ORGANIC LETTERS
2013
Vol. 15, No. 4
871–873

A Concise Formal Synthesis of (−)-Hamigeran B

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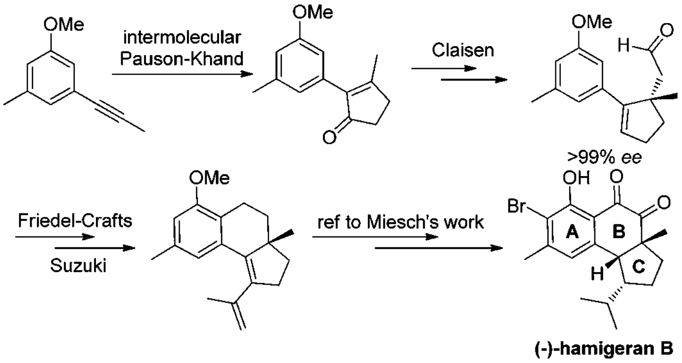
Received January 5, 2013

ABSTRACT



A concise and efficient formal synthesis of (−)-hamigeran B is reported. The critical intermediate was synthesized from 3-methoxy-5-methylphenyl trifluoromethanesulfonate with an 11-steps 7.2% total yield route. The chiral quaternary carbon was efficiently and steroselectively constructed through an intermolecular Pauson−Khand reaction and a Claisen rearrangement reaction with >99% *ee*; the cyclohexane B was then closed through an aldehyde Friedel−Crafts cyclization. Lastly, the isopropenyl group of ring C was introduced through a Suzuki coupling reaction.

Hamigeran B (**1**) is a member of the hamigerans which were first isolated from the poecilosclerid sponge *Hamigera tarangaensis* by Bergquist and Fromont.[1] Hamigeran B shows 100% *in vitro* inhibition against herpes and polio viruses at a concentration of 132 μg per disk and exhibits little cytotoxity. It also has strong *in vitro* antitumor activity against P-388 (IC_{50} = 13.5 μM). Because of its unique tricarbocyclic skeleton and high bioactivity, hamigeran B has been an attractive target for synthesis.

Since the first total synthesis of hamigeran B by the Nicolaou group,[2] several asymmetric and racemic total syntheses[3] or its core tricarbocyclic skeleton[4] have been reported. The generation of the three continuous chiral centers in (−)-hamigeran B could be achieved by asymmetric hydrogenation controlled by the stereocenter at C(9).[3a,d,4b]

Our retrosynthetic analysis of hamigeran B (Scheme 1) focused on constructing the Miesch's diene intermediate **2** which contains a chiral quaternary carbon center at C(9). The cyclohexane ring of **2** could be constructed through a Friedel−Crafts cyclization, and the isopropenyl group at C(5) could be introduced through a Suzuki cross-coupling from aldehyde **3**. The aldehyde **3** could be constructed by

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[1] Wellington, K. D.; Cambie, R. C.; Rutledge, P. S.; Bergquist, P. R. *J. Nat. Prod.* **2000**, *63*, 79.

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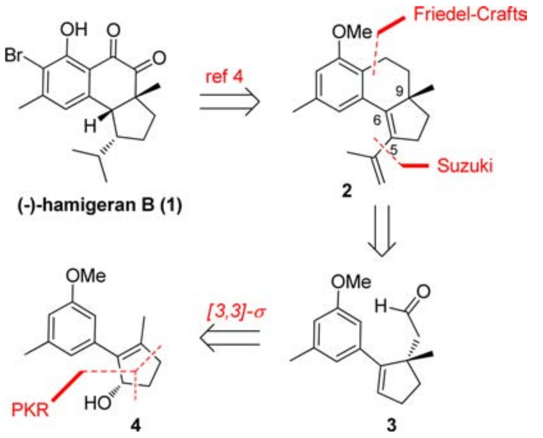
10.1021/ol400030a

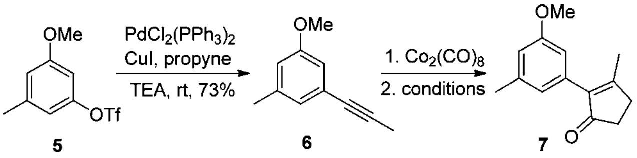
the [3,3]-sigmatropic rearrangement from a chiral cyclopentenol **4**. Cyclopentenol **4** was synthesized by an intermolecular Pauson−Khand reaction of aryl propyne with ethylene[5] and subsequent 1,2-reduction.

