DOI: 10.1002/adsc.201600416

Advanced Synthesis & Catalysis

Stereoselective Cascade Reactions of Donor–Acceptor Cyclopropanes with *m*-*N*,*N*-Dialkylaminophenyl α,β-Unsaturated Carbonyls: Diastereoselective Synthesis of *cis*- and *trans*-Tetralins

Seunghui Sin[a] and Sung-Gon Kim[a,*]

[a] Department of Chemistry, Kyonggi University, 154-42, Gwanggyosan-ro, Yeongtong-gu, Suwon 16227, Republic of Korea
Fax: (+82)-31-253-1165; phone: (+82)-31-249-9631; e-mail: sgkim123@kyonggi.ac.kr

Received: April 19, 2016; Revised: May 17, 2016; Published online: ■■ ■■, 0000

Supporting information for this article is available on the WWW under http://dx.doi.org/10.1002/adsc.201600416.

Abstract: The ytterbium(III) triflate [$Yb(OTf)_3$]-catalyzed diastereoselective cascade reaction of *m*-*N*,*N*-dimethylaminophenyl α,β-unsaturated carbonyls with cyclopropane 1,1-diesters under mild reaction conditions afforded highly substituted *cis*- and *trans*-tetralins. The reaction of *m*-*N*,*N*-dimethylaminophenyl α,β-unsaturated ketones with cyclopropane 1,1-diesters provided tetralins with a *trans* orientation of the 1,4-substitutents on the cyclohexyl ring; *cis*-tetralins were obtained from *m*-*N*,*N*-dimethylaminophenyl substituted methylidenemalonates with high diastereoselectivities.

Keywords: cascade reactions; donor–acceptor cyclopropanes; Friedel–Crafts reaction; Michael addition; tetralins

Tetralin is a well-known privileged scaffold commonly encountered in several biologically active natural products and synthetic pharmaceutical compounds.[1] In particular, the 1-aryltetralin skeleton belongs to a class of lignans found in natural cyclolignans and synthetic derivatives with a broad spectrum of biological activities including antimalarial, antifungal, antibacterial, anti-inflammatory, antitumor, anti-HIV, and antidepressant activities (Figure 1).[2] For example, sertraline (Zoloft) is primarily used to treat depression due to its selective inhibition of the reuptake of human synaptosomal serotonin.[3] Podophyllotoxin (Condylox) is applied to the skin as a topical treatment for external genital warts, and its synthetic derivatives such as etoposide and teniposide are type II topoisomerase targeting anticancer drugs used for the treatment of lung cancer, leukemia, lymphomas, and genital tumors.[4] In view of their potent biological activities and unique structural features, several synthetic approaches have been developed for aryltetralins.[5] However, only a few papers have reported the one-pot synthesis of the 1-aryltetralin skeleton.[6] Herein, we report the development of a short, one-pot diastereoselective synthesis of *cis*- and *trans*-tetralins by the Lewis acid-catalyzed Friedel–Crafts/Michael addition cascade reaction of *m*-*N*,*N*-dimethylaminophenyl α,β-unsaturated carbonyls with donor–acceptor (D–A) cyclopropanes.

D–A cyclopropanes with donor and acceptor substituents at the vicinal position have recently become popular and powerful building blocks in organic synthesis for the construction of various acyclic and cyclic compounds.[7] Owing to their special features and immense reactivity, they have been deployed in numerous synthetic methodologies and are widely used in organic synthesis. The common transformation of D–A cyclopropanes is a ring-opening reaction, providing access to 1,3-bifunctionalized compounds.[8]

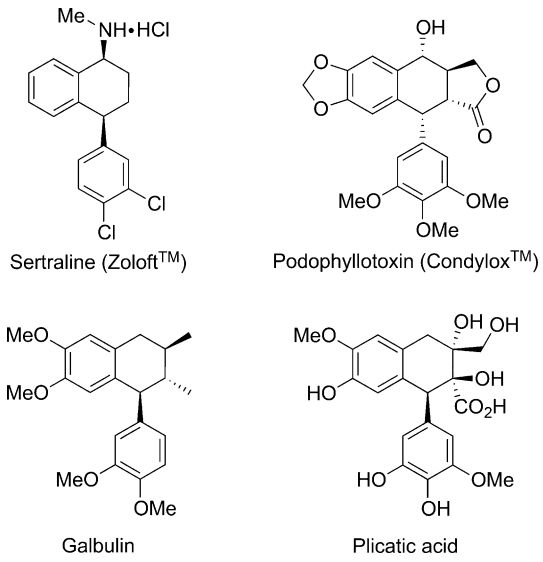
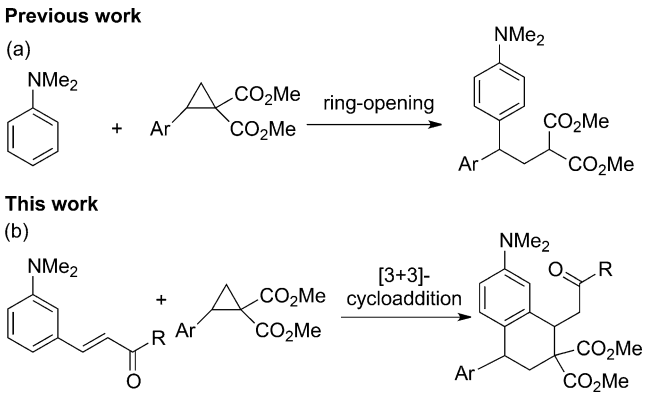


