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Asymmetric Construction of 2,3-Dihydroisoxazoles via an Organocatalytic Formal [3 + 2] Cycloaddition of Enynes with *N*-Hydroxylamines

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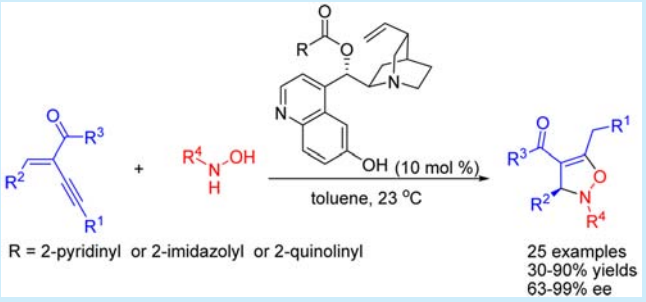
Supporting Information

ABSTRACT: An organocatalytic asymmetric formal [3 + 2] cycloaddition of enynones with *N*-hydroxylamines has been described. A newly designed multifunctional organocatalyst was found to be highly effective, and the method allowed the synthesis of a variety of 2,3-dihydroisoxazoles in good yields with excellent enantioselectivity.



2,3-Dihydroisoxazoles (4-isoxazolines) are a fundamental structural class in organic chemistry where they have served as useful synthetic intermediates.[1] This structure can be found in various biologically active compounds and natural products.[2] Considerable research efforts have been directed toward the development of synthetic methods for 2,3-dihydroisoxazoles, but their construction in a catalytic enantioselective manner is still a rather challenging subject in asymmetric synthesis.[3] The significance of these chiral 2,3-dihydroisoxazole motifs has led to the demand for efficient synthetic methods, and some progress has been made. For example, Ukaji, Inomata, and co-workers developed an asymmetric addition of alkynylzinc reagents to nitrones utilizing di-*tert*-butyl (*R*,*R*)-tartrate as a chiral auxiliary to afford the corresponding optically active propargyl hydroxylamines, and subsequent cyclization would produce the corresponding enantioenriched 2,3-dihydroisoxazoles.[4] One of the most attractive approaches to the enantioselective synthesis of 4-isoxazolines is asymmetric metal- or organocatalyst-catalyzed 1,3-diplolar cycloaddition of nitrones to acetylenes. For example, Ishihara and co-workers reported a highly enantioselective dipolar [3 + 2] cycloaddition of acetylenic derivatives, propioloylpyrazoles, with nitrones using a chiral copper complex to produce a set of chiral 2,3-dihydroisoxazoles.[5] Enantioselective methods employing organocatalytic approaches are more rarely reported. Recently, Sun and co-workers disclosed the first organocatalytic asymmetric dipolar [3 + 2] cycloaddition between acetylenic aldehydes and nitrones that are in situ formed from *N*-alkylhydroxylamines and aldehydes in one pot (Scheme 1a).[6] Meanwhile, the Alemán group devoted their independent efforts to the development of the organocatalytic enantioselective 1,3-dipolar cycloadditions of alkynals with nitrones through an iminium activation pathway (Scheme 1b).[7] Undoubtedly, with the significance of enantioenriched 2,3-dihydroisoxazoles, the development of a novel and efficient process is still highly desirable.

Over the past decade, with the rapid development of organocatalysis, cinchona alkaloids and their derivatives have been successfully applied in many enantioselective reactions.[8] Deng discovered that cinchona alkaloid derivatives bearing a free hydroxyl group at the 6′-position of the quinoline are especially effective.[9] Recent research efforts directed at modifying the H-bond donor of naturally occurring cinchona alkaloids (C9-OH), which can be advantageously exploited to fine-tune properties such as basicity and conformation, have led to the identification of more enantioselective and general catalysts for the enantioselective transformations.[10] While catalytic asymmetric conjugate additions to a carbon−carbon double bond with cinchona alkaloid-derived catalysts are well-established,[11] reports of stereocontrolled Michael addition reactions of α,β-disubstituted systems are scarce. During our ongoing investigation on base-catalyzed tandem reaction of electron-deficient 1,3-conjugated enynes[12] with hydroxylamines,[12a] we report herein an asymmetric formal [3 + 2] cycloaddition of enynones with hydroxylamines to furnish a series of highly substituted 2,3-dihydroisoxazoles in good yields and high ee values using a new organocatalyst derived from cinchona alkaloids (Scheme 1c).