Scheme 1. Retrosynthetic Analysis of (−)-Hamigeran B



We prepared the aryl propyne **6** via Sonogashira coupling of the readily available triflate **5** and propyne.[6] Alkyne **6** was then subjected to different Pauson−Khand conditions with ethylene to afford the cyclopentenone **7** (Table 1). Only moderate yields were achieved when NMO, TMANO, or ^{n}BuSMe was used as a promoter because of the relative bulky 3-methoxy-5-methylphenyl moiety (entries 1−3).[7] However, an excellent result was achieved when excessive Me_2S (30 equiv) was applied with the reaction temperature raised to 130 °C (entry 5). The reaction was very clean; the cyclopentenone **7** was separated by simple filtration through a Celite pad, and no further purification was needed.

Table 1. Optimization of the Intermolecular Pauson−Khand Reaction of **6** with Ethylene

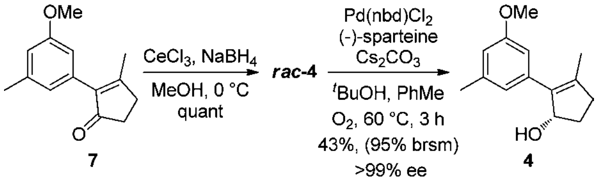


entry	promotors	conditions[a]	yield[b] (%)
1	TMANO (9 equiv)	PhMe, 40 °C	59
2	NMO (6 equiv)	DCM, 4 Å MS, rt	56
3	^{n}BuSMe (3.5 equiv)	$ClCH_2CH_2Cl$, 83 °C	44
4	Me_2S (30 equiv)	$ClCH_2CH_2Cl$, 83 °C	70
5	Me_2S (30 equiv)	xylene, 130 °C	89

[a] The pressure of ethylene used is ∼30 bar. [b] Yield of isolated product.

We anticipated a direct enantioselective carbonyl reduction of **7** to produce the key chiral intermediate cyclopentenol **4**. Unfortunately, we were able to obtain only low to moderate *ee* values under the conditions of CBS or Midland reduction.[8] The reactions normally proceeded slowly, and the byproducts increased gradually. This indicated that the steric hindrance of the cyclopentenone **7** might have prevented the approach of chiral reagents. Therefore, we seek other accesses to chiral cyclopentenol **4**. Among which, kinetic resolution is a good choice. Cyclopentone **7** was first converted into the corresponding racemic cyclopentenol in almost quantitative yield via a Luche reduction (Scheme 2), and then the gross product was subjected directly to the Pd-catalyzed oxidative resolution conditions developed by the Stoltz group.[9] Nearly optically pure cyclopentenol **4** (>99% *ee*) was obtained in 43% yield, and cyclopentenone **7** could be recovered in 52% yield by this procedure. This reaction could be applied well to a 15-g scale, and the recovered cyclopentenone **7** could be recycled.

Scheme 2. Kinetic Resolution of Allylic Alcohol **4**



Next, chiral allylic alcohol **4** was subjected to Claisen rearrangement conditions. However, neither Ireland−Claisen[10] nor Johnson−Claisen[11] conditions could work. A reductive Claisen rearrangement, reported also by the Stoltz group, proved to be effective (Scheme 3).[12] Cyclopentenol **4** was converted into the corresponding vinyl ester **8** via a Hg-catalyzed vinylation,[13] and **8** was prone to [3,3]-sigmatropic rearrangement in the presence of DIBAL-H to yield alcohol **9**. The configuration of the chiral quaternary carbon center contained in **9** was controlled by the substrate **4**.

