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Palladium-catalyzed asymmetric allylic amination of racemic butadiene monoxide with isatin derivatives†

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Isatins and their derivatives are important functional moities and building blocks in pharmaceutical and synthetic chemistry. Numerous enantioselective transformations at the C-3 carbonyl group have been well developed. However, the asymmetric substitution reaction with isatins and their derivatives as nucleophiles based on the free N–H groups has been less studied due to the relatively weaker nucleophilicity resulting from the two electron-withdrawing carbonyl groups. In this paper, a palladium-catalyzed asymmetric allylic amination of racemic butadiene monoxide with isatin derivatives using a chiral phosphoramidite olefin hybrid ligand has been successfully developed under mild conditions. A variety of chiral amino alcohols were afforded in 55–87% yields with 10/1->20/1 regioselectivity ratios and 80–97% ees.

Introduction

Isatins and their derivatives are important functional moieties widely present in natural products and biologically active compounds, which have attracted intensive attention in both synthetic and pharmaceutical chemistry.[1] Meanwhile, they are also important building blocks, which can be transformed to numerous useful optically active compounds. Undoubtedly, the most fascinating transformation occurred enantioselectively at the highly reactive C-3 carbonyl group.[2] The asymmetric substitution reaction with isatins and their derivatives as nucleophiles based on the free N–H groups also seems to be an efficient approach for the synthesis of optically active compounds. However, due to the relatively weak nucleophilicity that resulted from the two electron-withdrawing carbonyl groups, such an enantioselective reaction has seldom been reported. The majority of transformations based on the N–H groups are the introduction of protecting groups on the nitrogen atom.

Palladium-catalyzed asymmetric allylic amination has been one of the most useful methods for the synthesis of optically active amines.[3] Racemic vinyl epoxides were an important class of substrates for the Pd-catalyzed asymmetric substitutions with diverse nucleophiles.[4] Aliphatic amines,[5] phthalamides,[6] oxazolidinones,[7] and succinimides[8] were the most often used amine nucleophiles. Recently, Mangion and co-workers reported a Pd-catalyzed dynamic asymmetric allylic amination of vinyl epoxide with hydrazines and hydroxylamines as nucleophiles.[9] In 2011, Trost and co-workers reported an interesting asymmetric amination of divinyl carbonates with isatins for the synthesis of chiral diene ligands.[10a] Recently, Shi and co-workers developed an efficient enantioselective allylic amination of Morita–Baylis–Hillman carbonates and aromatic aldehydes with isatins in the presence of cinchona alkaloids.[10b] These reports represent the few asymmetric transformations with isatins as nucleophiles.

The field of chiral olefin ligands has witnessed an extremely rapid growth in recent years.[11,12] As a novel class of ligands, phosphine–alkene hybrid ligands have also been developed and successfully applied in a wide range of asymmetric reactions. Notably, these ligands exhibited obvious advantages over other ligand types in some cases.[13] As part of our general interest in exploring novel chiral olefin ligands, we have developed a variety of chiral P/terminal-olefin ligands, which were highly effective for Pd-catalyzed asymmetric allylic alkylations.[14] Herein, we report our efforts on the Pd-catalyzed asymmetric amination of butadiene monoxide with isatins and their derivatives as nucleophiles using a chiral phosphoramidite olefin hybrid ligand.

Results and discussion

The Pd-catalyzed asymmetric allylic amination of isatin derivative **1a** and racemic butadiene monoxide **2** (2.0 equiv.) at room

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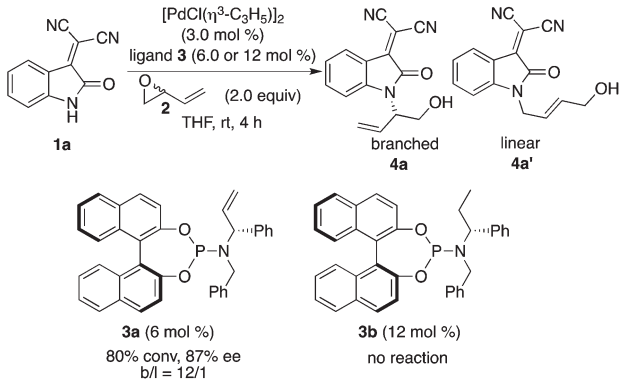


Scheme 1 Asymmetric allylic amination of isatin derivatives.