In initial attempts, the formal [3 + 2] cycloaddition of enynone **1a** with *N*-benzylhydroxylamine **2a** in the presence of 10 mol % of quinine was carried out in toluene at room temperature for 16

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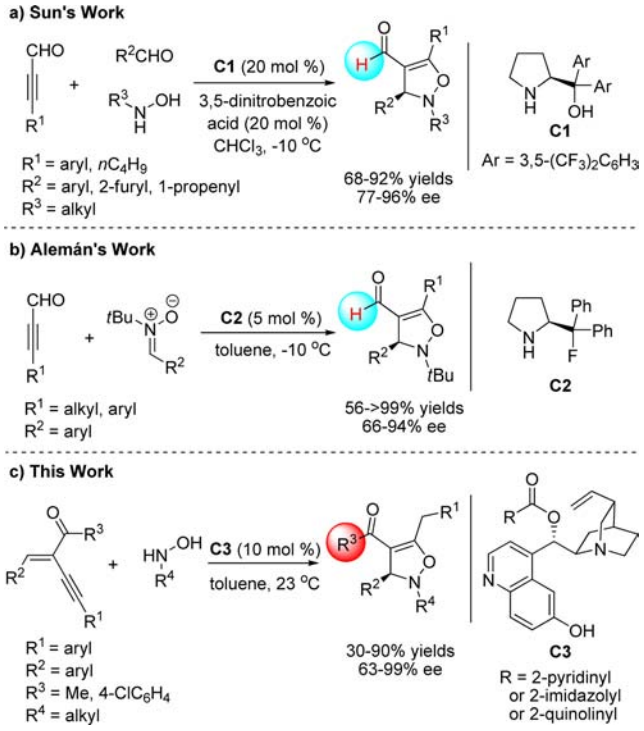
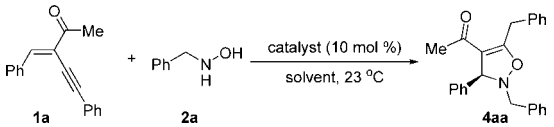
Scheme 1. Organocatalytic Access to Chiral 2,3-Dihydroisoxazoles



h to give 2,3-dihydroisoxazole **4aa** in 88% yield with an enantiomeric excess (ee) of 33% (Table 1, entry 1). The cycloaddition of **1a** and **2a** with QD (QD = quinidine) delivered the **4aa** in 59% ee (Table 1, entry 2). We then screened various

Table 1. Optimization of the Reaction Conditions[a]



entry	catalyst	solvent	time (h)	yield[b] (%)	ee[c] (%)
1	quinine	toluene	16	88	33
2	QD	toluene	17	81	59
3	**3a**	toluene	18	81	77
4	**3b**	toluene	16	98	73
5	**3c**	toluene	2	72	56
6	**3d**	toluene	9	72	63
7	**3e**	toluene	120	trace	
8	**3f**	toluene	5.5	90	59
9	**3g**	toluene	120	12	89
10	**3h**	toluene	120	22	94
11	**3i**	toluene	20	53	91
12	**3j**	toluene	16	58	90
13	**3j**	CH_2Cl_2	10	55	85
14	**3j**	DCE	10	55	87
15	**3j**	xylene	20	43	87
16	**3j**	Ph−Cl	20	60	83
17	**3k**	toluene	14	50	92
18	**3l**	toluene	72	31	87

[a]The reaction was conducted with **1a** (0.2 mmol) and **2a** (0.26 mmol) in solvent (5 mL) at 23 °C in the presence of catalyst. [b]Isolated yield. [c]The ee value was determined by chiral HPLC.

cinchona alkaloids (Figure 1, **3a**−**d**). It is noteworthy that the catalyst **3c** with a 2-pyridinyl substituent displayed substantially

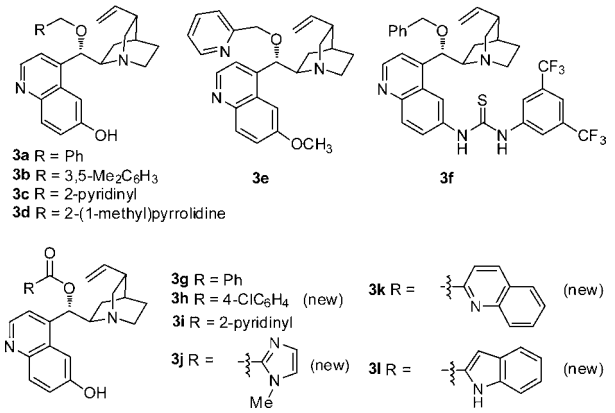


Figure 1. Screened organocatalysts.

