ORGANIC LETTERS

2011
Vol. 13, No. 15
3814–3817

Catalytic Asymmetric Conjugate Allylation of Coumarins

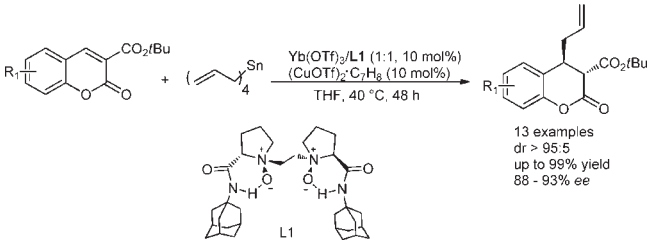
Yulong Kuang, Xiaohua Liu, Lu Chang, Min Wang, Lili Lin, and Xiaoming Feng*

Key Laboratory of Green Chemistry & Technology, Ministry of Education, College of Chemistry, Sichuan University, Chengdu 610064, P. R. China

xmfeng@scu.edu.cn

Received May 16, 2011

ABSTRACT



A catalytic asymmetric conjugate allylation was successfully developed to synthesize potential pharmacologically active 4-allyl-2-oxochroman skeletons. A dual activation strategy was employed by using *N,N′*-dioxide-Yb(OTf)$_3$ to activate coumarins and using (CuOTf)$_2$•C$_7$H$_8$ to activate tetraallyltin via transmetalation, respectively. Good yields and enantioselectivities were obtained under mild conditions.

The catalytic asymmetric allylation reaction is among the most important of C−C bond-forming reactions which constructs a stereocenter with an allyl group.[1] The asymmetric allylation of C=O and C=N bonds has been widely developed to afford homoallylic alcohols or amines.[2] Although the preferential conjugate addition of soft nucleophiles has been realized,[3] the asymmetric conjugate allylation reaction is still a challenge due to the relatively low nucleophilic nature of allyl species to the C=C bond.[4] Until now, only two examples of the catalytic asymmetric conjugate allylation reaction have been reported. The Morken group pioneered the nickel- or palladium-catalyzed enantioselective conjugate addition of allylboronic acid pinacol ester to dialkylidene ketones. The reaction proceeded via oxidative addition to form an unsaturated π-allyl complex, followed by transmetalation and reductive elimination steps.[5] The Snapper group realized the enantioselective Hosomi−Sakurai conjugate allylation of cyclic unsaturated ketoesters.[6] Good to excellent enantioselectivities have been obtained in both cases; nonetheless, the yield of the product and variety of substrate remain questionable. Herein, we describe an effective *N,N′*-dioxide-Yb(III) catalyst system for the conjugate allylation of coumarins. A dual activation strategy was employed to improve the yield by using a cocatalyst (CuOTf)$_2$•C$_7$H$_8$ to

(1) For selected application of catalytic asymmetric allylation in natural product syntheses, see: (a) de Fátima, Â.; Kohn, L. K.; Antônio, M. A.; de Carvalho, J. E.; Pilli, R. A. *Bioorg. Med. Chem.* **2005**, *13*, 2927. (b) Sanchez, C. C.; Keck, G. E. *Org. Lett.* **2005**, *7*, 3053. (c) Itoh, T.; Miyazaki, M.; Fukuoka, H.; Nagata, K.; Ohsawa, A. *Org. Lett.* **2006**, *8*, 1295. (d) Miyazaki, M.; Ando, N.; Sugai, K.; Seito, Y.; Fukuoka, H.; Kanemitsu, T.; Nagata, K.; Odanaka, Y.; Nakamura, K. T.; Itoh, T. *J. Org. Chem.* **2011**, *76*, 534.

