2a** was determined by measurement of its optical rotation. *N*-Diphenylphosphinyl imines **1** were prepared according to the literature.[9] Racemates of *N*-(diphenylphosphinyl)amines were prepared

by reduction of the corresponding imines using $NaBH_4$ in THF. For the preparation of complexes and other experimental details, see reference 8.

(15) Compound **1c**: white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 2.95 (d, *J* = 1.8 Hz, 3 H), 7.12–7.17 (m, 2 H), 7.43–7.45 (m, 6 H), 7.94–7.99 (m, 4 H), 8.09–8.12 (m, 2 H). ^{13}C NMR (100 MHz, $CDCl_3$): δ = 23.1 (d, *J* = 12.3 Hz), 115.8 (d, *J* = 21.7 Hz), 128.6 (d, *J* = 12.3 Hz), 130.6 (d, *J* = 8.9 Hz), 131.7, 131.8, 134.8 (d, *J* = 130.2 Hz), 135.9 (d, *J* = 25.8 Hz), 165.7 (d, *J* = 252.7 Hz), 180.2 (d, *J* = 7.0 Hz). ^{31}P NMR (162 MHz, $CDCl_3$): δ = 19.1. HRMS (ESI): *m*/*z* calcd for $C_{20}H_{18}FNOP$ [M + H$^+$]: 338.1105; found: 338.1082.
Compound **1f**: white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 2.95 (d, *J* = 2.1 Hz, 3 H), 3.88 (s, 3 H), 7.10 (m, 1 H), 7.39–7.46 (m, 7 H), 7.64 (d, *J* = 2.4 Hz, 2 H), 7.95–8.00 (m, 4 H). ^{13}C NMR (100 MHz, $CDCl_3$): δ = 23.3 (d, *J* = 12.4 Hz), 55.6, 113.6, 117.9, 120.7, 128.6 (d, *J* = 12.4 Hz), 129.7, 131.6, 131.7 (d, *J* = 9.0 Hz), 134.8 (d, *J* = 130.3 Hz), 141.0 (d, *J* = 23.9 Hz), 159.8, 181.5 (d, *J* = 7.5 Hz). ^{31}P NMR (162 MHz, $CDCl_3$): δ = 19.3. HRMS (ESI): *m*/*z* calcd for $C_{21}H_{21}NO_2P$ [M + H$^+$]: 350.1304; found: 350.1297.
Compound **1g**: white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 2.89 (d, *J* = 2.0 Hz, 3 H), 3.82 (d, *J* = 2.4 Hz, 3 H), 6.93 (d, *J* = 8.3 Hz, 1 H), 7.00 (s, 1 H), 7.40–7.45 (m, 7 H), 7.63 (dd, *J* = 1.7, 7.6 Hz, 1 H), 7.93–7.99 (m, 4 H). ^{13}C NMR (100 MHz, $CDCl_3$): δ = 28.3 (d, *J* = 13.6 Hz), 55.5, 111.6, 120.6, 128.4 (d, *J* = 12.3 Hz), 129.9, 131.4, 131.8 (d, *J* = 8.9 Hz), 132.3, 134.9 (d, *J* = 129.2 Hz), 158.0, 186.0 (d, *J* = 7.6 Hz). ^{31}P NMR (162 MHz, $CDCl_3$): δ = 18.5. HRMS (ESI): *m*/*z* calcd for $C_{21}H_{21}NO_2P$ [M + H$^+$]: 350.1304; found: 350.1288.
Compound **2a**: white solid; 95.3% ee (*R*); $[\alpha]_D^{26}$ +38.3 (*c* 0.54, EtOH); R_f 0.14 (PE–EtOAc, 2:1); HPLC (Chiralpak AS-H column, hexane–*i*-PrOH, 20:80, 1.0 mL/min, 254 nm): t_R 12.9 min (*R*), t_R 24.4 min (*S*). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.58 (d, *J* = 6.7 Hz, 3 H), 3.17 (dd, *J* = 5.9, 9.1 Hz, 1 H), 4.36–4.43 (m, 1 H), 7.26–7.45 (m, 11 H), 7.80–7.85 (m, 2 H), 7.89–7.93 (m, 2 H).