Table 1 Optimization of reaction conditions[a]

Entry	Solvent	Pd complex	Conv.[b](%)	ee[c](%)	*b*/*l*[d]
1	THF	$[PdCl(\eta^3\text{-}C_3H_5)]_2$	80	87	12/1
2	Dioxane	$[PdCl(\eta^3\text{-}C_3H_5)]_2$	84	84	4/1
3	Toluene	$[PdCl(\eta^3\text{-}C_3H_5)]_2$	15	69	6/1
4	EtOAc	$[PdCl(\eta^3\text{-}C_3H_5)]_2$	86	82	3/1
5	Et_2O	$[PdCl(\eta^3\text{-}C_3H_5)]_2$	45	82	5/1
6	CH_3CN	$[PdCl(\eta^3\text{-}C_3H_5)]_2$	Trace	—	—
7[e]	THF	$[PdCl(\eta^3\text{-}C_3H_5)]_2$	60	92	11/1
8[e]	THF	$Pd_2(dba)_3{\cdot}CHCl_3$	95	92	12/1

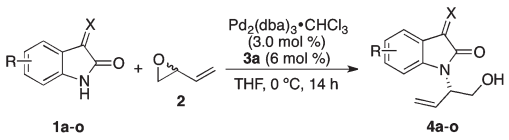
[a] Reactions with **1a** (0.2 mmol), **2** (0.4 mmol), Pd (0.012 mmol), ligand **3a** (0.012 mmol) and solvent (1.0 mL) at room temperate for 14 h unless otherwise noted. [b] Determined by crude ^{1}H NMR. [c] Determined by chiral HPLC. [d] Determined by crude ^{1}H NMR. [e] The reaction was performed at 0 °C for 14 h.

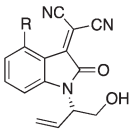
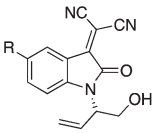
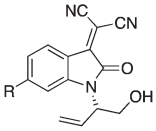
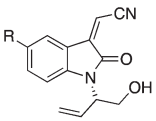
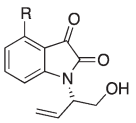
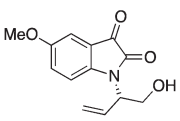
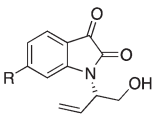
temperature was initially examined using 6 mol% of chiral phosphoramidite olefin ligand **3a** and 3 mol% of $[PdCl(\eta^3\text{-}C_3H_5)]_2$. We were pleased to find that this reaction went smoothly to furnish the branched substituted chiral amino alcohol **2a** as a major product in 80% conversion with 87% ee and 12/1 regioselectivity ratio (Scheme 1). When ligand **3b** was used, no desired product was observed, which indicates the importance of the terminal olefin moiety in ligand **3a** for the observed high activity and selectivity.

The reaction conditions were next optimized to further improve the reactivity and enantioselectivity. Solvents were found to have a large influence on this reaction, and THF proved to be the optimal solvent to give better conversion, ees, and regioselectivity ratios (Table 1, entries 1–6). Lowering the temperature to 0 °C gave 92% ee with 60% conversion (Table 1, entry 7). When $Pd_2(dba)_3{\cdot}CHCl_3$ was used as the catalyst precursor, the desired product **4a** was obtained in 95% conversion with 93% ee and a 12/1 regioselectivity ratio (Table 1, entry 8).

Various isatin derivatives **1a–i** were subsequently subjected to the Pd-catalyzed asymmetric amination of racemic butadiene monoxide **2** under the optimal reaction conditions. It was found that all these reactions proceeded well to give chiral amino alcohols **4a–i** in 55–87% yields with 90–97% ees and 10/1->20/1 *b*/*l* ratios (Table 2, entries 1–9). In comparison

Table 2 Asymmetric allylic aminations of butadiene monoxide with isatin derivatives[a]



Entry	Product (**4**)	Yield[b] (%)	ee[c] (%)	*b*/*l*[d]
				
1	**4a**: R = H	84	92	12/1
2	**4b**: R = Cl	61	91	11/1
				
3	**4c**: R = OMe	81	90	14/1
4	**4d**: R = Me	87	91	13/1
5	**4e**: R = Cl	55	92	10/1
				