(2) For selected examples of catalytic asymmetric allylation, see: (a) Shimada, T.; Kina, A.; Ikeda, S.; Hayashi, T. *Org. Lett.* **2002**, *4*, 2799. (b) Lu, J.; Ji, S. J.; Teo, Y. C.; Loh, T. P. *Org. Lett.* **2005**, *7*, 159. (c) Kiyohara, H.; Nakamura, Y.; Matsubara, R.; Kobayashia, S. *Angew. Chem., Int. Ed.* **2006**, *45*, 1615. (d) Wooten, A. J.; Kim, J. G.; Walsh, P. J. *Org. Lett.* **2007**, *9*, 381. (e) Massa, A.; Acocella, M. R.; De Sio, V.; Villano, R.; Scettri, A. *Tetrahedron: Asymmetry* **2009**, *20*, 202. (f) Shi, S. L.; Xu, L. W.; Oisaki, K.; Kanai, M.; Shibasaki, M. *J. Am. Chem. Soc.* **2010**, *132*, 6638. (g) Chakrabarti, A.; Konishi, H.; Yamaguchi, M.; Schneider, U.; Kobayashi, S. *Angew. Chem., Int. Ed.* **2010**, *49*, 1838. (h) Boyd, D. R.; Sharma, N. D.; Sbircea, L.; Murphy, D.; Malone, J. F.; James, S. L.; Allen, C. C. R.; Hamilton, J. T. G. *Org. Biomol. Chem.* **2010**, *8*, 1081. (i) Li, J.; Lutz, M.; Spek, A. L.; van Klink, G. P. M.; van Koten, G.; Klein Gebbink, R. J. M. *Organometallics* **2010**, *29*, 1379. (j) Qiao, X. C.; Zhu, S. F.; Chen, W. Q.; Zhou, Q. L. *Tetrahedron: Asymmetry* **2010**, *21*, 1216. (k) Wu, Q. F.; He, H.; Liu, W. B.; You, S. L. *J. Am. Chem. Soc.* **2010**, *132*, 11418. (l) Zhu, S. F.; Qiao, X. C.; Zhang, Y. Z.; Wang, L. X.; Zhou, Q. L. *Chem. Sci.* **2011**, *2*, 1135.

(3) For the character of nucleophiles to Michael reaction, see: Poon, T. *J. Chem. Educ.* **2002**, *79*, 264.

(4) For the studies of character of allyl anion, see: (a) Brickhouse, M. D.; Squires, R. R. *J. Am. Chem. Soc.* **1988**, *110*, 2706. (b) Linares, M.; Humbel, S.; Braïda, B. *J. Phys. Chem. A* **2008**, *112*, 13249.

(5) (a) Sieber, J. D.; Liu, S.; Morken, J. P. *J. Am. Chem. Soc.* **2007**, *129*, 2214. (b) Sieber, J. D.; Morken, J. P. *J. Am. Chem. Soc.* **2008**, *130*, 4978. (c) Brozek, L. A.; Sieber, J. D.; Morken, J. P. *Org. Lett.* **2011**, *13*, 995.

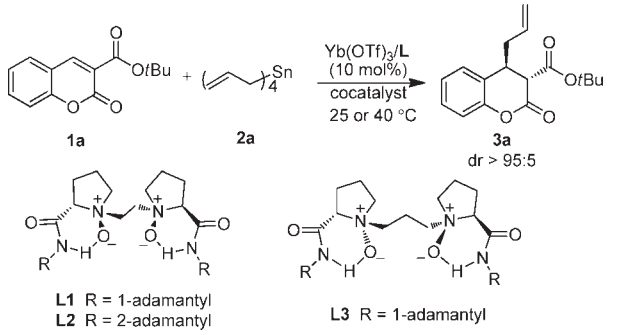
(6) Shizuka, M.; Snapper, M. L. *Angew. Chem., Int. Ed.* **2008**, *47*, 5049.

