Total Synthesis

Deutsche Ausgabe: DOI: 10.1002/ange.201601834
Internationale Ausgabe: DOI: 10.1002/anie.201601834

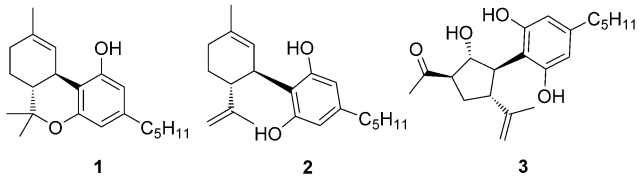
Synthesis of (−)-Cannabimovone and Structural Reassignment of Anhydrocannabimovone through Gold(I)-Catalyzed Cycloisomerization

*Javier Carreras, Mariia S. Kirillova, and Antonio M. Echavarren**

Dedicated to Professor Miquel A. Pericàs on the occasion of his 65th birthday

Abstract: *The first total synthesis of cannabimovone from Cannabis sativa and anhydrocannabimovone was achieved by means of a highly stereoselective gold(I)-catalyzed cycloisomerization. The results led to reassignment of the structure of anhydrocannabimovone.*

The herbaceous plant *Cannabis sativa* has been used in medicine for centuries and still attracts significant interest due to the biological and pharmaceutical activity of many of its metabolites.[1] More than 60 compounds, known as cannabinoids (a group of C_{21} terpenophenolic compounds), are exclusively found in *Cannabis sativa*.[2] Owing to the development of synthetic cannabinoids,[3,4] the unique components of *Cannabis sativa* are known as phytocannabinoids. The most abundant compound is Δ^9-tetrahydrocannabinol (THC, **1**; Figure 1), which shows interesting pharmacological activity as an analgesic, antiemetic, and appetite stimulant, among others, besides its well-known psychotropic effects.[5] Several total syntheses of **1** have been accomplished to date.[6]

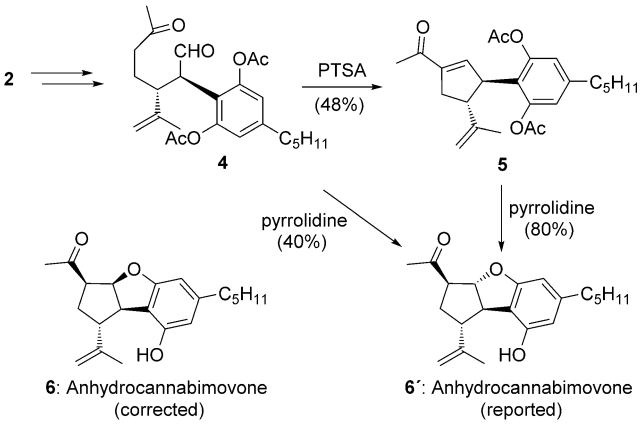


1 2 3

Figure 1. Cannabinoids THC (**1**), CBD (**2**), and cannabimovone (**3**).

Cannabidiol (CBD, **2**) is another important phytocannabinoid with great potential as a drug[7] since it modulates the undesired effects of THC when they are administrated together.[8]

A structurally different cannabinoid named cannabimovone (**3**) has recently been isolated by the groups of Taglialatela-Scafati and Appendino from a nonpsychotropic variety of hemp (*Cannabis sativa L.*; Figure 1).[9] In their attempt at preparing **3** from CBD (**2**) through an intramolecular aldol reaction of keto aldehyde **4** under mild acidic conditions, the product of dehydration (**5**) was formed instead (Scheme 1). Under basic conditions, the novel cannabinoid

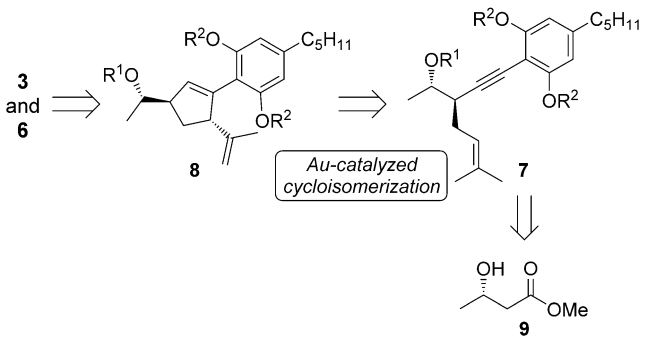


Scheme 1. Synthesis of anhydrocannabimovone (**6**) from cannabidiol (CBD, **2**).[9]

anhydrocannabimovone (**6**) was directly formed through an intramolecular oxy-Michael addition of one of the phenol groups to the intermediate enone. Synthetic **6** was found to be active against metabotropic and ionotropic cannabinoid receptors, showing a similar biological profile to THC, whereas cannabimovone (**3**) has affinity only for ionotropic receptors.[9]