6	**4f**: R = Cl	59	91	10/1
7	**4g**: R = Me	62	91	12/1
				
8	**4h**: R = H	67	94	>20/1
9	**4i**: R = Me	75	97	>20/1
				
10	**4j**: R = H	68	93	>20/1
11	**4k**: R = Me	65	89	>20/1
12	**4l**: R = Cl	69	90	>20/1
				
13	**4m**	65	80	>20/1
				
14	**4n**: R = Me	71	87	>20/1
15	**4o**: R = Cl	76	93	>20/1

[a] Reactions with **1a** (0.4 mmol), **2** (0.8 mmol), $Pd_2(dba)_3{\cdot}CHCl_3$ (0.012 mmol), **3a** (0.024 mmol) in THF (2.0 mL). [b] Isolated yield for the branched product. [c] Determined by chiral HPLC. [d] Determined by crude ^{1}H NMR.

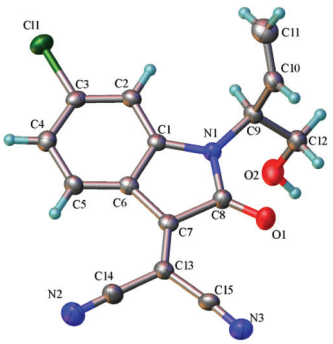


Fig. 1 X-ray structure of compound **4f**.

with the substrates **1a–g** containing two cyano groups, the substrates **1h–i** bearing only one cyano group gave better ees and regioselectivity ratios (Table 2, entries 1–7 *vs.* 8–9). Isatins **1j–o** were also suitable substrates for this reaction to afford the desired chiral amino alcohols **4j–o** as the predominant products in 65–76% yields with 80–93% ees (Table 2, entries 10–15). The absolute configuration of product **4** was tentatively assigned as *R* by analogy with compound (*R*)-**4f**, which was determined by its X-ray structure (Fig. 1).

Experimental section

General experimental procedure for the Pd-catalyzed asymmetric allylic amination of racemic butadiene monoxide with isatins (Table 2, entry 1)

To a Schlenk tube was added $Pd_2(dba)_3{\cdot}CHCl_3$ (0.0062 g, 0.012 mmol), ligand **3a** (0.013 g, 0.024 mmol) and dry THF (0.5 mL) under an argon atmosphere. The resulting mixture was stirred for 15 min at room temperature followed by the addition of 2-(2-oxoindolin-3-ylidene)malononitrile **1a** (0.078 g, 0.4 mmol) then racemic butadiene monoxide **2** (0.056 g, 0.8 mmol) in THF (0.5 mL) was added to the reaction mixture slowly. The reaction mixture was stirred at 0 °C for 14 h, and the solvent was removed under reduced pressure. The crude residue was purified by flash chromatography on silica gel using PE/EtOAc (2/1) as the eluent to give the desired **4a** as a red solid (0.089 g, 84% yield, 92% ee).

2-(1-(1-Hydroxybut-3-en-2-yl)-2-oxoindolin-3-ylidene)malononitrile (4a). Red solid; mp. 148–150 °C; $[\alpha]_D^{20}$ = −36.0 (*c* 0.2, $CHCl_3$) (92% ee); IR (film) 3420, 2230, 1723, 1611, 1595 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.15 (d, *J* = 8.0 Hz, 1H), 7.54 (dd, *J* = 8.0, 8.0 Hz, 1H), 7.15 (dd, *J* = 8.0, 8.0 Hz, 1H), 6.96 (d, *J* = 8.0 Hz, 1H), 6.02 (ddd, *J* = 17.6, 12.0, 8.0 Hz, 1H), 5.39 (d, *J* = 12.0 Hz, 1H), 5.31 (d, *J* = 17.6 Hz, 1H), 4.81 (m, 1H), 4.28–4.17 (m, 1H), 4.07–4.04 (m, 1H), 2.21–2.17 (brs, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 163.4, 149.5, 146.2, 137.8, 130.7, 127.1, 124.1, 119.9, 118.7, 112.5, 111.9, 110.9, 82.8, 61.7, 58.0; HRMS (ESI): Calcd for $C_{15}H_{11}O_2N_3Na$ (M + Na): 288.0744; found: 288.0740.