higher reactivity in this transformation (Table 1, entry 5). When C6′-OH of catalyst **3c** was changed to C6′-OMe of catalyst **3e**, the cycloaddition delivered only a trace amount of the [3 + 2] annulation product (Table 1, entry 7), indicating that C6′-OH plays a crucial role for the activity. Meanwhile, the catalyst **3f** with the dual H-bond component displayed similar reactivity but significantly lower enantioselectivity relative to catalyst **3a** (Table 1, entry 8). Further modification of the catalyst structure with introduction of an ester group on the C9 substituent had a pronounced beneficial effect on the enantioselectivity. Catalysts **3g** and **3h** afforded the product in very good enantioselectivity but with low yields (Table 1, entries 9 and 10). Catalyst **3i**, which bears a pyridinyl group on the ester moiety, attained a higher yield with 91% ee in shorter time (Table 1, entries 11 vs 9 and 10).[13,14] Interestingly, the use of **3j** or **3k** as catalysts with an *N*-methylimidazole group or a 2-quinoline group also gave moderate yield and good ee (Table 1, entries 12 and 17). In addition, catalyst **3l** with an indole moiety could give good ee but low catalytic activity (Table 1, entry 18). The solvent effect was then examined, and no better result could be obtained (Table 1, entries 13−16). These results imply that the multifunctionality consisting of an ester group, the basic heterocycle (pyridine, imidazole, and quinoline), and a hydroxyl group is crucial for catalytic activity and enantioselectivity. On the basis of the ee values of the products, catalysts **3i**−**k** (Figure 1) were selected for further investigation.

With optimized reaction conditions in hand, we evaluated this methodology with various *N*-substituted hydroxylamines **2** (Scheme 2). The *N*-(naphthalen-1-ylmethyl)hydroxylamine **2b** smoothly underwent the asymmetric cycloaddition to furnish the corresponding cyclic product **4ab** in 52% yield with 93% ee. Additionally, sterically hindered *N*-(anthracen-9-ylmethyl)-hydroxylamine **2c** gave cycloadduct **4ac** in 66% yield and 91% ee. A range of *N*-(2-aryl)hydroxylamines (**2d**−**g**) bearing either electron-deficient or -rich aryl substituents underwent the tandem reactions smoothly to afford the desired products **4ad**−**ag** in 33−72% yields with 83−99% ee. By increasing the catalyst loading of **3k** to 15 mol %, the reaction of **1a** with **2g** gave the corresponding product **4ag** in 72% yield and 94% ee. As for *N*-(2-methoxybenzyl)hydroxylamine **2f** and *N*-benzhydrylhydroxylamine **2h**, the reactions resulted in low yields but excellent enantioselectivity (**4af**, 33%, 99% ee; **4ah**, 30%, 99% ee). Remarkably, the hydroxylamine **2i** bearing a furan-2-yl group

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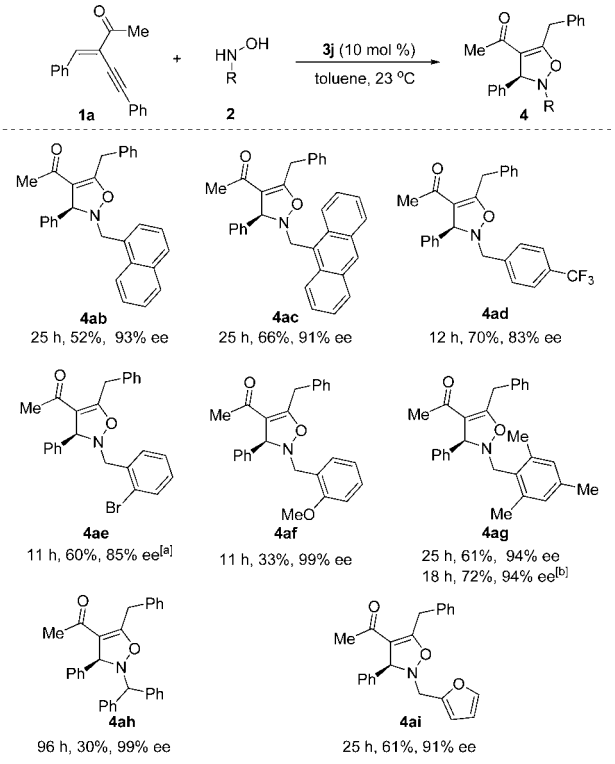
Scheme 2. Organocatalytic Access to Chiral 2,3-Dihydroisoxazoles