Figure 1. Biologically active compounds containing the aryltetralin scaffold.



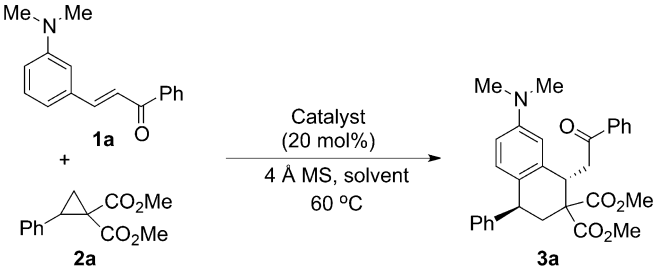
Scheme 1. Lewis acid-catalyzed reaction of donor-acceptor cylopropanes with electron-enriched arenes.

The cycloadditions of D–A cyclopropanes with dienes, dipolarophiles, or 1,3-dipoles, which have attracted much interest, afford various highly functionalized carbo- and heterocyclic compounds.[9]

Recently, we developed a Friedel–Crafts type ring-opening reaction of D–A cyclopropanes with electron-enriched benzenes including *N,N*-dialkylaniline providing a valuable method for the synthesis of 1,1-diarylalkane derivatives (Scheme 1a).[10] *N,N*-Dialkylaniline acts as a good nucleophile without any deactivation or decomposition by Lewis acids such as $Yb(OTf)_3$, which was used as the catalyst in this Friedel–Crafts reaction. In the present study, we further advanced this ring-opening strategy to achieve the stereoselective Friedel–Crafts type ring-opening/intramolecular Michael addition cascade reaction of D–A cyclopropanes with *m-N,N*-dimethylaminophenyl α,β-unsaturated carbonyl compounds leading to the formation of the corresponding tetralin derivatives (Scheme 1b).[11]

Based on these considerations, we began our studies on the cascade reaction of *m-(N,N*-dimethylanilinyl)-α,β-unsaturated phenyl ketone **1a** with dimethyl 2-phenylcyclopropane-1,1-dicarboxylate **2a** as the model substrates using 20 mol% $Sc(OTf)_3$ as the catalyst in $CHCl_3$ at 60 °C. To our delight, the desired tetralin compound **3a** was produced in a 78% yield and with good diastereoselectivity (8:1 *dr*) (Table 1, entry 1). To optimize the reaction conditions for maximum yield, higher diastereoselectivity, and a shorter reaction time, several Lewis acid catalysts such as $Ni(ClO)_4$, $Cu(OTf)_2$, $Zn(OTf)_2$, $Sm(OTf)_3$, and $Yb(OTf)_3$ were screened (entries 2–6). The $Yb(OTf)_3$-catalyzed reaction afforded the product in an excellent yield (85%) and with a high diastereoselectivity (12:1 *dr*) in a shorter reaction time (entry 6). To further optimize the reaction efficiency, various solvents were examined in the $Yb(OTf)_3$-catalyzed reaction (entries 7–13). The reaction medium was found to have substantial impact on the conversion efficiency

Table 1. Optimization of the reaction conditions.[a]



Entry	Catalyst	Solvent	*t* [h]	Yield [%][b]	*trans/cis*[c]
1	$Sc(OTf)_3$	$CHCl_3$	72	78	8:1
2	$Ni(ClO_4)_2$	$CHCl_3$	72	72	3:1
3	$Cu(OTf)_2$	$CHCl_3$	96	23	13:1
4	$Zn(OTf)_2$	$CHCl_3$	96	30	6:1
5	$Sm(OTf)_3$	$CHCl_3$	60	65	12:1
6	$Yb(OTf)_3$	$CHCl_3$	48	85	12:1
7	$Yb(OTf)_3$	CH_2Cl_2	120	73	12:1
8	$Yb(OTf)_3$	$ClCH_2CH_2Cl$	48	64	12:1
9	$Yb(OTf)_3$	toluene	48	62	12:1
10	$Yb(OTf)_3$	CH_3CN	120	80	8:1
11	$Yb(OTf)_3$	THF	96	70	10:1
12	$Yb(OTf)_3$	1,4-dioxane	120	45	9:1
13	$Yb(OTf)_3$	acetone	120	48	12:1
14[d]	$Yb(OTf)_3$	$CHCl_3$	60	80	12:1