The unprecedented *abeo*-menthane terpenoid structure of cannabimovone (**3**) includes a densely functionalized cyclopentane with four contiguous stereocenters. The novel structure of **3**, coupled with its lability towards dehydration under acidic or basic conditions and the interesting biological profiles of both **3** and **6**, inspired us to develop a total synthesis that could allow access to a wide variety of

[*] Dr. J. Carreras, M. S. Kirillova, Prof. A. M. Echavarren
Institute of Chemical Research of Catalonia (ICIQ)
Barcelona Institute of Science and Technology
Av. Països Catalans 16, 43007 Tarragona (Spain)
E-mail: aechavarren@iciq.es
Prof. A. M. Echavarren
Departament de Química Analítica i Química
Orgànica, Universitat Rovira i Virgili
C/ Marcel·li Domingo s/n, 43007 Tarragona (Spain)
Supporting information and the ORCID identification number(s) for the author(s) of this article can be found under http://dx.doi.org/10.1002/anie.201601834.

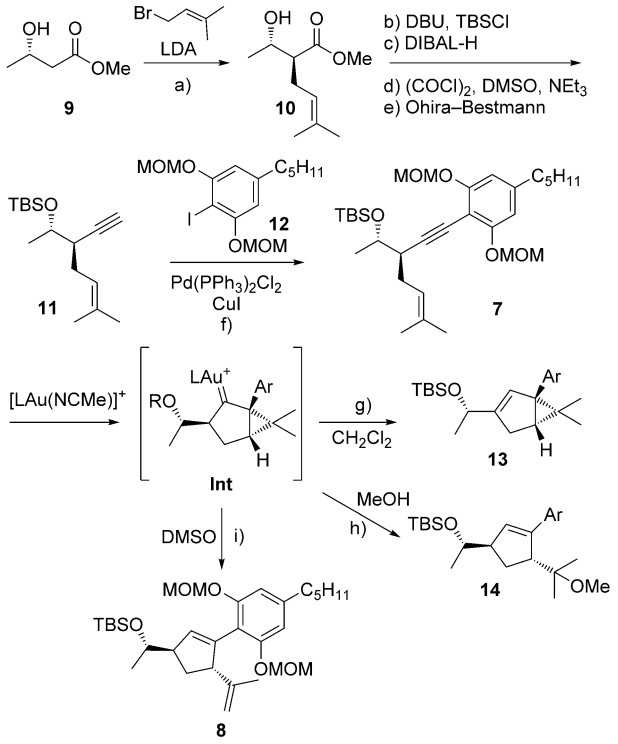


Scheme 2. Retrosynthetic analysis for **3** and **6**.

analogues. Herein, we report the first total synthesis of enantiopure cannabimovone (**3**) and also revise the structure originally assigned to anhydrocannabimovone from *trans*-fused **6′** to *cis*-tetrahydro-1*H*-cyclopenta[*b*]benzofuran **6**. Our approach to the synthesis of these compounds relies on a gold(I)-catalyzed cycloisomerization[10–15] of aryl-substituted 1,5-enyne **7**, which could be obtained in a few steps from commercially available (+)-methyl (*S*)-3-hydroxybutyrate (**9**; Scheme 2).