10.1021/ol201312y
Published on Web 06/21/2011

generate a more active organometallic agent from tetraallyltin through transmetalation.[7]

We chose 3-carboxylate-coumarin as the model substrate which presents a kind of privileged scaffold of biological and pharmaceutical interest.[8] The introduction of a 3-carboxylate group would enhance the activity and chelating capability. Initially, allyl reagents such as allylbromide/zinc,[9] allyltrichlorosilane, and allyltrimethylsilane[10] with various Lewis acids were examined. Unfortunately, no desired conjugate addition product was obtained. Only when tetraallyltin was used could the product **3a** be detected. Then we extended the scope to chiral Lewis acid catalysts of *N,N′*-dioxide to promote the asymmetric conjugate allylation reaction, which have been used in the allylation of carbonyl compounds[11] and other nucleophilic additions[12] in our group. A variety of metal−ligand combinations showed that chiral rare earth metal complexes of *N,N′*-dioxide with sterically hindered aliphatic amide moieties could give moderate results.[13] In the presence of 10 mol % of $Yb(OTf)_3$ and ligand **L1** which contains a 1-adamantyl group and a two-carbonic linkage, 4-allyl chroman-2-one derivative **3a** was obtained with 67% yield, 76% *ee*, and an up to 95:5 *anti*/*syn* ratio in $ClCH_2CH_2Cl$ (Table 1, entry 1). With ligand **L2** derived from 2-adamantyl amine, both the yield and the enantioselectivity of the reaction dropped (Table 1, entry 2). When ligand **L3** with a three-carbonic linkage was used, the enantioselectivity of the reaction deteriorated sharply (26% *ee*, Table 1, entry 3). It indicated that the compact structure of the catalyst benefited the enantioselectivity in the asymmetric transformation which was also in accord with the sterical influence of the ester group of coumarins. The substrate with a bulky ester group could afford higher stereoselectivity, and substrate **1a** was the best candidate.[13] Further optimization of the reaction conditions showed that THF benefited the reaction with a higher *ee* value and increasing the reaction temperature to 40 °C could lead to a moderate improvement of the yield (77% yield, 86% *ee*, Table 1, entries 4 and 5). Lowering the concentration of the reaction system resulted in the enantioselectivity slightly increasing to 89% *ee*, whereas a low yield was obtained even with a prolonged reaction time (40% yield, Table 1, entry 6).

Table 1. Optimization of the Reaction Conditions[a]



entry	L	Cocatalyst	Solvent	*T* [°C]	yield [%][b]	*ee* [%][c]
1	**L1**	none	DCE	25	67	76
2	**L2**	none	DCE	25	58	50
3	**L3**	none	DCE	25	60	26
4	**L1**	none	THF	25	22	86
5	**L1**	none	THF	40	77	86
6[e]	**L1**	none	THF	40	40	89
7[e]	**L1**	CuCl	THF	40	21	90
8[e]	**L1**	CuBr	THF	40	15	89
9[e]	**L1**	CuI	THF	40	NR[d]	
10[e]	**L1**	CuOAc	THF	40	50	90
11[e]	**L1**	$(CuOTf)_2{\bullet}C_7H_8$	THF	40	63	90
12[f]	**L1**	$(CuOTf)_2{\bullet}C_7H_8$	THF	40	99	91

[a] Unless otherwise noted, the reactions were performed with **1a** (0.1 mmol), **2a** (0.1 mmol), $Yb(OTf)_3$ (10 mol %), **L** (10 mol %), cocatalyst (10 mol %) in 0.4 mL of solvent for 24 h under a nitrogen atmosphere. Up to 95:5 dr values were observed which were determined by ^1H NMR or HPLC on a chiral stationary phase. [b] Isolated yield. [c] Determined by HPLC on a chiral stationary phase (chiralcel OD-H). [d] NR = No Reaction. [e] THF (0.8 mL) was used. [f] THF (1.2 mL) was used, and the reaction time was prolonged to 48 h.