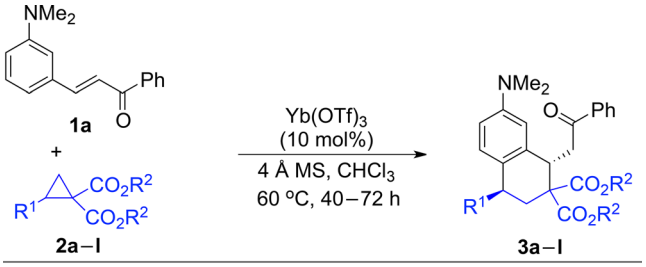
[a] Unless otherwise specified, the reactions were carried out in solvent (0.2 M) with **1a** (0.10 mmol), **2a** (0.12 mmol), 4 Å molecular sieve (20 mg), and Lewis acid (20 mol%).
[b] Isolated yield after chromatographic purification.
[c] Determined by ^1H NMR analysis.
[d] 10 mol% Lewis acid was used.

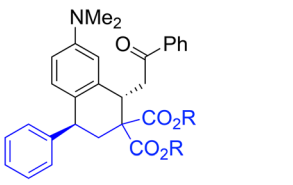
and stereoselectivity of the reaction. The best results were obtained with $CHCl_3$. Moreover, 10 mol% $Yb(OTf)_3$ was sufficient to catalyze the reaction without significantly affecting the yield, reaction time, or diastereoselectivity (entry 14).

With the optimized reaction conditions in hand [1 equiv. of **1**, 1.2 equiv. of **2**, and 10 mol% catalyst $Yb(OTf)_3$ in $CHCl_3$], the substrate scope and generality of the reaction were investigated (Table 2). Firstly, diverse D–A cyclopropanes **2** were investigated to examine the generality of this cascade reaction with *m-(N,N*-dimethylanilinyl)-α,β-unsaturated phenyl ketone **1a**, and the results are shown in Table 2.

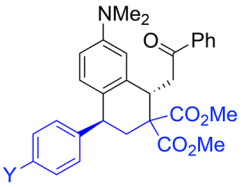
In general, the reactions of all the substrates smoothly afforded the corresponding tetralins in moderate to good yields (51–89%). The reactions of the diethyl and dibenzyl ester compounds resulted in slightly decreased yields and diastereoselectivities (Table 2, **3b** and **3c**). The cyclopropanes with electron-donating groups (Me/OMe) on the phenyl ring were more reactive than those with an unsubstituted phenyl group, producing the corresponding 1,4-disubstituted tetralins **3d**, **3e**, and **3f**, respectively, in good

Table 2. Substrate scope of D-A cyclopropnes in the Friedel–Crafts/Michael addition cascade reaction.[a]

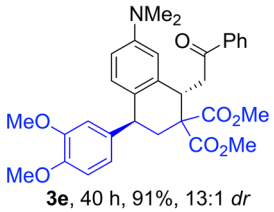




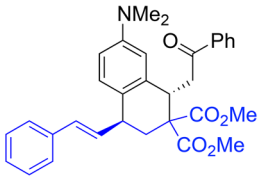
3a, R = Me: 72 h, 80%, 12:1 *dr*
3b, R = Et: 72 h, 54%, 7:1 *dr*
3c, R = Bn: 72 h, 57%, 8:1 *dr*



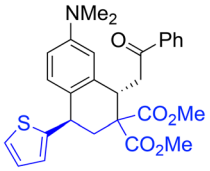
3d, Y = OMe: 64 h, 71%, 13:1 *dr*
3f, Y = Me: 48 h, 85%, 16:1 *dr*
3g, Y = F: 72 h, 76%, 16:1 *dr*
3h, Y = Cl: 72 h, 72%, 16:1 *dr*
3i, Y = Br: 54 h, 76%, 13:1 *dr*