The synthesis commenced with alkylation of the lithium enolate of **9** with prenyl bromide to provide known compound **10** with excellent diastereoselectivity (98:2) by following a slight modification of the reported procedure[16] (Scheme 3). Protection of the alcohol of **10** as a silyl ether, conversion of the ester into an aldehyde by a two-step procedure (DIBAL reduction/Swern oxidation), and subsequent homologation with the Ohira–Bestmann reagent led to 1,5-enyne **11** (31% over 5 steps). Sonogashira coupling of **11** with iodo arene **12**, prepared in two steps from olivetol, gave **7** in 83% yield on a multi-gram scale. The gold(I)-catalyzed cyclization of 1,5-enyne **7** was highly solvent dependent. Exposing **7** to the cationic gold(I) complex [(JohnPhos)Au(MeCN)]SbF_6 in CH_2Cl_2 led to bicyclic compound **13** (49%). A similar result was obtained using other solvents such as Et_2O or toluene. Reaction in MeOH afforded methyl ether **14** (93%). However, when the reaction was performed in DMSO, cyclopentene **8** was obtained in excellent yield (88%). This reaction was performed up to a 2.1 g scale. A similar result was observed when the reaction was performed in DMF (79%). Presumably, the initial intermediate of the gold(I)-catalyzed cyclization (**Int**) undergoes proton elimination assisted by the solvent to give **8** after protodeauration. Notably, the gold-catalyzed cyclization led exclusively to the product with the correct relative configuration, thereby setting two of the final four stereocenters.

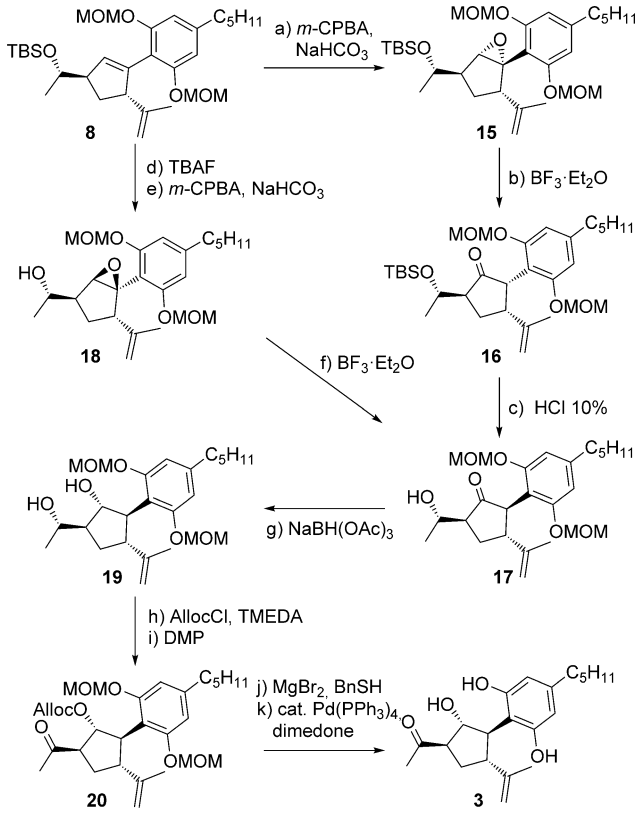
Although deprotection of the TBS group of **8** followed by oxidation of the alcohol to the methyl ketone could be carried out uneventfully, isomerization to form the α,β-unsaturated ketone failed under all the conditions we examined with this and with other intermediates with different phenol protecting groups. Fortunately, the desired functionality in the five-membered ring could be introduced by epoxidation with *m*-CPBA and $NaHCO_3$ to exclusively form **15**, followed by Meinwald rearrangement with stoichiometric $BF_3{\cdot}Et_2O$ to