(7) For the precedent example of generating active organometallic agents from organotin through transmetalation in a conjugate allylation reaction, see: Shibata, I.; Kano, T.; Kanazawa, N.; Fukuoka, S.; Baba, A. *Angew. Chem., Int. Ed.* **2002**, *41*, 1389.

(8) For the biological and pharmaceutical activity of coumarins, see: (a) Takechi, M.; Tanaka, Y.; Takehara, M.; Nonaka, G. I.; Nishioka, I. *Phytochemistry* **1985**, *24*, 2245. (b) Iinuma, M.; Tanaka, T.; Mizuno, M.; Katsuzaki, T.; Ogawa, H. *Chem. Pharm. Bull.* **1989**, *37*, 1813. (c) Iinuma, M.; Ohyama, M.; Tanaka, T.; Mizuno, M.; Hong, S. K. *Phytochemistry* **1991**, *30*, 3153. (d) Vilain, A. C.; Okochi, V.; Vergely, I.; Reboud-Ravaux, M.; Mazaleyrat, J. P.; Wakselman, M. *Biochim. Biophys. Acta* **1991**, *1076*, 401. (e) Chang, Y. C.; Nair, M. G. *J. Nat. Prod.* **1995**, *58*, 1901. (f) Hoult, J. R. S.; Payá, M. *Gen. Pharmacol.* **1996**, *27*, 713. (g) Boyle, F. T.; Costello, G. F. *Chem. Soc. Rev.* **1998**, *27*, 251. (h) Tillekeratne, L. M. V.; Sherette, A.; Grossman, P.; Hupe, L.; Hupe, D.; Hudson, R. A. *Bioorg. Med. Chem. Lett.* **2001**, *11*, 2763. (i) Bailly, C.; Bal, C.; Barbier, P.; Combes, S.; Finet, J. P.; Hildebrand, M. P.; Peyrot, V.; Wattez, N. *J. Med. Chem.* **2003**, *46*, 5437. (j) Roelens, F.; Huvaere, K.; Dhooge, W.; Van Cleemput, M.; Comhaire, F.; De Keukeleire, D. *Eur. J. Med. Chem.* **2005**, *40*, 1042. (k) Kumar, A.; Singh, B. K.; Tyagi, R.; Jain, S. K.; Sharma, S. K.; Prasad, A. K.; Raj, H. G.; Rastogi, R. C.; Watterson, A. C.; Parmar, V. S. *Bioorg. Med. Chem.* **2005**, *13*, 4300. (l) Menasria, F.; Azebaze, A. G. B.; Billard, C.; Faussat, A. M.; Nkengfack, A. E.; Meyer, M.; Kolb, J. P. *Leuk. Res.* **2008**, *32*, 1914.

(9) For examples of allylbromide/zinc in an allylation reaction, see: (a) Li, H.; Cheng, H. S.; Seow, A. H.; Loh, T. P. *Tetrahedron Lett.* **2007**, *48*, 2209. (b) Kong, W.; Fu, C.; Ma, S. *Org. Biomol. Chem.* **2008**, *6*, 4587.

(10) For selected examples of allyltrimethylsilane as the nucleophilic reagent in a conjugate allylation reaction, see: (a) Hosomi, A.; Sakurai, H. *J. Am. Chem. Soc.* **1977**, *99*, 1673. (b) Majetich, G.; Casares, A.; Chapman, D.; Behnke, M. *J. Org. Chem.* **1986**, *51*, 1745. (c) Hayashi, M.; Mukaiyama, T. *Chem. Lett.* **1987**, 289. (d) Lee, P. H.; Lee, K.; Sung, S.; Chang, Y.; S. *J. Org. Chem.* **2001**, *66*, 8646.