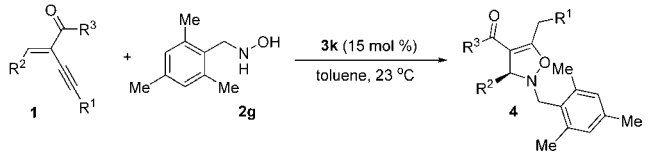


[a]Catalyst **3i** (15 mol %), **2e** (0.3 mmol). [b]Catalyst **3k** (15 mol %).

worked well in the presence of catalyst **3j** to provide the product **4ai** in 61% yield with 91% ee.

To further investigate the substrate scope of the present catalytic system, we performed the catalytic asymmetric formal [3 + 2] cycloaddition with a range of enynones using **3k** as the catalyst (Table 2). In general, electron-deficient conjugated enynes favored this process. Reactions of various enynes containing electron-rich or electron-deficient aryl groups on the alkenyl moiety (R^2) with **2g** afforded the corresponding 2,3-dihydroisoxazoles in good yields with excellent enantioselectivities (**4bg**–**cg**, **4lg**–**og**: 54–89% yield, 89–93% ee) (entries 1, 2, and 11–14). It should be noted that the reaction required a longer time for achieving full conversion when the substrate contained electron-donating groups. To our delight, the substrate **1d** with a nitrophenyl group on the alkyne moiety (R^1) could deliver **4dg** in 90% yield and 90% ee (entry 3). Various enynes (**1e**–**g**) with halogen substituents reacted successfully under the optimized conditions (**4eg**–**gg**: 62–83% yield, 90–93% ee) (entries 4–6). Furthermore, different electron-withdrawing groups on the aromatic ring of the alkyne moiety (R^1), such as aldehyde, ketone, and ester substituents, were well compatible, providing the desired products in 62–81% yields and 87–91% ee (entries 7–9). Gratifyingly, substrate **1k** with a 2-thienyl substituent on the alkyne moiety (R^1) treated with **2g** afforded the cycloaddition product **4kg** in 94% ee (entry 10). In the case of **1p** and **1q** bearing an aryl substituent on the ketone moiety, the reaction was successfully performed, giving highly substituted 2,3-dihydroisoxazoles **4pg** and **4qg** in moderate yield and good ee (entries 15 and 16). The absolute configuration of adduct **4ag**, generated from reaction of enynone **1a** and hydroxylamine **2g**, was determined by X-ray crystallography.[15] Furthermore, the use of $NaBH_4$ enabled reduction of

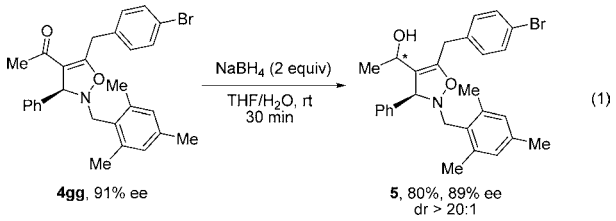
Table 2. Substrate Scope of Enynones[a]



entry	$R^1/R^2/R^3$ (**1**)	time (h)	**4**, yield (ee) (%)
1	Ph/4-ClC_6H_4/Me (**1b**)	36	**4bg**, 89 (89)
2	Ph/4-$CF_3C_6H_4$/Me (**1c**)	22	**4cg**, 83 (89)
3	4-$NO_2C_6H_4$/Ph/Me (**1d**)	10	**4dg**, 90 (90)
4	4-FC_6H_4/Ph/Me (**1e**)	39	**4eg**, 62 (93)
5	4-ClC_6H_4/Ph/Me (**1f**)	34	**4fg**, 67 (90)
6	4-BrC_6H_4/Ph/Me (**1g**)	20	**4gg**, 83 (91)
7	4-$HOCC_6H_4$/Ph/Me (**1h**)	10	**4hg**, 62 (87)
8	4-$MeOCC_6H_4$/Ph/Me (**1i**)	10	**4ig**, 81 (91)
9	4-$MeO_2CC_6H_4$/Ph/Me (**1j**)	20	**4jg**, 79 (87)
10	Th/Ph/Me (**1k**)	13	**4kg**, 53 (94)
11	4-$MeO_2CC_6H_4$/4-$MeOC_6H_4$/Me (**1l**)	9	**4lg**, 75 (90)
12	4-BrC_6H_4/4-$MeOC_6H_4$/Me (**1m**)	64	**4mg**, 67 (93)
13	4-MeC_6H_4/4-ClC_6H_4/Me (**1n**)	64	**4ng**, 64 (90)
14	4-$MeOC_6H_4$/4-$CF_3C_6H_4$/Me (**1o**)	72	**4og**, 54 (90)
15	Ph/Ph/Ph (**1p**)	34	**4pg**, 54 (63)
16	Ph/Ph/4-ClC_6H_4 (**1q**)	10	**4qg**, 77 (83)