Compound **2b**: white solid; 96.6% ee (*S*); $[\alpha]_D^8$ –66.5 (*c* 1.08, MeOH); R_f 0.22 (PE–EtOAc, 2:1); HPLC (Chiralpak AS-H column, hexane–*i*-PrOH, 80–20, 1.0 mL/min, 254 nm): t_R 11.4 min (*R*), t_R 15.8 min (*S*). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.56 (d, *J* = 6.8 Hz, 3 H), 2.34 (s, 3 H), 3.14–3.17 (m, 1 H), 4.32–4.39 (m, 1 H), 7.15 (dd, *J* = 8.0, 20.4 Hz, 4 H), 7.37–7.48 (m, 6 H), 7.81–7.91 (m, 4 H).
Compound **2c**: white solid; 94.0% ee (*S*); $[\alpha]_D^8$ –41.9 (*c* 1.04, MeOH); R_f 0.18 (PE–EtOAc, 2:1); HPLC (Chiralpak AS-H column, hexane–*i*-PrOH, 80:20, 1.0 mL/min, 254 nm): t_R 10.0 min (*R*), t_R 27.0 min (*S*). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.55 (d, *J* = 6.8 Hz, 3 H), 3.11 (dd, *J* = 5.9, 9.2 Hz, 1 H), 4.35–4.42 (m, 1 H), 6.98 (t, *J* = 8.7 Hz, 2 H), 7.23–7.25 (m, 2 H), 7.36–7.37 (m, 2 H), 7.44–7.46 (m, 4 H), 7.78–7.81 (m, 2 H), 7.88–7.92 (m, 2 H).
Compound **2d**: white solid; 94.2% ee (*S*); $[\alpha]_D^8$ –73.4 (*c* 1.14, MeOH); R_f 0.33 (PE–EtOAc, 1:1); HPLC (Chiralpak AS-H column, hexane–*i*-PrOH, 80:20, 1.0 mL/min, 254 nm): t_R 11.4 min (*R*), t_R 26.3 min (*S*). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.55 (d, *J* = 6.8 Hz, 3 H), 3.17 (dd, *J* = 5.7, 9.5 Hz, 1 H), 4.33–4.40 (m, 1 H), 7.24 (dd, *J* = 8.5, 23.0 Hz, 4 H), 7.37–7.47 (m, 6 H), 7.79 (dd, *J* = 7.0, 12.0, 2 H), 7.90 (dd, *J* = 6.9, 11.9 Hz, 2 H).
Compound **2e**: white solid; 96.0% ee (*S*); $[\alpha]_D^8$ –66.4 (*c* 1.30, MeOH); HPLC (Chiralpak AS-H column, hexane–*i*-PrOH, 80:20, 1.0 mL/min, 254 nm): t_R 15.9 min (*R*), t_R 26.8 min (*S*). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.55 (d, *J* = 6.7 Hz, 3 H), 3.12 (dd, *J* = 5.9, 9.4 Hz, 1 H), 3.80 (s, 3 H), 4.31–4.41 (m, 1 H), 6.85 (d, *J* = 8.7 Hz, 2 H), 7.21 (d, *J* = 8.7 Hz, 2 H), 7.37–7.48 (m, 6 H), 7.81–7.91 (m, 4 H).
Compound **2f**: white solid; 96.0% ee (*S*); $[\alpha]_D^8$ –52.1 (*c* 1.32, MeOH); R_f 0.38 (PE–EtOAc, 1:1); HPLC (Chiralpak AS-H column, hexane–*i*-PrOH, 80:20, 1.0 mL/min, 254 nm): t_R 14.5 min (*R*), t_R 29.4 min (*S*). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.57 (d, *J* = 6.8 Hz, 3 H), 3.22 (dd, *J* = 5.9, 9.5 Hz, 1 H), 3.78 (s, 3 H), 4.31–4.39 (m, 1 H), 6.82–6.88 (m, 3 H), 7.21–7.23 (m, 1 H), 7.36–7.47 (m, 6 H), 7.80–7.93 (m, 4 H).