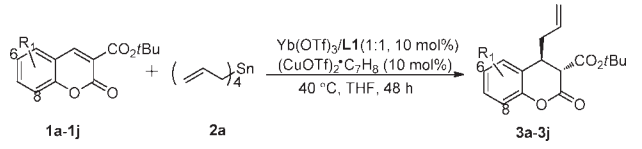
(11) For *N,N′*-dioxide in an asymmetric allylation reaction of carbonyl, see: (a) Zhang, X.; Chen, D. H.; Liu, X. H.; Feng, X. M. *J. Org. Chem.* **2007**, *72*, 5227. (b) Zheng, K.; Qin, B.; Liu, X. H.; Feng, X. M. *J. Org. Chem.* **2007**, *72*, 8478. (c) Huang, J. L.; Wang, J.; Chen, X. H.; Wen, Y. H.; Liu, X. H.; Feng, X. M. *Adv. Synth. Catal.* **2008**, *350*, 287.

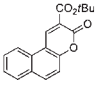
(12) For selected examples of *N,N′*-dioxide-metal complexes in nucleophilic addition reactions, see: (a) Xie, M. S.; Chen, X. H.; Zhu, Y.; Gao, B.; Lin, L. L.; Liu, X. H.; Feng, X. M. *Angew. Chem., Int. Ed.* **2010**, *49*, 3799. (b) Cai, Y. F.; Liu, X. H.; Hui, Y. H.; Jiang, J.; Wang, W. T.; Chen, W. L.; Lin, L. L.; Feng, X. M. *Angew. Chem., Int. Ed.* **2010**, *49*, 6160. (c) Chang, L.; Kuang, Y. L.; Qin, B.; Zhou, X.; Liu, X. H.; Lin, L. L.; Feng, X. M. *Org. Lett.* **2010**, *12*, 2214. (d) Li, W.; Wang, J.; Hu, X. L.; Shen, K.; Wang, W. T.; Chu, Y. Y.; Lin, L. L.; Liu, X. H.; Feng, X. M. *J. Am. Chem. Soc.* **2010**, *132*, 8532. (e) Wang, W. T.; Liu, X. H.; Cao, W. D.; Wang, J.; Lin, L. L.; Feng, X. M. *Chem.—Eur. J.* **2010**, *16*, 1664. (f) Wang, W. T.; Liu, X. H.; Cao, W. D.; Wang, J.; Lin, L. L.; Feng, X. M. *Chem.—Eur. J.* **2010**, *16*, 1664. (g) Zheng, K.; Yin, C. K.; Liu, X. H.; Lin, L. L.; Feng, X. M. *Angew. Chem., Int. Ed.* **2011**, *50*, 2573.

(13) For details, see the Supporting Information.

Further attempts to increase the yield were carried out. It was found that the reaction was sensitive to the amount of water which might be crucial for the process of protonation to form the desired product. Other additives were also tested with negative results. Organotin compounds are liable to participate in transmetalation to generate more active organometallic reagents.[7,14] Therefore, cocatalysts were employed to accelerate the reaction. Among the copper salts surveyed in Table 1, $(CuOTf)_2{\bullet}C_7H_8$ was beneficial for the yield of the reaction, and other Cu(I) salts such as CuCl, CuBr, CuI, and CuOAc gave lower yields (Table 1, entries 7−10 vs 11). This disparity might be due to the exchanging counterion with $Yb(OTf)_3$ which would affect the activation of coumarin **1a**. In the presence of 10 mol % of $(CuOTf)_2{\bullet}C_7H_8$, the yield of the reaction was elevated from 40% to 63% without affecting the enantioselectivity (Table 1, entry 11 vs 6). Further dilution of the reaction system and a prolonged reaction time resulted in a 99% yield and 91% *ee* (Table 1, entry 12). Under the optimized reaction conditions, the outcomes of the reaction became insensitive to moisture.