[a]The reaction was conducted with **1** (0.2 mmol) and **2g** (0.26 mmol) in toluene (5 mL) at room temperature in the presence of catalyst **3k** (15 mol %). Yield of the isolated product after column chromatography. The ee value was determined by chiral HPLC.

obtained product **4gg** to give the corresponding alcohol **5** with excellent diastereoselectivities and good yields, maintaining the enantiomeric excess of the starting ketone (eq 1).



(1)

On the basis of our previous work,[12] the plausible mechanism of this multifunctional organocatalyst-catalyzed cycloaddition reaction is proposed in Figure 2. The Michael donor was

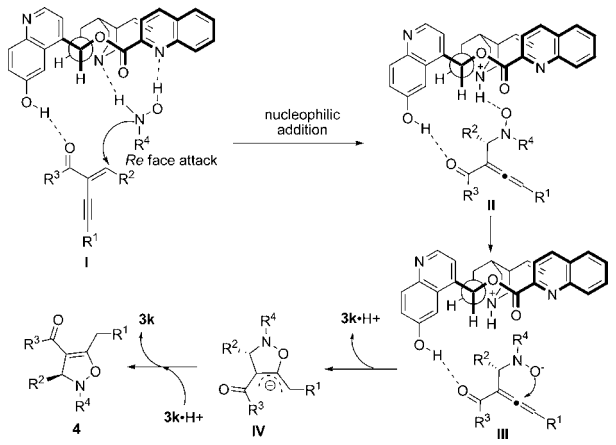


Figure 2. Plausible mechanism.

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activated through the quinuclidine amine function and the *N*-hetaryl substituents on a C-9 ester, and the Michael acceptor was associated with the quinoline phenol through a developing hydrogen bond.[16] The enantioselective nucleophilic addition takes place via a concerted hydrogen transfer. Then the chiral base captures another proton of the hydrozylamine to give oxygen anion **III**. After nucleophilic attack of the oxygen anion to the allenyl ketone intermediate **III**, transition state **IV** forms and subsequent protonation affords product **4**.

In summary, we have developed a facile asymmetric formal cycloaddition of electron-deficient 1,3-enynes and *N*-hydroxylamines. The newly designed organocatalysts derived from cinchona alkaloids were demonstrated as optimal catalytic systems for inducing asymmetry in the synthesis of highly substituted 2,3-dihydroisoxazoles in high yields (up to 90%) with excellent enantioselectivities (ee up to 99%). Further development of a novel asymmetric organocatalytic system is ongoing in our laboratory.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.orglett.6b01737.

Descriptions of experimental procedures for compounds and analytical characterization (PDF)
X-ray data for compound **4ag** (CIF)

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Notes

The authors declare no competing financial interest.

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■ REFERENCES

(1) For reviews of 2,3-dihydroisoxazoles, see: (a) Freeman, J. P. *Chem. Rev.* **1983**, *83*, 241. (b) Grünanger, P.; Vita-Finzi, P. Isoxazolines. In *The Chemistry of Heterocyclic Compounds*; Taylor, E. C., Weissberger, A., Ed.; John Wiley & Sons, 1991; Chapter 2, pp 416−647. (c) Pinho e Melo, T. M. V. D. *Eur. J. Org. Chem.* **2010**, *2010*, 3363.