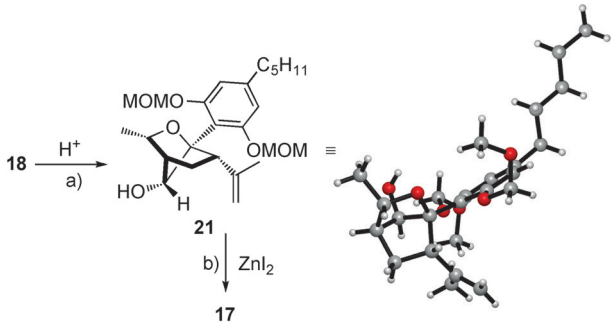
Scheme 3. a) LDA, HMPA, prenyl bromide, THF, −70 °C to −10 °C, 3 h, 81%; b) TBSCl, DBU, CH_2Cl_2, 25 °C, 14 h, 89%; c) DIBAL-H, Toluene, −78 °C to −50 °C, 4 h, 84%; d) Oxalyl chloride, DMSO, Et_3N, CH_2Cl_2, −60 °C to 25 °C, 1 h; e) Ohira–Bestmann reagent, K_2CO_3 MeOH, 25 °C, 5 h, 51% (2 steps); f) $Pd(PPh_3)_2Cl_2$ (5 mol %), CuI (10 mol %), Et_3N/iPr_2EtN (1:1), 25 °C, 16 h, 83%; g) [(JohnPhos)Au(MeCN)]SbF_6 (5 mol %), CH_2Cl_2 1 M, 25 °C, 30 min, 49%; h) [(JohnPhos)Au(MeCN)]SbF_6 (5 mol %), MeOH 1 M, 25 °C, 30 min, 93%. i) [(JohnPhos)Au(MeCN)]SbF_6 (5 mol %), DMSO 0.5 M, 25 °C, 3 h, 88%. LDA = lithium diisopropylamide, HMPA = hexamethylphosphoramide, THF = tetrahydrofuran, TBSCl = *tert*-butylsilyl chloride, DBU = 1,8-diazabicyclo[5.4.0]undec-7-ene, DIBAL-H = diisobutylalane, DMSO = dimethyl sulfoxide, JohnPhos = (2-biphenyl)-di-*tert*-butylphosphine.

give ketone **16** (2,3-*cis*). Epimerization and cleavage of the silyl ether was achieved with aqueous HCl to give **17** (Scheme 4). The relative configuration of **17** was determined by NMR studies and was confirmed by preparation of the same compound by a different route, namely cleavage of the TBS group of **8** followed by epoxidation to give **18**, which underwent Meinwald rearrangement to provide **17**. Diastereoselective reduction of β-hydroxy ketone **17** by Saksena–Evans reaction with $NaBH(OAc)_3$ in CH_2Cl_2 afforded diol **19**. Protection with AllocCl, which proceeded with moderate selectivity, followed by Dess–Martin oxidation gave protected cannabimovone **20**. Cleavage of the MOM groups using $MgBr_2$ and BnSH,[17] followed by Pd^0 deprotection of the allyl carbonate provided **3** (53% over 2 steps). The spectral data and optical rotation of the synthetic cannabimovone (**3**) matched those reported for the natural compound.[18]

Whereas the synthesis of **3** fully supported the assigned configuration for all of the intermediates, a crystalline oxabicycle intermediate **21** was obtained through treatment of epoxide **18** with a Brønsted acid, which led to opening of the

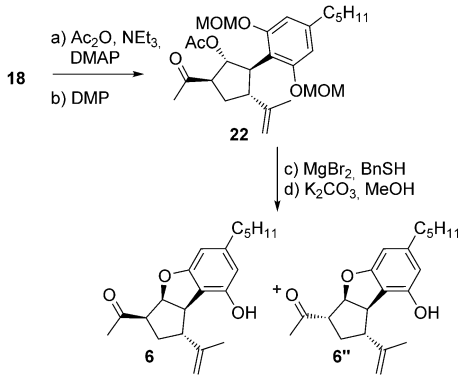


Scheme 4. a) *m*CPBA, $NaHCO_3$, CH_2Cl_2, 0 °C to 25 °C, 3 h, 57%; b) $BF_3{\cdot}OEt_2$, THF, 25 °C, 30 min, 93%; c) HCl dil./THF, 25 °C, 1 h, 88%; d) TBAF, THF, 25 °C, 14 h, 83%; e) *m*CPBA, $NaHCO_3$, CH_2Cl_2, 0 °C to 25 °C, 4 h, 58%; f) $BF_3{\cdot}OEt_2$, THF, 25 °C, 1 h, 48%; g) $NaBH(OAc)_3$, CH_2Cl_2, 25 °C, 48 h, 48% (77% brsm); h) AllocCl, TMEDA, CH_2Cl_2, −40 °C, 1.5 h, 41% (72% brsm); i) DMP, $NaHCO_3$, CH_2Cl_2, 25 °C, 1.5 h, 87%; j) $MgBr_2$, BnSH, Et_2O, 25 °C, 30 h, 62%; k) $Pd(PPh_3)_4$ (5 mol %), dimedone, THF, 25 °C, 1 h, 85%. *mCPBA* = *m*-chloroperbenzoic acid, TBAF = tetrabutylammonium fluoride, Alloc = allyloxycarbonyl, TMEDA = tetramethylethylenediamine, DMP = Dess–Martin periodinane.