Table 2. Substrate Scope of Coumarin Derivatives in the Catalytic Asymmetric Conjugate Allylation[a]



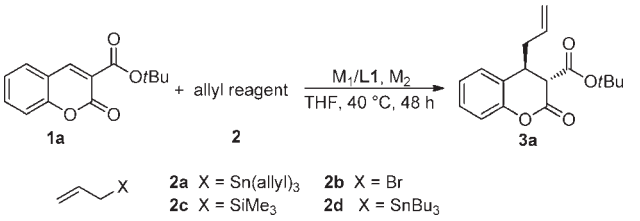
entry	R_1	Product	yield [%][b]	*ee* [%][c]
1	H	**3a**	99	91 (3*S*,4*S*)
2	6-MeO	**3b**	95	89
3	7-MeO	**3c**	35	88
4	5,8-Me_2	**3d**	83	92
5	6-Me	**3e**	96	90
6	7-Me	**3f**	55	88
7	8-Me	**3g**	83	91
8	8-*t*Bu	**3h**	78	93
9	6-Br	**3i**	99	91
10	6,8-Br_2	**3j**	83	92
11	6,8-Cl_2	**3k**	73	91
12	6-NO_2	**3l**	86	92
13		**3m**	94	92

[a] The reactions were performed with **1** (0.1 mmol), **2a** (0.1 mmol), prepared $Yb(OTf)_3$/**L1** (1:1, 10 mol %), $(CuOTf)_2{\bullet}C_7H_8$ (10 mol %), THF (1.2 mL) at 40 °C for 48 h under a nitrogen atmosphere. All dr values were > 95:5, detected by ^{1}H NMR. [b] Isolated yield. [c] Determined by HPLC on a chiral stationary phase.

After identifying the optimal reaction conditions, a range of substrates with different substituents on the aromatic ring were examined. High diastereoselectivities (> 95:5, detected by ^{1}H NMR) were achieved for both the racemic products and the asymmetric catalytic products. Substituted coumarin derivatives were very tolerant with up to a 99% yield and 93% *ee*. As shown in Table 2, there was no pronounced distinctness of the enantioselectivity between electron-withdrawing and -donating substituents. The yields were closely related to the position of the substituent. Generally, 7- and 8-substituted coumarins resulted in lower yields compared with 6-substituted substrates (Table 2, entries 3, 4, 6, 7, 8, 10, 11 vs entries 2, 5, 9, 12).

Moreover, fused ring coumarin derivative **1m** was also tolerable, affording the desired product with a 94% yield and 92% *ee* (Table 2, entry 13). Besides, the absolute configuration of **3a** was determined to be (3*S*,4*S*) by X-ray crystallography.[15]

Table 3. Control Experiments[a]



entry	Allyl source	M_1	M_2	yield [%][b]	*ee* [%][c]
1	**2a**	none	$Cu(OTf)_2$	NR[d]	
2	**2a**	none	$(CuOTf)_2{\bullet}C_7H_8$	NR[d]	
3[e]	**2a**	$Yb(OTf)_3$, $(CuOTf)_2{\bullet}C_7H_8$		Trace	
4[f]	**2a**	$Yb(OTf)_3$	$(CuOTf)_2{\bullet}C_7H_8$	Trace	
5	**2b**	$Yb(OTf)_3$	$(CuOTf)_2{\bullet}C_7H_8$	NR[d]	
6	**2c**	$Yb(OTf)_3$	$(CuOTf)_2{\bullet}C_7H_8$	NR[d]	
7[g]	**2d**	$Yb(OTf)_3$	$(CuOTf)_2{\bullet}C_7H_8$	30	86
8[g]	**2d**	$Yb(OTf)_3$	none	28	80
9	**2a**	$Yb(OTf)_3$	LiBr+AgOTf	65	9
10	**2a**	$Yb(OTf)_3$	$FeCl_2$+2AgOTf	67	85
11	**2a**	$Yb(OTf)_3$	$PdCl_2$+2AgOTf	81	88

[a] General conditions: **1a** (0.1 mmol), **2** (0.1 mmol), prepared M_1/**L1** (1:1, 10 mol %), M_2 (10 mol %), THF (1.2 mL) at 40 °C for 48 h under a nitrogen atmosphere. [b] Isolated yield. [c] Determined by HPLC (chiralcel OD-H). [d] NR = No Reaction. [e] M_1 and M_2 were mixed together with **L1** for 1 h before the reactants were added. [f] Without nitrogen replacement. [g] The reaction time was prolonged to 96 h.