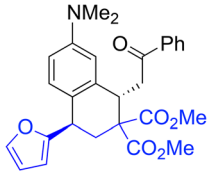
3e, 40 h, 91%, 13:1 *dr*



3j, 72 h, 53%, 3:1 *dr*



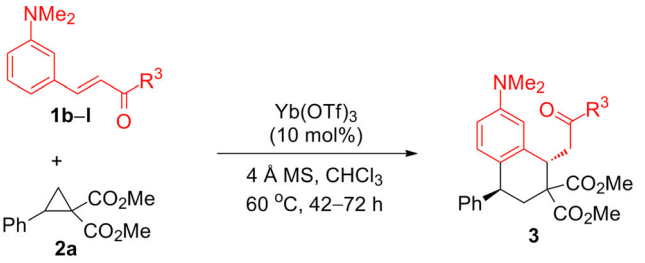
3k,72 h, 76%, 10:1 *dr*

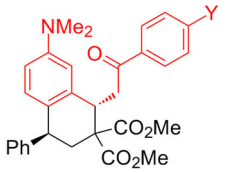


3l, 72 h, 51%, 16:1 *dr*

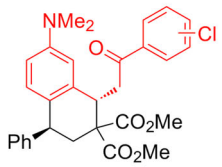
[a] All of the reactions were carried out in $CHCl_3$ (0.2 M) with **1a** (0.10 mmol), **2** (0.12 mmol), 4 Å molecular sieve (20 mg), and $Yb(OTf)_3$ (10 mol%). Isolated yields are shown.

Table 3. Substrate scope of the *m*-*N*,*N*-dimethylaminophenyl-α,β-unsaturated ketones in the Friedel–Crafts/Michael addition cascade reaction.[a]

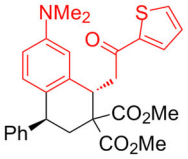




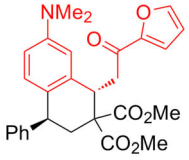
3m, Y = OMe: 72 h, 77%, 13:1 *dr*
3n, Y = Me: 72 h, 79%, 16:1 *dr*
3o, Y = F: 42 h, 64%, 16:1 *dr*
3p, Y = Br: 48 h, 76%, 12:1 *dr*



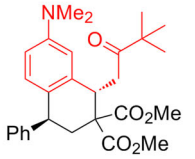
3q, *p*-Cl: 68 h, 73%, 13:1 *dr*
3r, *m*-Cl: 72 h, 66%, 12:1 *dr*
3s, *o*-Cl: 48 h, 81%, 16:1 *dr*



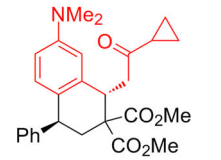
3t, 72 h, 61%, 12:1 *dr*



3u, 72 h, 75%, 16:1 *dr*

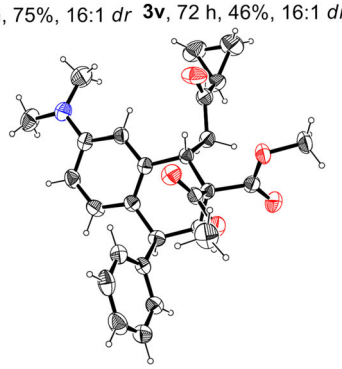


3v, 72 h, 46%, 16:1 *dr*



3w, 72 h, 75%, 10:1 *dr*

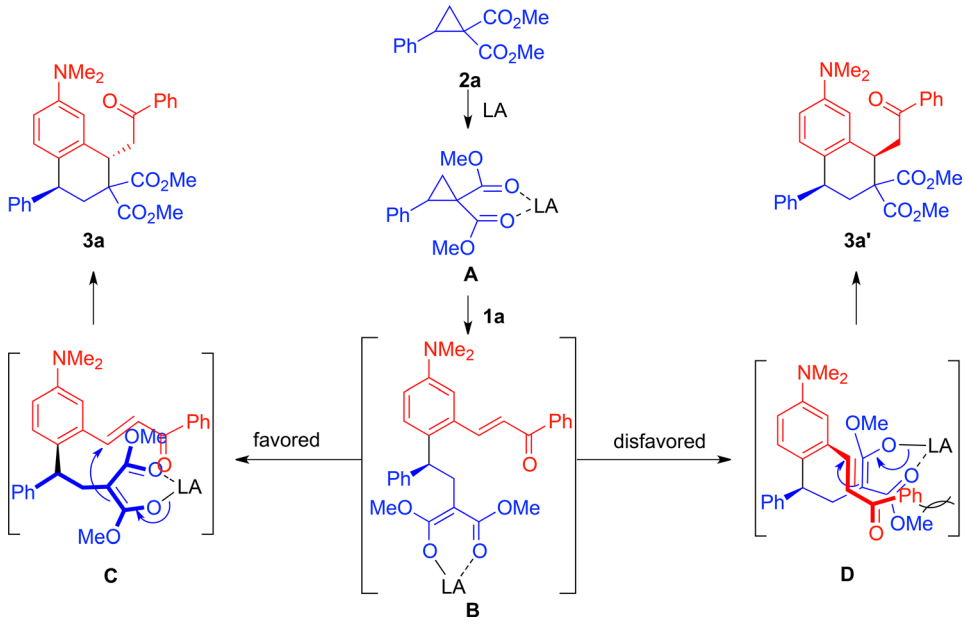
≡



[a] All of the reactions were carried out in $CHCl_3$ (0.2 M) with **1** (0.10 mmol), **2a** (0.12 mmol), 4 Å molecular sieve (20 mg), and $Yb(OTf)_3$ (10 mol%). Isolated yields are shown.