Scheme 5. a) *m*-$ClC_6H_4CO_2H$, CH_2Cl_2, 25 °C, 1 h, 77%; b) ZnI_2, ($NaBH_4$), $(CH_2Cl)_2$, 25 °C, 14 h, 63%. X-Ray structure for **21**.

epoxide and trapping of the benzylic carbocation by the free alcohol (Scheme 5). The molecular structure of **21** was determined by X-ray diffraction, which confirmed the relative configuration between the isopropenyl and the hydroxyethyl substituents.[19] Treatment of **21** with ZnI_2 effected a pinacol rearrangement to give ketone **17**.



Scheme 6. a) Ac_2O, Et_3N, DMAP, CH_2Cl_2, −30 °C, 1 h, 50% (56% brsm); b) DMP, $NaHCO_3$, CH_2Cl_2, 25 °C, 1 h, 73%; c) $MgBr_2$, BnSH, Et_2O, 25 °C, 24 h, 82%; d) K_2CO_3, MeOH, 25 °C, 15 min, 60% (**6**) and 19% (**6″**).

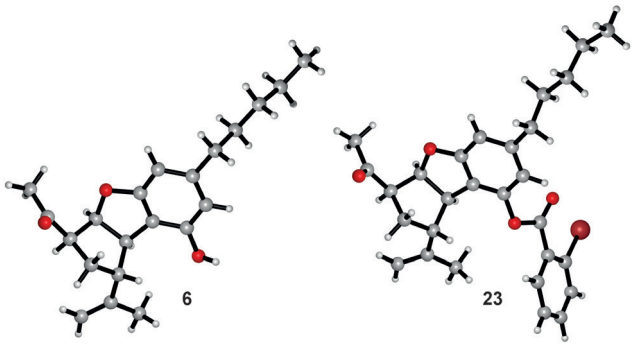


Figure 2. X-Ray structures for **6** and **23**.

The synthesis of anhydrocannabimovone (**6**) was carried out from acetate **22** by MOM cleavage followed by treatment with K_2CO_3 to promote the oxy-Michael addition. Under these conditions, two separable epimers (**6** and **6″**) were formed in a 4:1 ratio (Scheme 6). Surprisingly, although ^{1}H NMR of the major isomer **6** was identical to that reported for anhydrocannabimovone, very significant differences were observed in the ^{13}C NMR spectrum.[20] Furthermore, the optical rotation of **6** ($[\alpha]_D^{22} = +40.6°$ ($c = 0.29$, $CHCl_3$)) was very different to that reported ($[\alpha]_D^{22} = -17°$ ($c = 0.02$, $CHCl_3$)).[9] The structure of anhydrocannabimovone (**6**) was finally confirmed by X-ray diffraction[19] and its absolute configuration was assigned on the basis of the X-ray structure of anhydrocannabimovone 2-bromobenzoate (**23**; Figure 2).[19]

In order to clarify the discrepancy between our structural assignment and that originally reported,[9] we performed DFT calculations to study the oxy-Michael cyclization. Under basic conditions, oxy-Michael cyclization of the phenolate anion leads to *cis* fusion, which is more favored than the *trans* addition by 19.8 Kcal mol^{-1} (Figure 3).[21] Furthermore, DFT calculations were employed to predict the expected ^{13}C NMR chemical shifts of the different possible products.[22] Our data were in better agreement with the *cis*-tetrahydro-1*H*-

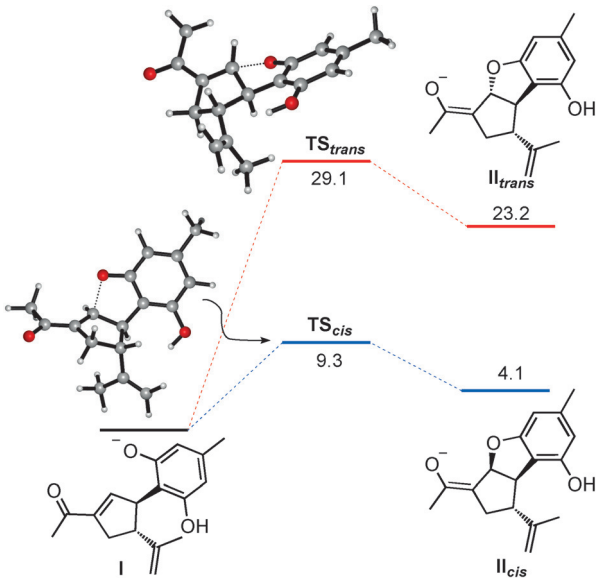


Figure 3. Energy profile (*cis* and *trans*) for the oxy-Michael cyclization. DFT calculations (M06-2x/6-31G(d,p) (MeOH), ΔG (kcal mol^{-1}).