2-(4-Chloro-1-(1-hydroxybut-3-en-2-yl)-2-oxoindolin-3-ylidene)-malononitrile (4b). Yellow solid; mp. 164–166 °C; $[\alpha]_D^{20}$ = −32.0 (*c* 0.2, CH_2Cl_2) (91% ee); IR (film) 3531, 2222, 1725, 1601 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.44 (dd, *J* = 8.0, 8.0 Hz, 1H), 7.10 (d, *J* = 8.0 Hz, 1H), 6.88 (d, *J* = 8.0 Hz, 1H), 6.01 (ddd, *J* = 17.6, 11.0, 4.8 Hz, 1H), 5.40 (d, *J* = 11.0 Hz, 1H), 5.31 (d, *J* = 17.6 Hz, 1H), 4.87–4.85 (m, 1H), 4.06–4.04 (m, 1H), 4.03–4.01 (m, 1H), 2.26 (brs, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 163.6, 147.6, 146.6, 137.6, 135.5, 130.5, 126.0, 120.2, 117.3, 113.3, 112.4, 109.9, 86.0, 61.6, 58.4; HRMS (ESI): Calcd for $C_{15}H_{10}N_3O_2ClNa$ (M + Na): 322.0354; found: 322.0356.

2-(1-(1-Hydroxybut-3-en-2-yl)-5-methoxy-2-oxoindolin-3-ylidene)-malononitrile (4c). Purple solid; mp. 157–159 °C; $[\alpha]_D^{20}$ = −48.0 (*c* 0.2, CH_2Cl_2) (90% ee); IR (film) 3504, 2237, 1714 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.67 (s, 1H), 7.08 (d, *J* = 8.8 Hz, 1H), 6.86 (d, *J* = 8.8 Hz, 1H), 5.97 (ddd, *J* = 17.6, 10.8, 4.8 Hz, 1H), 5.37 (d, *J* = 10.8 Hz, 1H), 5.30 (d, *J* = 17.6 Hz, 1H), 4.76 (m, 1H), 4.20–4.18 (m, 1H), 4.07–4.00 (m, 1H), 3.82 (s, 3H), 2.31–2.27 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 165.2, 156.5, 149.8, 140.4, 130.9, 124.6, 119.9, 119.2, 112.7, 112.6, 111.1, 110.9, 82.9, 62.0, 58.2, 56.2; HRMS (ESI): Calcd for $C_{16}H_{13}N_3O_3Na$ (M + Na): 318.0849; found: 318.0846.

2-(1-(1-Hydroxybut-3-en-2-yl)-5-methyl-2-oxoindolin-3-ylidene)-malononitrile (4d). Brown solid; mp. 165–167 °C; $[\alpha]_D^{20}$ = −31.0 (*c* 0.2, CH_2Cl_2) (91% ee); IR (film) 3565, 2230, 1713 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.92 (s, 1H), 7.33 (d, *J* = 8.4 Hz, 1H), 6.85 (d, *J* = 8.4 Hz, 1H), 5.99 (ddd, *J* = 17.6, 10.8, 5.6 Hz, 1H), 5.37 (d, *J* = 10.8 Hz, 1H), 5.30 (d, *J* = 17.6 Hz, 1H), 4.81–4.79 (m, 1H), 4.20–4.16 (m, 1H), 4.05–4.01 (m, 1H), 2.49 (brs, 1H), 2.35 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 163.5, 149.6, 144.2, 138.5, 134.0, 130.8, 127.3, 119.8, 118.8, 112.6, 111.7, 111.0, 82.3, 61.8, 58.0, 21.1; HRMS (ESI): Calcd for $C_{16}H_{13}O_2N_3Na$ (M + Na): 302.0900; found: 302.0896.

2-(5-Chloro-1-(1-hydroxybut-3-en-2-yl)-2-oxoindolin-3-ylidene)-malononitrile (4e). Purple solid; mp. 169–172 °C; $[\alpha]_D^{20}$ = −45.0 (*c* 0.2, CH_2Cl_2) (92% ee); IR (film) 3406, 1731, 1614 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.11 (s, 1H), 7.48 (d, *J* = 8.2 Hz, 1H), 6.94 (d, *J* = 8.2 Hz, 1H), 5.99 (ddd, *J* = 16.0, 12.0, 4.0 Hz, 1H), 5.40 (d, *J* = 12.0 Hz, 1H), 5.31 (d, *J* = 16.0 Hz, 1H), 4.86–4.84 (m, 1H), 4.06–4.05 (m, 1H), 4.03–4.01 (m, 1H), 2.14 (brs, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 163.0, 148.3, 144.7, 137.2, 130.5, 129.8, 126.6, 120.2, 119.7, 113.1, 112.1, 110.6, 84.4, 61.7, 58.1; HRMS (ESI): Calcd for $C_{15}H_{10}N_3O_2ClNa$ (M + Na): 322.0354; found: 322.0350.