yields and with high diastereoselectivities. Halogen substituents in the 4-position of the benzene ring in D–A cyclopropane did not affect the reactivity or stereoselectivity; halo-substituted analogs **3g–i** were obtained in good yields from the corresponding D–A cyclopropanes **1g–i**. Moreover, cyclopropane **1j** with a styryl substituent provided the corresponding product **3j** in moderate yield, and the diastereoselectivity in this case was the lowest in the series. Notably, 1-heteroaryl-substituted tetralins **3k** and **3l** were also obtained when the corresponding D–A cyclopropanes **2k** and **l** bearing thienyl and furanyl groups, respectively, were reacted with substrate **1a**.

Next, the scope of *m*-*N*,*N*-dimethylaminophenyl-α,β-unsaturated ketones **1** was investigated, and the results are shown in Table 3. In the case of the R^3 group, the reactions proceeded well with electron-donating (**3m** and **3n**) and electron-withdrawing (**3o–3s**) substituents. Notably, the *ortho*-chloro substituent on the phenyl R^3 group afforded the corresponding product in a better reactivity and with a higher diastereoselectivity than the *meta*- or *para*-chloro substituents (**3s** *vs.* **3q** and **3r**). When a heteroaryl group was introduced at the R^3 position, the reactions showed good stereocontrol and produced the corresponding products **3t** and **3u** in good yields. Furthermore, the reac-



Scheme 2. Proposed mechanism of the reaction and origin of diastereoselectivity.

tions of aliphatic α,β-unsaturated ketones with a bulkier group, such as *tert*-butyl and cyclopropyl, proceeded smoothly to afford the corresponding products **3v** and **3w** with good stereoselectivities, even though the yield of product **3v** decreased slightly.

The relative configuration of product **3w** was found to be *trans* by single-crystal X-ray diffraction analysis; those of the others in this series were assigned by analogy.[12]

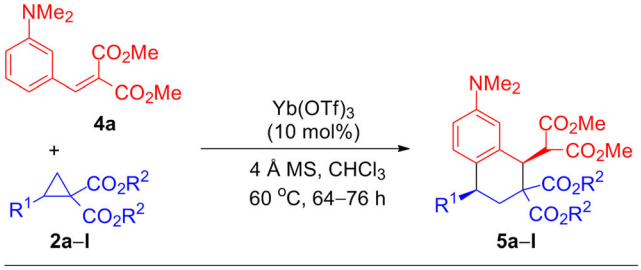
Based on the experimental results, the mechanism of this reaction is depicted in Scheme 2. The Lewis acid activates D–A cyclopropane **2a** generating complex **A**. Subsequent Friedel–Crafts type attack of the *m-(N,N*-dimethylanilinyl)-α,β-unsaturated phenyl ketone **1a** at the benzylic position provides ring-opening complex **B**. This intermediate **B** undergoes cyclization *via* the attack of the generated enolate on malonate, producing the corresponding tetralin. To align itself in the proper position for the intramolecular Michael addition, intermediate **B** can adopt two different conformations **C** and **D**. Conformer **D** suffers from a severe eclipsing interaction of the phenyl group with the malonyl methyl ester group, whereas conformer **C** experiences a less eclipsing interaction from its phenyl and ester moieties. The more stable conformer **C** is preferred over **D** providing product **3a** with a *trans* configuration of the 1,4-substituents.

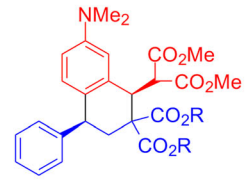
Interestingly, from examining the models and rough MM2 calculations of the intermediates to better understand the mechanism, the **D**-type conformer was found to be more stable than the **C**-type conformer when *m-N,N*-dimethylaminophenyl-substituted methylidenemalonate was used instead of *m-N,N*-dimethylaminophenyl-α,β-unsaturated ketone (see the Supporting Information for details).