cyclopenta[*b*]benzofuran structure for anhydrocannabimovone (**6**).[20]

In conclusion, we have accomplished the first total synthesis of cannabimovone (**3**). The four stereogenic centers of the target molecule were set up starting from the stereogenic center present in commercially available (+)-methyl (*S*)-3-hydroxybutyrate (**9**) and by using a fully diastereoselective gold(I)-catalyzed cyclization. Interestingly, this is the first example of the cycloisomerization of simple 1,5-enynes into 3-vinylcyclopent-1-enes catalyzed by gold in the context of natural product synthesis. We also synthesized anhydrocannabimovone (**6**) and revised the stereochemistry at the ring fusion by X-ray crystallography and DFT calculations. This synthetic endeavor provides ready access to **3** and **6**, as well as other synthetic cannabinoids, for biological testing.

Acknowledgements

We thank MINECO (Severo Ochoa Excellence Accreditation 2014-2018 (SEV-2013-0319), and project CTQ2013-42106-P), the European Research Council (Advanced Grant No. 321066), the AGAUR (2014 SGR 818 and Beatriu de Pinós Postdoctoral Fellowship to J. C.), and the ICIQ Foundation. We thank the ICIQ X-ray Diffraction and Chromatograpy units. We also thank Núria Huguet and Verónica L. Carrillo (ICIQ) for additional experiments and Dr. G. Jiménez-Osés (Universidad de La Rioja) for computational advice.

Keywords: cannabinoids · cycloisomerization · gold · oxy-Michael reaction · total synthesis

How to cite: *Angew. Chem. Int. Ed.* **2016**, *55*, 7121–7125
Angew. Chem. **2016**, *128*, 7237–7241

[1] a) G. A. Thakur, R. I. Duclos Jr, A. Makriyannis, *Life Sci.* **2005**, *78*, 454–466; b) *Marijuana and the Cannabinoids* (Ed. M. A. ElSohly), Humana, Totowa, NJ, **2007**; c) P. J. Robson, *Drug Test. Anal.* **2014**, *6*, 24–30; d) R. Mechoulam, L. O. Hanus, R. Pertwee, A. C. Howlett, *Nat. Rev. Neurosci.* **2014**, *15*, 757–764; e) Special issue, *Nature* **2015**, *525*, S1–S18.

[2] O. Aizpurua-Olaizola, U. Soydaner, E. Öztürk, D. Schibano, Y. Simsir, P. Navarro, N. Etxebarria, A. Usobiaga, *J. Nat. Prod.* **2016**, *79*, 324–331.

[3] For example: a) R. A. Archer, W. B. Blanchard, W. A. Day, D. W. Johnson, E. R. Lavagnino, C. W. Ryan, J. E. Baldwin, *J. Org. Chem.* **1977**, *42*, 2277–2284; b) R. Mechoulam, N. Lander, A. University, J. Zahalka, *Tetrahedron: Asymmetry* **1990**, *1*, 315–318; c) S. H. Burstein, C. A. Audette, A. Breuer, W. A. Devane, S. Colodner, S. A. Doyle, R. Mechoulam, *J. Med. Chem.* **1992**, *35*, 3135–3141.

[4] a) D. D. Dixon, D. Sethumadhavan, T. Benneche, A. R. Banaag, M. A. Tius, G. A. Thakur, A. Bowman, J. T. Wood, A. Makriyannis, *J. Med. Chem.* **2010**, *53*, 5656–5666; b) F. Gläser, M. C. Bröhmer, T. Hurrle, M. Nieger, S. Bräse, *Eur. J. Org. Chem.* **2015**, 1516–1524.