2-(6-Chloro-1-(1-hydroxybut-3-en-2-yl)-2-oxoindolin-3-ylidene)-malononitrile (4f). Red solid; mp. 152–154 °C; $[\alpha]_D^{20}$ = −52.0 (*c* 0.2, CH_2Cl_2) (91% ee); IR (film) 3555, 2228, 1715, 1607, 1594 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.07 (d, 1H, *J* = 8.2 Hz, 1H), 7.12 (d, *J* = 8.2 Hz, 1H), 7.0 (s, 1H), 6.0 (ddd, *J* = 17.6, 10.4, 5.6 Hz, 1H), 5.42 (d, *J* = 10.4 Hz, 1H), 5.33 (d, *J* = 17.6 Hz, 1H), 4.84–4.82 (m, 1H), 4.21–4.20 (m, 1H), 4.05–4.02 (m, 1H), 2.14–2.12 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 163.2, 147.8, 144.1, 130.2, 127.6, 124.1, 120.2, 116.9, 112.56, 112.2, 110.6, 82.8, 61.6, 57.9; HRMS (ESI): Calcd for $C_{15}H_{10}O_2N_3ClNa$ (M + Na): 322.0354; found: 322.0354.

2-(1-(1-Hydroxybut-3-en-2-yl)-6-methyl-2-oxoindolin-3-ylidene)-malononitrile (4g). Purple solid; mp. 154–157 °C; $[\alpha]_D^{20}$ = −38.0 (*c* 0.2, CH_2Cl_2) (91% ee); IR (film) 3524, 2226, 1716, 1616, 1592 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.02 (d, *J* = 8.0 Hz, 1H), 6.94 (d, *J* = 8.2 Hz, 1H), 6.75 (s, 1H), 6.03 (ddd, *J* = 16.8, 10.8, 6.0 Hz, 1H), 5.40 (d, *J* = 10.0 Hz, 1H), 5.31 (d, *J* = 16.8 Hz, 1H), 4.80–4.75 (m, 1H), 4.26–4.19 (m, 1H), 4.07–4.01 (m, 1H), 2.44 (s, 3H), 2.27–2.22 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 164.5, 150.4, 149.1, 146.7, 130.9, 127.4, 125.0, 119.8, 116.4, 112.8, 112.3, 111.1, 81.2, 61.9, 58.2, 23.4; HRMS (ESI): Calcd for $C_{16}H_{13}N_3O_2ClNa$ (M + Na): 302.0900; found: 302.0903.

(*Z*)-2-(1-(1-Hydroxybut-3-en-2-yl)-2-oxoindolin-3-ylidene)-acetonitrile (4h). Yellow solid; mp. 122–125 °C; $[\alpha]_D^{20}$ = −26.0 (*c* 0.2, CH_2Cl_2) (94% ee); IR (film) 3446, 2216, 1716, 1606 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 8.09 (d, *J* = 7.6 Hz, 1H), 7.41 (dd, *J* = 8.0, 7.2 Hz, 1H), 7.13 (dd, *J* = 8.0, 7.2 Hz, 1H), 6.91 (d, *J* = 8.0 Hz, 1H), 6.31 (s, 1H), 6.0 (ddd, *J* = 17.2, 10.8, 5.6 Hz, 1H), 5.33 (d, *J* = 10.8 Hz, 1H), 5.26 (d, *J* = 17.2 Hz, 1H), 4.82–4.78 (m, 1H), 4.20–4.13 (m, 1H), 4.07–4.01 (m, 1H), 2.88–2.84 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.3, 144.7, 143.4, 133.8, 131.3, 125.3, 123.6, 119.7, 119.2, 116.2, 111.0, 98.1, 62.2, 58.0; HRMS (ESI): Calcd for $C_{14}H_{12}O_2N_2Na$ (M + Na): 263.0791; found: 263.0794.