Encouraged by these MM2 results, the cascade reactions of D–A cyclopropanes **2** with *m-N,N*-dimethylaminophenyl-substituted methylidenemalonate **4a** were subsequently investigated under the same optimized reaction conditions. As shown in Table 4, the reaction products, tetralin tetraesters, were obtained in moderate to good yields. As expected, the relative stereochemistry was found to be *cis* by the single-crystal X-ray diffraction data of **5f**.[12] With an increase in the sterically bulky benzyl ester group in D–A cyclopropane, the diastereoselectivity increased, whereas the yield decreased slightly (**5c**). The reactions tolerated cyclopropanes with electron-donating or electron-withdrawing groups, and the desired products **5d**–**5i** were obtained in good yields (62–88%) and with high diastereoselectivities (8:1 to 16:1 *dr*). When styryl-cyclopropane **1j** was reacted with **4a**, the corresponding product **5j** was obtained in a moderate yield and with a high diastereoselectivity. 1-Heteroaryl-substituted tetralins **5k** and **5l** were also obtained, even though the yield and diastereoselectivity were low in the case of **5k** (48%, 2:1 *dr*).

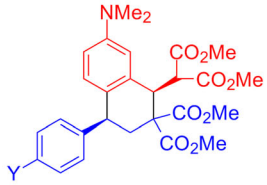
In conclusion, we have developed a simple and efficient protocol for the synthesis of 1,4-substituted tetralins *via* the reactions of *m-N,N*-dimethylaminophenyl-α,β-unsaturated carbonyls with D–A cyclopropanes in a cascade fashion. This method selectively provides both 1,4-substituted *cis* and *trans* tetralins depending on the *m-N,N*-dimethylaminophenyl-α,β-unsaturated carbonyls used. The reaction of *m-N,N*-dimethylaminophenyl-α,β-unsaturated ketones with D–A cyclo-

Table 4. Friedel–Crafts/Michael addition cascade reaction of *m-N,N*-dimethylaminophenyl methylidenemalonate **4a** with D–A cyclopropanes **2**.[a]

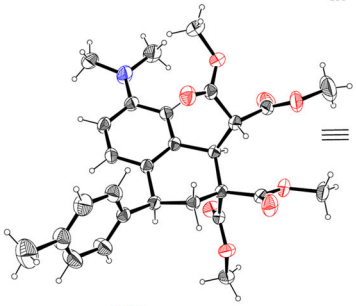


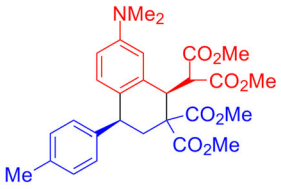


5a, R = Me: 72 h, 78%, 9:1 *dr*
5b, R = Et: 72 h, 82%, 4:1 *dr*
5c, R = Bn: 72 h, 51%, 16:1 *dr*

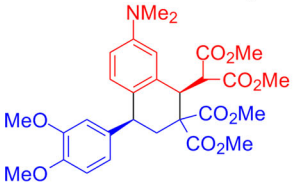


5d, Y = OMe: 68 h, 75%, 10:1 *dr*
5g, Y = F: 72 h, 62%, 16:1 *dr*
5h, Y = Cl: 72 h, 79%, 13:1 *dr*
5i Y = Br: 72 h, 88%, 13:1 *dr*

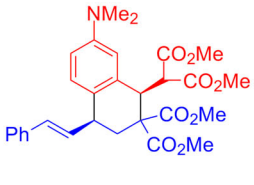




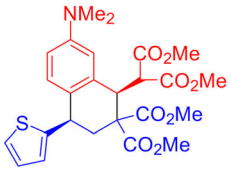
5f, 72 h, 86%, 8:1 *dr*



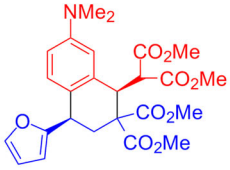
5e, 64 h, 83%, 13:1 *dr*



5j, 72 h, 58%, 9:1 *dr*



5k, 72 h, 75%, 7:1 *dr*



5l, 72 h, 48%, 2:1 *dr*

[a] All of the reactions were carried out in $CHCl_3$ (0.2 M) with **4a** (0.10 mmol), **2** (0.12 mmol), 4 Å molecular sieve (20 mg), and $Yb(OTf)_3$ (10 mol%). Isolated yields are shown.

propanes provided tetralins with a *trans* orientation of the 1,4-substitutents on the cyclohexyl ring, and *cis*-tetralins were obtained from *m-N,N*-dimethylamino-phenyl-substituted methylidenemalonates.