To shed light on the function of $(CuOTf)_2{\bullet}C_7H_8$ in catalytic asymmetric conjugate allylation, comparative experiments were performed. The reaction did not proceed using the complex of $Cu(OTf)_2$ or $(CuOTf)_2{\bullet}C_7H_8$ (Table 3, entries 1 and 2), which implied that the chiral copper complex could not provide sufficient Lewis acidity for the activation of coumarin **1a**. When the mixture of $(CuOTf)_2{\bullet}C_7H_8$, $Yb(OTf)_3$ and **L1** was served as the catalyst, only trace amounts of product **3a** was detected with the disappearance of tetraallyltin (Table 3, entry 3). Thus, the formation of a

(14) For primary studies of the copper effect of organotin, see: (a) Han, X.; Stoltz, B. M.; Corey, E. J. *J. Am. Chem. Soc.* **1999**, *121*, 7600. (b) Mee, S. P. H.; Lee, V.; Baldwin, J. E. *Angew. Chem., Int. Ed.* **2004**, *43*, 1132.

(15) CCDC822331 (**1a**) contains the supplementary crystallographic data for this paper. These data can be obtained free from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_requst/cif.

heterobimetallic catalyst could be ruled out, and copper(I) might serve as the cocatalyst to react with tetraallyltin. An HRMS spectrum was obtained to identify the intermediates generated from equivalent $(CuOTf)_2{\bullet}C_7H_8$ and tetraallyltin.[13] The spectrum of the mixture revealed an ion signal at m/z 104.9766 which corresponds to allyl copper(I) $[CH_2{=}CHCH_2{-}Cu(I){+}H^+]$, and the characteristic ion peak of tetraallyltin was not detected. The actual structure determining whether the allyl group is σ- or π-bonding to Cu(I) was not confirmed, while the role of $(CuOTf)_2{\bullet}C_7H_8$ could be deduced to generate a more active allyl reagent by transmetalation. In the presence of $(CuOTf)_2{\bullet}C_7H_8$, the reaction system became sensitive to oxygen rather than moisture, and trace amounts of product but depleted tetraallyltin were observed in the absence of a nitrogen atmosphere (Table 3, entry 4). The reason might be that the newly formed allyl Cu(I) intermediate was too active to undergo oxidation. Additionally, the transmetalation role of other Lewis acids and allyl reagents was checked under the optimized conditions. The reaction could not take place with allyl bromide or allyltricholrosilane with $(CuOTf)_2{\bullet}C_7H_8$ as the cocatalyst (Table 3, entries 5 and 6). Besides, the tributylallyltin also did not show obvious efficiency (Table 3, entries 7 and 8). Among other metal salts investigated such as Li(I), Fe(II), and Pd(II), only Pd(II) could raise the yield to some degree (Table 3, entries 9–11).

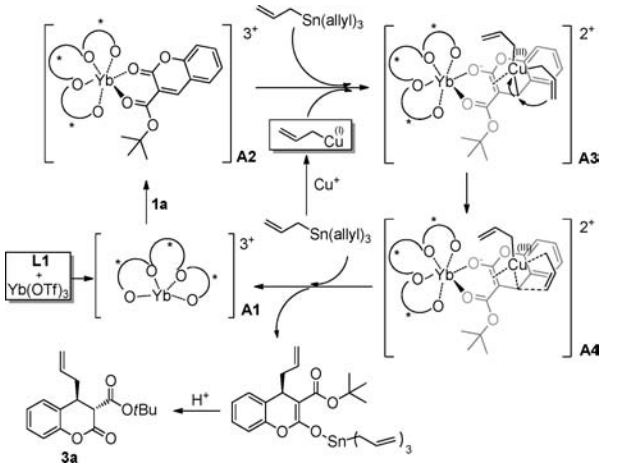


Figure 1. Proposed catalytic cycle.