(*Z*)-2-(1-(1-Hydroxybut-3-en-2-yl)-5-methyl-2-oxoindolin-3-ylidene)-acetonitrile (4i). Red solid; mp. 116–119 °C; $[\alpha]_D^{20}$ = −14.0 (*c* 0.2, CH_2Cl_2) (97% ee); IR (film) 3446, 2216, 1716, 1615 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.90 (s, 1H), 7.20 (d, *J* = 8.0 Hz, 1H), 6.79 (d, *J* = 8.0 Hz, 1H), 6.31 (s, 1H), 6.0 (ddd, *J* = 16.8, 10.4, 6.0 Hz, 1H), 5.33 (d, *J* = 10.4 Hz, 1H), 5.25 (d, *J* = 17.6 Hz, 1H), 4.75–4.74 (m, 1H), 4.18–4.13 (m, 1H), 4.07–4.02 (m, 1H), 2.77–2.76 (m, 1H), 2.36 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.3, 143.7, 142.6, 134.3, 133.4, 131.5, 125.8, 119.8, 119.1, 116.3, 110.7, 97.7, 62.4, 58.2, 21.1; HRMS (ESI): Calcd for $C_{15}H_{14}O_2N_2Na$ (M + Na): 277.0948; found: 277.0951.

1-(1-Hydroxybut-3-en-2-yl)indoline-2,3-dione (4j). Yellow solid; mp. 147–149 °C; $[\alpha]_D^{20}$ = +30.0 (*c* 0.2, CH_2Cl_2) (93% ee); IR (film) 3447, 2216, 1716, 1617 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.63 (d, *J* = 8.0 Hz, 1H), 7.57 (dd, *J* = 7.6, 7.6 Hz, 1H), 7.0 (dd, *J* = 7.6, 7.6 Hz, 1H), 7.0 (d, *J* = 8.0 Hz, 1H), 6.04 (ddd, *J* = 16.4, 10.6, 6.0 Hz, 1H), 5.38 (d, *J* = 10.6 Hz, 1H), 5.34 (d, *J* = 17.2 Hz, 1H), 4.81–4.77 (m, 1H), 4.20–4.20 (m, 1H), 4.09–4.05 (m, 1H), 2.76 (brs, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 183.1, 158.9, 150.9, 138.4, 131.1, 125.7, 124.1, 119.6, 118.1, 112.2, 62.1, 60.6, 58.2; HRMS (ESI): Calcd for $C_{12}H_{11}O_3NNa$ (M + Na): 240.0631; found: 240.0634.

1-(1-Hydroxybut-3-en-2-yl)-4-methylindoline-2,3-dione (4k). Red solid; mp. 130–132 °C; $[\alpha]_D^{20}$ = +48.0 (*c* 0.2, CH_2Cl_2) (89% ee); IR (film) 3443, 1732, 1641, 1601 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.40 (dd, *J* = 8.0, 8.0 Hz, 1H), 6.89 (d, *J* = 8.0 Hz, 1H), 6.80 (d, *J* = 8.0 Hz, 1H), 6.02 (ddd, *J* = 16.4, 10.4, 5.6 Hz, 1H), 5.35 (d, *J* = 10.4 Hz, 1H), 5.30 (d, *J* = 16.4 Hz, 1H), 4.78–4.74 (m, 1H), 4.22–4.17 (m, 1H), 4.06–4.02 (m, 1H), 3.05 (brs, 1H), 2.56 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 183.5, 158.9, 150.9, 141.7, 137.5, 131.3, 126.4, 119.3, 116.3, 109.3, 62.0, 58.3, 18.4; HRMS (ESI): Calcd for $C_{13}H_{13}O_3NNa$ (M + Na): 254.0788; found: 254.0787.

4-Chloro-1-(1-hydroxybut-3-en-2-yl)indoline-2,3-dione (4l). Red solid; mp. 118–120 °C; $[\alpha]_D^{20}$ = +55.0 (*c* 0.2, CH_2Cl_2) (90% ee); IR (film) 3462, 1739, 1600 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.45 (dd, *J* = 8.0, 8.0 Hz, 1H), 7.06 (d, *J* = 8.0 Hz, 1H), 6.93 (d, *J* = 8.0 Hz, 1H), 6.01 (ddd, *J* = 17.6, 10.8, 6.4 Hz, 1H), 5.37 (d, *J* = 10.4 Hz, 1H), 5.32 (d, *J* = 16.8 Hz, 1H), 4.83–4.79 (m, 1H), 4.22–4.20 (m, 1H), 4.06–4.02 (m, 1H), 2.92–2.90 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 180.0, 158.1, 152.0, 138.5, 134.2, 130.9, 125.8, 119.8, 115.2, 110.5, 61.8, 58.4. HRMS (ESI): Calcd for $C_{12}H_{10}NO_3Na$ (M + Na): 274.0241; found: 274.0242.