Experimental Section

General Procedure for the Friedel–Crafts/Michael Addition Cascade Reaction of D–A Cyclopropanes with *m-N,N*-Dimethylaminophenyl α,β-Unsaturated Carbonyls

To a solution of *m-N,N*-dimethylaminophenyl-α,β-unsaturated carbonyl **1** or **4a** (0.10 mmol, 1.0 equiv.), $Yb(OTf)_3$ (0.020 mmol, 20 mol%), and 4 Å molecular sieve in $CHCl_3$ (0.5 mL) was added D–A cyclopropane **2** (0.12 mmol, 1.2 equiv.). The resulting mixture was stirred at 60 °C until complete consumption of *m-N,N*-dimethylaminophenyl-α,β-unsaturated carbonyl **1** or **4a** was observed as determined by TLC. The resulting mixture was cooled to room temperature and was quenched with saturated $NaHCO_3$ solution. The mixture was extracted with CH_2Cl_2. The combined organic layer were washed with brine, dried over anhydrous $MgSO_4$, and concentrated under vacuum. The crude residue was purified by flash column chromatography with EtOAc/hexanes as the eluent to afford the desired tetralin compound **3**or **5**.

Acknowledgements

This research was supported by the Nanomaterial Technology Development Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT and Future Planning (NRF-2012M3A7B4049645) and the Basic Science Research Program through NRF funded by the Ministry of Education (NRF-2013R1A1A2009850).

References

[1] For biologically active compounds with the tetralin skeleton, see: a) M. Royer, V. Eparvier, B. Thibaut, D. Stien, G. Herbette, J. Beauchene, *Phytochemistry* **2010**, *71*, 1708; b) H. Xu, M. Lv, X. Tian, *Curr. Med. Chem.* **2009**, *16*, 327; c) A. Fiorentino, B. D'Abrosca, S. Pacifico, R. Iacovino, A. Izzo, P. Uzzo, A. Russo, B. Di Blasio, P. Monaco, *Tetrahedron* **2008**, *64*, 7782; d) A. Fiorentino, B. D'Abrosca, S. Pacifico, A. Natale, P. Monaco, *Phytochemistry* **2006**, *67*, 971; e) M. Gordaliza, P. A. Garcia, J. M. Miguel del Corral, M. A. Castro, M. A. Gomez-Zurita, *Toxicon* **2004**, *44*, 441; f) J. Piel, K. Hoang, B. S. Moore, *J. Am. Chem. Soc.* **2000**, *122*, 5415.

[2] For reviews on lignans and their biological activities, see: a) R. S. Ward, *Nat. Prod. Rep.* **1999**, *16*, 75; b) T. F. Imbert, *Biochimie* **1998**, *80*, 207; c) Y. Damayanthi, J. W. Lown, *Curr. Med. Chem.* **1998**, ***5***, 205; d) R. S. Ward, *Nat. Prod. Rep.* **1997**, *14*, 43.

[3] C. Sanchez, E. H. Reines, S. A. Montgomery, *Int. Clin. Psychopharmacol.* **2014**, *29*, 185.

[4] a) G. M. Cragg, *J. Ethnopharmacol.* **2005**, *100*, 72; b) K. R. Hande, *Eur. J. Cancer* **1998**, *34*, 1514.

[5] For reviews on the synthesis of aryltetralins and lignans, see: a) J.-S. Sun, H. Liu, X.-H. Guo, J.-X. Liao, *Org. Biomol. Chem.* **2016**, *14*, 1188; b) J.-Y. Pan, S.-L. Chen, M.-H. Yang, J. Wu, J. Sinkkonen, K. Zou, *Nat. Prod. Rep.* **2009**, *26*, 1251.

[6] a) M.-Y. Chang, Y.-C. Cheng, *Org. Lett.* **2016**, *18*, 608; b) R. A. Novikov, A. V. Tarasova, V. A. Korolev, E. V. Shulishov, V. P. Timofeev, Y. V. Tomilov, *J. Org. Chem.* **2015**, *80*, 8225; c) R. A. Novikov, A. V. Tarasova, V. A. Korolev, V. P. Timofeev, Y. V. Tomilov, *Angew. Chem.* **2014**, *126*, 3251; *Angew. Chem. Int. Ed.* **2014**, *53*, 3187; d) M. Davoust, J. A. Kitching, M. J. Fleming, M. Lautens, *Chem. Eur. J.* **2010**, *16*, 50; e) C. Dockendorff, S. Sahli, M. Olsen, L. Milhau, M. Lautens, *J. Am. Chem. Soc.* **2005**, *127*, 15028; f) V. Nair, R. Rajan, N. P. Rath, *Org. Lett.* **2002**, *4*, 1575.