Compound **2g**: white solid; 98.6% ee (*S*); $[\alpha]_D^8$ –22.1 (*c* 1.13, MeOH); R_f 0.33 (PE–EtOAc, 1:1). HPLC (Chiralpak AS-H column, hexane–*i*-PrOH, 80:20, 1.0 mL/min, 254 nm): t_R 11.9 min (*R*), t_R 21.3 min (*S*). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.50 (d, *J* = 6.8 Hz, 3 H), 3.69 (s, 3 H), 3.87 (dd, *J* = 8.0, 10.5 Hz, 1 H), 4.36–4.43 (m, 1 H), 6.78–6.82 (m, 2 H), 6.97 (s, 1 H), 7.19 (t, *J* = 7.7 Hz, 1 H), 7.33–7.38 (m, 6 H), 7.72 (dd, *J* = 7.3, 11.9 Hz, 2 H), 7.79 (dd, *J* = 7.1, 11.8 Hz, 2 H). ^{13}C NMR (100 MHz, $CDCl_3$): δ = 25.1, 49.6, 55.4, 111.2, 121.0, 128.3 (d, *J* = 7.0 Hz), 128.5, 131.7, 131.8, 128.1 (d, *J* = 108.6 Hz), 131.7, 131.8, 132.0 (d, *J* = 9.3 Hz), 132.8 (d, *J* = 9.4 Hz), 133.0, 133.1, 133.8 (d, *J* = 119.7 Hz), 157.0. ^{31}P NMR (162 MHz, $CDCl_3$): δ = 22.9. HRMS (ESI): *m*/*z* calcd for $C_{21}H_{23}NO_2P$ [M + H$^+$], 352.1461; found, 352.1451.
Compound **2h**: white solid; 86.7% ee (*S*); $[\alpha]_D^8$ –38.5 (*c* 1.26, MeOH); R_f 0.31 (PE–EtOAc, 1:1); HPLC (Chiralpak AS-H column, hexane–*i*-PrOH, 80:20, 1.0 mL/min, 254 nm): t_R 9.6 min (*R*), t_R 17.7 min (*S*). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 0.79 (t, *J* = 7.4 Hz, 3 H), 1.80–1.89 (m, 1 H), 1.97–2.04 (m, 1 H), 3.25 (dd, *J* = 6.4, 9.4 Hz, 1 H), 4.08–4.11 (m, 1 H), 7.14–7.16 (m, 2 H), 7.23–7.33 (m, 5 H), 7.42–7.44 (m, 4 H), 7.73–7.87 (m, 4 H).
Compound **2i**: white solid; 92.8% ee (*S*); $[\alpha]_D^8$ –77.8 (*c* 1.02, MeOH); R_f 0.39 (PE–EtOAc, 1:1); HPLC (Chiralpak AS-H column, hexane–*i*-PrOH, 80:20, 1.0 mL/min, 254 nm): t_R 21.6 min (*R*), t_R 27.7 min (*S*). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.66 (d, *J* = 6.7 Hz, 3 H), 3.27–3.31 (m, 1 H), 4.51–4.61 (m, 1 H), 7.32–7.33 (m, 2 H), 7.43–7.48 (m, 7 H), 7.65 (s, 1 H), 7.80–7.83 (m, 5 H), 7.93 (m, 2 H).
Compound **2j**: white solid, 87.0% ee (*S*), $[\alpha]_D^8$ –42.1 (*c* 0.60, CH_2Cl_2); R_f 0.34 (PE–CH_2Cl_2,1:4); HPLC (Chiralpak AS-H column, hexane–*i*-PrOH, 80:20, 1.0 mL/min, 254 nm): t_R 12.1 min (*R*), t_R 17.0 min (*S*). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.60 (d, *J* = 6.8 Hz, 3 H), 3.19 (dd, *J* = 6.6, 10.3 Hz, 1 H), 4.38–4.44 (m, 1 H), 6.13 (d, *J* = 3.2 Hz, 1 H), 6.28 (dd, *J* = 1.9, 3.2 Hz, 1 H), 7.35 (m, 1 H), 7.42–7.49 (m, 6 H), 7.87–7.95 (m, 4 H).