Next, the relationship between the *ee* value of ligand **L1** and the product **3a** showed a linear effect,[13] which implied that the monomeric catalyst might be the main catalytically active species. A possible catalytic cycle was raised to explain the asymmetric induction and the special function of $(CuOTf)_2{\bullet}C_7H_8$ (Figure 1). The **L1**-$Yb(OTf)_3$ catalyst first coordinated with the coumarin **1a** to form intermediate **A2**. The allyl copper(I) reagent generated from $(CuOTf)_2{\bullet}C_7H_8$ and tetraallyltin would undergo charge transfer from cuprate(I) species to the substrate[16] to form the intermediate **A3**, following cleavage of the allyl–Cu^{III} bond. Then, the interaction between tetraallyltin and the intermediate **A4** would release the catalyst and regenerate the active allyl copper(I) species. The desired product **3a** was obtained by protonation in the workup procedure.

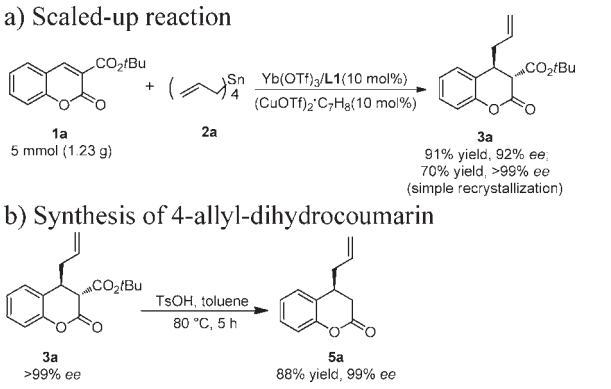


Figure 2. The synthetic utility of the reaction.

To show the prospect of the methodology in synthesis, the scaled-up reaction was performed with subgram quantities of coumarin **1a** (1.23 g, 5 mmol), and 91% yield with 92% *ee* could be achieved (Figure 2a). The enantiopure product could be obtained by a simple recrystallization. The 4-allyl-dihydrocoumarin which has a similar skeleton with coumarin-based drugs could be produced by decarboxylation from **3a** by *p*-toluenesulfonic acid in toluene at 80 °C for 5 h with the maintained enantioselectivity (Figure 2b).[17]

In summary, a dual activation strategy has been developed in the asymmetric conjugate allylation reaction to synthesize optically active 4-allyl-2-oxochroman skeletons. A chiral *N,N′*-dioxide-$Yb(OTf)_3$ complex was responsible for the activation of coumarins, and $(CuOTf)_2{\bullet}C_7H_8$ operated to form an active allyl nucleophile by transmetalation. Excellent results were obtained under mild reaction conditions. Further efforts should be devoted to exploring the method to the asymmetric conjugate allylation of simple enones.

Acknowledgment. We appreciate the National Natural Science Foundation of China (Nos. 20732003 and 21021001), and the Basic Research Program of China (973 Program: 2010CB833300) for financial support. We also thank Sichuan University Analytical & Testing Center for NMR and X-ray analysis.

Supporting Information Available. Experimental procedures, spectral and analytical data for the products. This material is available free of charge via the Internet at http://pubs.acs.org.

(16) Mori, S.; Nakamura, E. *Morden Organocopper Chemistry*; Wiley: 2002; Vol. 10, pp 315–346.

(17) (a) Biddle, M. M.; Lin, M.; Scheidt, K. A. *J. Am. Chem. Soc.* **2007**, *129*, 3830. (b) Liu, X.; Lu, Y. *Org. Lett.* **2010**, *12*, 5592.