[5] a) J. Zajicek, P. Fox, H. Sanders, D. Wright, J. Vickery, A. Nunn, A. Thompson, *Lancet* **2003**, *362*, 1517–1526; b) K. R. Müller-Vahl, H. Prevedel, K. Theloe, H. Kolbe, H. M. Emrich, U. Schneider, *Neuropsychopharmacology* **2003**, *28*, 384–388; c) K. Mackie, *Annu. Rev. Pharmacol. Toxicol.* **2006**, *46*, 101–122; d) A. T. El-Alfy, K. Ivey, K. Robinson, S. Ahmed, M. Radwan, D. Slade, I. Khan, M. ElSohly, S. Ross, *Pharmacol. Biochem. Behav.* **2010**, *95*, 434–442; e) M. E. Lynch, F. Campbell, *Br. J. Clin. Pharmacol.* **2011**, *72*, 735–744.

[6] a) D. A. Evans, E. A. Shaughnessy, D. M. Barnes, *Tetrahedron Lett.* **1997**, *38*, 3193–3194; b) B. M. Trost, K. Dogra, *Org. Lett.* **2007**, *9*, 861–863; c) L.-J. Cheng, J.-H. Xie, Y. Chen, L.-X. Wang, Q.-L. Zhou, *Org. Lett.* **2013**, *15*, 764–767; d) M. A. Schafroth, G. Zuccarello, S. Krautwald, D. Sarlah, E. M. Carreira, *Angew. Chem. Int. Ed.* **2014**, *53*, 13898–13901; *Angew. Chem.* **2014**, *126*, 14118–14121; e) F. Klotter, A. Studer, *Angew. Chem. Int. Ed.* **2015**, *54*, 8547–8550; *Angew. Chem.* **2015**, *127*, 8667–8670.

[7] a) R. Mechoulam, L. A. Parker, R. Gallily, *J. Clin. Pharmacol.* **2002**, *42*, 11S–19S; b) C. Scuderi, D. D. Filippis, T. Iuvone, A. Blasio, A. Steardo, G. Esposito, *Phytother. Res.* **2009**, *23*, 597–602; c) E. Blessing, M. Steenkamp, J. Manzanares, C. Marmar, *Neurotherapeutics* **2015**, *12*, 825–836.

[8] a) I. G. Karniol, I. Shirakawa, N. Kasinski, A. Pfeferman, E. A. Carlini, *Eur. J. Pharmacol.* **1974**, *28*, 172–177; b) C. J. A. Morgan, G. Schafer, T. P. Freeman, H. V. Curran, *Br. J. Psychiatry* **2010**, *197*, 285–290; c) J. Sastre-Garriga, C. Vila, S. Clissold, X. Montalban, *Expert Rev. Neurother.* **2011**, *11*, 627–637.

[9] O. Taglialatela-Scafati, A. Pagani, F. Scala, L. De Petrocellis, V. Di Marzo, G. Grassi, G. Appendino, *Eur. J. Org. Chem.* **2010**, 2067–2072.

[10] a) C. Nieto-Oberhuber, M. P. Muñoz, S. López, E. Jiménez-Núñez, C. Nevado, E. Herrero-Gómez, M. Raducan, A. M. Echavarren, *Chem. Eur. J.* **2006**, *12*, 1677–1693; b) V. López-Carrillo, N. Huguet, Á. Mosquera, A. M. Echavarren, *Chem. Eur. J.* **2011**, *17*, 10972–10978.

[11] R. Dorel, A. M. Echavarren, *Chem. Rev.* **2015**, *115*, 9028–9072.

[12] Synthesis of indenes by cycloisomerization of 1,5-enynes: A. Martínez, P. García-García, M. A. Fernández-Rodríguez, F. Rodríguez, R. Sanz, *Angew. Chem. Int. Ed.* **2010**, *49*, 4633–4637; *Angew. Chem.* **2010**, *122*, 4737–4741.

[13] Total synthesis through gold- or platinum catalyzed cycloisomerization of 1,5-enynes: a) V. Mamane, T. Gress, H. Krause, A. Fürstner, *J. Am. Chem. Soc.* **2004**, *126*, 8654–8655; b) Y. Harrak, C. Blaszykowski, M. Bernard, K. Cariou, E. Mainetti, V.