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Scheme 3. Construct of the A/B/C Tricarbocyclic Skeleton

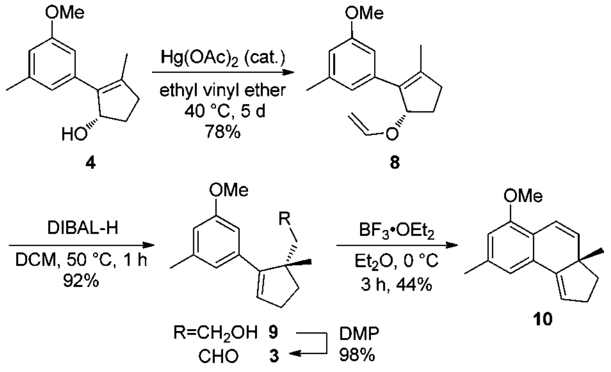
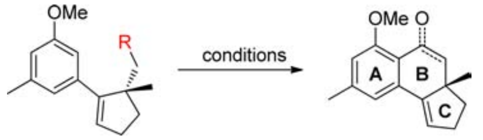


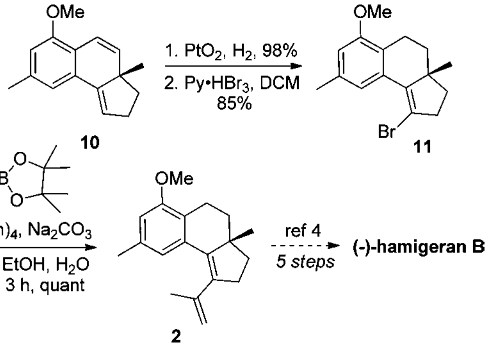
Table 2. Construct of the A/B/C Tricarbocyclic Skeleton



entry	R	conditions	[c]yield (%)
1	CH_2OH	BF_3•OEt_2, OEt_2, rt	–
2	CH_2OTs	TMEDA, ^{n}BuLi, THF, −78 °C	–
3	COCl	DCM, $AlCl_3$, 0 °C	–
4	CHO	$TiCl_4$, OEt_2, rt	–
5[a]	CHO	BF_3•OEt_2, OEt_2, rt	28
6[b]	CHO	BF_3•OEt_2, OEt_2, 0 °C	44

[a] In a 0.1 M solution, *ortho*/*para* = 1:1. [b] In a 0.008 M solution, *ortho*/*para* = 3:2. [c] Isolated yield of ortho isomer.

Scheme 4. Synthesis of Key Intermediate **2**



Subsequently, we tried to close the cyclohexane B through a Friedel–Crafts reaction (Table 2). Friedel–Crafts cyclization of **9** or its oxidation product carboxylic acid (R = COX) failed (entries 1, 3). Cyclization of its sulfonates (R = CH_2OTs) with the *ortho*-MeO-directed lithiation of the benzene ring was also problematic (entry 2). A direct Friedel–Crafts cyclization with aldehyde (R = CHO) was also tried (entries 4–6). Oxidation of **9** with DMP afforded the aldehyde **3**, and cyclization according to the Taber protocol by treatment with BF_3•Et_2O in diluted ether at 0 °C afforded diene **10** in 44% yield (*ortho*/*para* = 3:2).[14]

Hydrogenation of the less substituted double bond using Adam's catalyst in EtOH gave a nearly quantitative yield, and the crude product was treated directly with Py•HBr_3 in dry DCM at 0 °C and afforded the allyl bromide **11** in 85% yield (Scheme 4).[15] A Suzuki coupling of **11** with an isopropenyl borate gave diene **2** with the desired isopropenyl group,[16] which had previously been converted to hamigeran B in five steps.[3b,e,4b] Therefore, we completed the formal synthesis of (−)-hamigeran B.

In summary, we have developed an efficient and concise formal synthesis of (−)-hamigeran B in an 11-step, 7.2% total yield. The key steps involve an intermolecular Pauson–Khand reaction and a reductive Claisen rearrangement. The route is highly enantioselective and essentially free of protecting groups. Besides, minimum or no column chromatography separations and purifications in most of the steps were needed because of the generally high conversions as well as excellent regioslectivity and yields. In fact, we have presented a general and efficient method to construct a chiral quaternary carbon center containing a five-membered ring, via a Pauson–Khand/asymmetric reduction/[3,3]-sigmatropic process.

Acknowledgment. This work was supported by the National Basic Research Program of China (973-2010CB833200 and 973-2010CB833300), the National Natural Science Foundation of China (20832007 and 21102167), the Science and Technology Commission of Shanghai Municipality (12DZ1930902), and the Knowledge Innovation Program of the Chinese Academy of Sciences.

Supporting Information Available. Full experimental details, spectroscopic data, and copies of ^1H and ^{13}C NMR for compounds **2**–**11**. This material is available free of charge via the Internet at http://pubs.acs.org.

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The authors declare no competing financial interest.