1-(1-Hydroxybut-3-en-2-yl)-5-methoxyindoline-2,3-dione (4m). Red solid; mp. 122–125 °C; $[\alpha]_D^{20}$ = +54.0 (*c* 0.2, CH_2Cl_2) (80% ee); IR (film) 3458, 1732, 1624, 1596 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.13 (s, 1H), 7.10 (d, *J* = 8.2 Hz, 1H), 6.91 (d, *J* = 8.2 Hz, 1H), 6.01 (ddd, *J* = 17.6, 10.8, 6.4 Hz, 1H), 5.40 (d, *J* = 10.8 Hz, 1H), 5.35 (d, *J* = 17.6 Hz, 1H), 4.77–4.76 (m, 1H), 4.18–4.16 (m, 1H), 4.06–4.02 (m, 1H), 3.79 (s, 1H), 3.06–3.04 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 183.4, 159.1, 156.6, 144.6, 131.2, 124.7, 119.4, 118.6, 113.4, 109.7, 62.0, 58.1, 56.1; HRMS (ESI): Calcd for $C_{13}H_{13}O_4NNa$ (M + Na): 270.0737; found: 270.0738.

1-(1-Hydroxybut-3-en-2-yl)-6-methylindoline-2,3-dione (4n). Yellow solid; mp. 166–169 °C; $[\alpha]_D^{20}$ = +45.0 (*c* 0.2, CH_2Cl_2) (87% ee); IR (film) 3406, 1731, 1721, 1614 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.50 (d, *J* = 7.6 Hz, 1H), 6.91 (d, *J* = 7.6 Hz, 1H), 6.79 (s, 1H), 6.0 (ddd, *J* = 18.8, 12.0, 6.4 Hz, 1H), 5.35 (d, *J* = 12.0 Hz, 1H), 5.32 (d, *J* = 18.8 Hz, 1H), 4.77–4.76 (m, 1H), 4.20–4.05 (m, 1H), 4.04–4.02 (m, 1H), 3.02 (brs, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 182.4, 159.6, 151.3, 150.8, 131.2, 125.74, 124.7, 119.4, 116.0, 112.8, 62.0, 58.2, 23.3; HRMS (ESI): Calcd for $C_{13}H_{13}O_3NNa$ (M + Na): 254.0788; found: 254.0790.

6-Chloro-1-(1-hydroxybut-3-en-2-yl)indoline-2,3-dione (4o). Yellow solid; mp. 127–129 °C; $[\alpha]_D^{20}$ = +65.0 (*c* 0.2, CH_2Cl_2) (93% ee); IR (film) 3461, 1743, 1608 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.54 (d, *J* = 8.0 Hz, 1H), 7.09 (d, *J* = 8.0 Hz, 1H), 7.02 (s, 1H), 6.01 (ddd, *J* = 17.2, 10.6, 5.6 Hz, 1H), 5.40 (d, *J* = 10.6 Hz, 1H), 5.35 (d, *J* = 17.2 Hz, 1H), 4.83–4.78 (m, 1H), 4.20–4.05 (m, 1H), 4.04–4.02 (m, 1H), 2.85 (brs, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 181.7, 159.0, 151.8, 144.8, 130.7, 126.7, 124.3, 120.0, 116.4, 113.1, 61.7, 58.2; HRMS (ESI): Calcd for $C_{12}H_{10}O_3NClNa$ (M + Na): 274.0241; found: 274.0242.

Conclusions

A palladium-catalyzed asymmetric allylic amination of racemic butadiene monoxide with isatins and their derivatives as nucleophiles under mild reaction conditions was successfully realized using a chiral P/terminal-olefin ligand. A variety of optically active chiral amino alcohols can be obtained in 55–87% yields with 80–97% ees and 10/1->20/1 regioselectivity ratios. Further expansion of the application of the chiral P/olefin ligands in other asymmetric reactions is currently underway in our laboratory.

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