Mouriès, A.-L. Dhimane, L. Fensterbank, M. Malacria, *J. Am. Chem. Soc.* **2004**, *126*, 8656 – 8657; c) A. Fürstner, P. Hannen, *Chem. Eur. J.* **2006**, *12*, 3006 – 3019; d) A. Fürstner, A. Schlecker, *Chem. Eur. J.* **2008**, *14*, 9181 – 9191; e) G. Lemière, V. Gandon, K. Cariou, A. Hours, T. Fukuyama, A.-L. Dhimane, L. Fensterbank, M. Malacria, *J. Am. Chem. Soc.* **2009**, *131*, 2993 – 3006.

[14] Total synthesis through gold-catalyzed Conia-type cyclizations of 1,5-enynes: a) S. T. Staben, J. J. Kennedy-Smith, D. Huang, B. K. Corkey, R. L. LaLonde, F. D. Toste, *Angew. Chem. Int. Ed.* **2006**, *45*, 5991 – 5994; *Angew. Chem.* **2006**, *118*, 6137 – 6140; b) X. Linghu, J. J. Kennedy-Smith, F. D. Toste, *Angew. Chem. Int. Ed.* **2007**, *46*, 7671 – 7673; *Angew. Chem.* **2007**, *119*, 7815 – 7817; c) G. Bellavance, L. Barriault, *Angew. Chem. Int. Ed.* **2014**, *53*, 6701 – 6704; *Angew. Chem.* **2014**, *126*, 6819 – 6822.

[15] Reviews on the application of gold catalysis to the synthesis of natural products: a) A. Fürstner, *Chem. Soc. Rev.* **2009**, *38*, 3208 – 3221; b) M. Rudolph, A. S. K.; Hashmi, *Chem. Soc. Rev.* **2012**, *41*, 2448 – 2462; Hashmi, *Chem. Soc. Rev.* **2012**, *41*, 2448 – 2462; c) A. Fürstner, *Acc. Chem. Res.* **2014**, *47*, 925 – 938; d) Y. Zhang, T.; Luo, Z. Yang, *Nat. Prod. Rep.* **2014**, *31*, 489 – 503; Luo, Z. Yang, *Nat. Prod. Rep.* **2014**, *31*, 489 – 503; e) D. Pflästerer, A. S. K. Hashmi, *Chem. Soc. Rev.* **2016**, *45*, 1331 – 1367.

[16] a) Procedure according to: G. Koza, C. Theunissen, J. R. Al Dulayymi, M. S. Baird, *Tetrahedron* **2009**, *65*, 10214 – 10229; b) Spectral data and optical rotation in accordance with those previously reported for **(*R*,*R*)-10**: A. Kramer, H. Pfander, *Helv. Chim. Acta* **1982**, *65*, 293 – 301.

[17] For example: a) S. Kim, I. S. Kee, Y. H. Park, J. H. Park, *Synlett* **1991**, 183 – 184; b) W. H. Kim, A. R. Angeles, J. H. Lee, S. J. Danishefsky, *Tetrahedron Lett.* **2009**, *50*, 6440 – 6441.

[18] See the Supporting Information for more details. Optical rotation: $[\alpha]_D^{28} = -6.8°$ ($c = 0.70$, $CHCl_3$); (lit. $[\alpha]_D^{22} = -10°$ ($c = 0.07$, $CHCl_3$)).[9].

[19] CCDC 1454956 (**6**), CCDC 1454957 (**21**) and CCDC 1454958 (**23**) contain the supplementary crystallographic data. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre.

[20] See the Supporting Information for more details.

[21] Similarly, the *cis* addition was also favored for the pyrrolidine-promoted process. See the Supporting Information for more details.

[22] a) M. W. Lodewyk, M. R. Siebert, D. J. Tantillo, *Chem. Rev.* **2012**, *112*, 1839 – 1862; some recent examples: b) K. N. White, T. Amagata, A. G. Oliver, K. Tenney, P. J. Wenzel, P. Crews, *J. Org. Chem.* **2008**, *73*, 8719 – 8722; c) G. Hu, K. Liu, L. J. Williams, *Org. Lett.* **2008**, *10*, 5493 – 5496; d) Y. Li, *RSC Adv.* **2015**, *5*, 36858 – 36864.

Received: February 22, 2016
Published online: April 27, 2016