(2) (a) Atienza, J. M.; Susanto, D.; Huang, C.; McCarty, A. S.; Colicelli, J. *J. Biol. Chem.* **1999**, *274*, 4839. (b) Habeeb, A. G.; Praveen Rao, P. N.; Knaus, E. E. *J. Med. Chem.* **2001**, *44*, 2921. (c) Cramer, R. D.; Jilek, R. J.; Guessregen, S.; Clark, S. J.; Wendt, B.; Clark, R. D. *J. Med. Chem.* **2004**, *47*, 6777. (d) Hubich, A. I.; Zheldakova, T. A.; Chernikhova, T. V.; Koroleva, E. V.; Lakhvich, F. A.; Sholukh, M. V. *Biochem. Biophys. Res. Commun.* **2006**, *341*, 357. (e) Fraley, M. E.; Garbaccio, R. M.; Hartman, G. D. PCT Int. Appl. WO2006/023440, 2006.

(3) (a) Bruché, L.; Arnone, A.; Bravo, P.; Panzeri, W.; Pesenti, C.; Viani, F. *Eur. J. Org. Chem.* **1999**, *1999*, 1665. (b) Busqué, F.; de March, P.; Figueredo, M.; Font, J.; Gallagher, T.; Milán, S. *Tetrahedron: Asymmetry* **2002**, *13*, 437. (c) François, D.; Maden, A.; Murray, W. V. *Org. Lett.* **2004**, *6*, 1931. (d) Cantagrel, F.; Pinet, S.; Gimbert, Y.; Chavant, P. Y. *Eur. J. Org. Chem.* **2005**, *2005*, 2694.

(4) Ukaji, Y.; Inomata, K.; Wei, W.; Kobayashi, M. *Heterocycles* **2009**, *78*, 717.

(5) Sakakura, A.; Hori, M.; Fushimi, M.; Ishihara, K. *J. Am. Chem. Soc.* **2010**, *132*, 15550.

(6) Cai, X.; Wang, C.; Sun, J. *Adv. Synth. Catal.* **2012**, *354*, 359.

(7) Alemán, J.; Fraile, A.; Marzo, L.; Ruano, J. L. G.; Izquierdo, C.; Díaz-Tendero, S. *Adv. Synth. Catal.* **2012**, *354*, 1665.

(8) For selected reviews on asymmetric organocatalysis with cinchona and their derivatives, see: (a) Tian, S.-K.; Chen, Y.; Hang, J.; Tang, L.; McDaid, P.; Deng, L. *Acc. Chem. Res.* **2004**, *37*, 621. (b) Hoffmann, H. M. R.; Frackenpohl, J. *Eur. J. Org. Chem.* **2004**, *2004*, 4293. (c) Chen, Y.-C. *Synlett* **2008**, *2008*, 1919. (d) Marcelli, T.; Hiemstra, H. *Synthesis* **2010**, *2010*, 1229.

(9) (a) Li, H.; Wang, Y.; Tang, L.; Deng, L. *J. Am. Chem. Soc.* **2004**, *126*, 9906. (b) Li, H.; Wang, Y.; Tang, L.; Deng, L. *Angew. Chem., Int. Ed.* **2005**, *44*, 105. (c) Li, H.; Wang, B.; Deng, L. *J. Am. Chem. Soc.* **2006**, *128*, 732. (d) Wu, F.; Li, H.; Hong, R.; Deng, L. *Angew. Chem., Int. Ed.* **2006**, *45*, 947. (e) Wu, F.; Hong, R.; Khan, J.; Liu, X.; Deng, L. *Angew. Chem., Int. Ed.* **2006**, *45*, 4301.

(10) For selected examples of 6′-OH cinchona alkaloids as bifunctional catalysts, see: (a) Wang, J.; Li, H.; Zu, L.; Wang, W. *Org. Lett.* **2006**, *8*, 1391. (b) Wang, Y.; Li, H.; Wang, Y.-Q.; Liu, Y.; Foxman, B. M.; Deng, L. *J. Am. Chem. Soc.* **2007**, *129*, 6364. (c) Bandini, M.; Sinisi, R.; Umani-Ronchi, A. *Chem. Commun.* **2008**, 4360. (d) Wang, H.-F.; Cui, H.-F.; Chai, Z.; Li, P.; Zheng, C.-W.; Yang, Y.-Q.; Zhao, G. *Chem. - Eur. J.* **2009**, *15*, 13299. (e) Liu, Y.; Sun, B.; Wang, B.; Wakem, M.; Deng, L. *J. Am. Chem. Soc.* **2009**, *131*, 418. (f) Chauhan, P.; Chimni, S. S. *Eur. J. Org. Chem.* **2011**, *2011*, 1636. (g) Métro, T.-X.; Cochi, A.; Pardo, D. G.; Cossy, J. *J. Org. Chem.* **2011**, *76*, 2594. (h) Chauhan, P.; Chimni, S. S. *RSC Adv.* **2012**, *2*, 737.