[7] For reviews on D–A cyclopropanes, see: a) H. K. Grover, M. R. Emmett, M. A. Kerr, *Org. Biomol. Chem.* **2015**, *13*, 655; b) R. A. Novikov, V. Tomilov, *Mendeleev Commun.* **2015**, *25*, 1; c) F. De Nanteuil, F. De Simone, R. Frei, F. Benfatti, E. Serrano, J. Waser, *Chem. Commun.* **2014**, *50*, 10912; d) T. F. Schneider, J. Kaschel, D. B. Werz, *Angew. Chem.* **2014**, *216*, 5608; *Angew. Chem. Int. Ed.* **2014**, *53*, 5504; e) S. H. Liao, X. L. Sun, Y. Tang, *Acc. Chem. Res.* **2014**, *47*, 2260; f) M. A. Cavitt, L. H. Phun, S. France, *Chem. Soc. Rev.* **2014**, *43*, 804; g) F. D. Simone, J. Waser, *Synthesis* **2009**, 3353; h) C. A. Carson, M. A. Kerr, *Chem. Soc. Rev.* **2009**, *38*, 3051; i) M. Yu, B. L. Pagenkopf, *Tetrahedron* **2005**, *61*, 321; j) H. U. Reissig, R. Zimmer, *Chem. Rev.* **2003**, *103*, 1151.

[8] For selected recent examples of ring-opening reactions of D–A cyclopropanes, see: a) Y. Xia, L. Lin, F. Chang, X. Fu, X. Liu, X. Feng, *Angew. Chem. Int. Ed.* **2015**, *127*, 13952; *Angew. Chem. Int. Ed.* **2015**, *54*, 13748; b) K. L. Ivanov, E. V. Villemson, E. M. Budynina, O. A. Ivanova, I. V. Trushkov, M. Y. Melnikov, *Chem. Eur. J.* **2015**, *21*, 4975; c) L. K. B. Garve, P. Barkawitz, P. G. Jones, D. B. Werz, *Org. Lett.* **2014**, *16*, 5804; d) F. De Nanteuil, J. Loup, J. Waser, *Org. Lett.* **2013**, *15*, 3738; e) A. Kreuzer, S. Kerres, T. Ertl, H. Rücker, S. Amslinger, O. Reiser, *Org. Lett.* **2013**, *15*, 3420; f) S. M. Wales, M. M. Walker, J. S. Johnson, *Org. Lett.* **2013**, *15*, 2558.

[9] For selected recent examples of cycloadditions of D–A cyclopropanes, see: a) L. K. B. Garve, M. Petzold, P. G. Jones, D. B. Werz, *Org. Lett.* **2016**, ***18***, 564; b) H. Xu, J.-L. Hu, L. Wang, S. Liao, Y. Tang, *J. Am. Chem. Soc.* **2015**, *137*, 8006; c) H. Liu, C. Yuan, Y. Wu, Y. Xiao, H. Guo, *Org. Lett.* **2015**, *17*, 4220; d) Q.-Q. Cheng, Y. Qian, P. Y. Zavalij, M. P. Doyle, *Org. Lett.* **2015**, *17*, 3568; e) J. Zhang, S. Xing, J. Ren, S. Jiang, Z. Wang, *Org. Lett.* **2015**, *17*, 218; f) H.-H. Zhang, Y.-C. Luo, H.-P. Wang, W. Chen, P.-F. Xu, *Org. Lett.* **2014**, *16*, 4896; g) P. M. Truong, M. D. Mandler, P. Y. Zavalij, M. P. Doyle, *Org. Lett.* **2013**, *15*, 3278; h) Y. Miyake, S. Endo, T. Moriyama, K. Sakata, Y. Nishibayashi, *Angew. Chem.* **2013**, *125*, 1802; *Angew. Chem. Int. Ed.* **2013**, *52*, 1758.

[10] A. Kim, S.-G. Kim, *Eur. J. Org. Chem.* **2015**, 6419.

[11] For selected reviews on cascade reactions, see: a) L. Q. Lu, J. R. Chen, W. J. Xiao, *Acc. Chem. Res.* **2012**, *45*, 1278; b) H. Clavier, H. Pellissier, *Adv. Synth. Catal.* **2012**, *354*, 7134; c) D. W. C. MacMillan, A. M. Walji, *Synthesis* **2007**, 1477; d) H. Pellissier, *Tetrahedron* **2006**, *62*, 2143; e) K. C. Nicolaou, D. J. Edmonds, P. C. Bulger, *Angew. Chem.* **2006**, *118*, 7292; *Angew. Chem. Int. Ed.* **2006**, ***45***, 7134; f) L. F. Tietze, G. Brasche, K. M. Gericke, *Domino Reactions in Organic Synthesis*, Wiley-VCH, Weinheim, **2006**.

[12] CCDC 1458566 (**3w**) and CCDC 1458567 (**5f**) contain the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre *via* www.ccdc.cam.ac.uk/data_request/cif.

Stereoselective Cascade Reactions of Donor–Acceptor Cyclopropanes with *m-N,N*-Dialkylaminophenyl α,β-Unsaturated Carbonyls: Diastereoselective Synthesis of *cis*- and *trans*-Tetralins

Adv. Synth. Catal. **2016**, *358*, 1 – 7

Seunghui Sin, Sung-Gon Kim*