(11) For selected examples, see: (a) Li, H.; Song, J.; Liu, X.; Deng, L. *J. Am. Chem. Soc.* **2005**, *127*, 8948. (b) Wang, J.; Li, H.; Zu, L.; Jiang, W.; Wang, W. *Adv. Synth. Catal.* **2006**, *348*, 2047. (c) Dodda, R.; Goldman, J. J.; Mandal, T.; Zhao, C. G.; Broker, G. A.; Tiekink, E. R. T. *Adv. Synth. Catal.* **2008**, *350*, 537. (d) Lu, J.; Zhou, W.; Liu, F.; Loh, T. *Adv. Synth. Catal.* **2008**, *350*, 1796. (e) Li, H.; Zhang, S.; Yu, C.; Song, X.; Wang, W. *Chem. Commun.* **2009**, 2136. (f) Xuan, Y.; Nie, S.; Dong, L.; Zhang, J.; Yan, M. *Org. Lett.* **2009**, *11*, 1583. (g) Raimondi, W.; Lettieri, G.; Dulcere, J. P.; Bonne, D.; Rodriguez, J. *Chem. Commun.* **2010**, *46*, 7247. (h) Chauhan, P.; Chimni, S. S. *Adv. Synth. Catal.* **2011**, *353*, 3203. (i) He, P.; Liu, X.; Shi, J.; Lin, L.; Feng, X. *Org. Lett.* **2011**, *13*, 936. (j) Buyck, T.; Wang, Q.; Zhu, J. *Angew. Chem., Int. Ed.* **2013**, *52*, 12714. (k) Zhao, Y.; Wang, X.-J.; Lin, Y.; Cai, C.-X.; Liu, J.-T. *Tetrahedron* **2014**, *70*, 2523. (l) Cabanillas, A.; Davies, C. D.; Male, L.; Simpkins, N. S. *Chem. Sci.* **2015**, *6*, 1350.

(12) (a) Yu, X.; Du, B.; Wang, K.; Zhang, J. *Org. Lett.* **2010**, *12*, 1876. (b) Xiao, Y.; Yu, Y.; Zhang, J. *Angew. Chem., Int. Ed.* **2008**, *47*, 1903. (c) Liu, F.; Yu, Y.; Zhang, J. *Angew. Chem., Int. Ed.* **2009**, *48*, 5505. (d) Liu, F.; Qian, D.; Li, L.; Zhao, X.; Zhang, J. *Angew. Chem., Int. Ed.* **2010**, *49*, 6669. (e) Zhang, Z.-M.; Chen, P.; Li, W.; Niu, Y.; Zhao, X.; Zhang, J. *Angew. Chem., Int. Ed.* **2014**, *53*, 4350. (f) Zhou, L.; Zhang, M.; Li, W.; Zhang, J. *Angew. Chem., Int. Ed.* **2014**, *53*, 6542. (g) Wang, Y.; Zhang, P.; Qian, D.; Zhang, J. *Angew. Chem., Int. Ed.* **2015**, *54*, 14849.

(13) Catalyst **3i** was reported as a ligand in an asymmetric cycloaddition reaction; see: Wang, L.; Yang, D.; Han, F.; Li, D.; Zhao, D.; Wang, R. *Org. Lett.* **2015**, *17*, 176.

(14) A similar catalyst was reported as an effective catalyst for asymmetric aldol reaction; see: Zheng, Y.; Deng, L. *Chem. Sci.* **2015**, *6*, 6510.

(15) CCDC 1495440 (**4ag**) contains the supplementary crystallographic data for this compound.

(16) (a) Wang, B.; Wu, F.; Wang, Y.; Liu, X.; Deng, L. *J. Am. Chem. Soc.* **2007**, *129*, 768. (b) Li, H.; Song, J.; Deng, L. *Tetrahedron* **2009**, *65*, 3139. (c) Deng, Y.; Zhang, Z.; Feng, Y.; Chan, A. S. C.; Lu, G. *Tetrahedron: Asymmetry* **2012**, *23*, 1647.

DOI: 10.1021/acs.orglett.6b01737
Org. Lett. 2016, 18, 3972−3975