All non-hydrogen atoms were located and refined anisotropically. Hydrogen atoms were located from different Fourier maps and refined with a riding mode. Crystallographic data (excluding structure factors) for the structures reported in this paper have been deposited with the Cambridge Crystallographic Data Center as supplementary publication no. CCDC-101917 and CCDC-101918. Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (fax: (+44) 1223-336-033; e-mail: deposit@ccdc.cam.ac.uk).

Received: August 21, 1998 [Z12313IE]
German version: *Angew. Chem.* **1999**, *111*, 1507 – 1510

Keywords: alkene complexes · lanthanides · macrocyclic ligands · samarium

[1] a) W. J. Evans, L. A. Hughes, T. P. Hanusa, *Organometallics* **1986**, *5*, 1285; b) W. J. Evans, L. A. Hughes, T. P. Hanusa, *J. Am. Chem. Soc.* **1984**, *106*, 4270; c) W. J. Evans, D. K. Drummond, S. G. Bott, J. L. Atwood, *Organometallics* **1986**, *5*, 2389; d) W. J. Evans, T. A. Ulibarri, J. W. Ziller, *J. Am. Chem. Soc.* **1988**, *110*, 6877; e) W. J. Evans, R. K. Keyer, H. Zhang, J. L. Atwood, *J. Chem. Soc. Chem. Commun.* **1987**, 837; f) W. J. Evans, D. K. Drummond, J. W. Grate, H. Zhang, J. L. Atwood, *J. Am. Chem. Soc.* **1987**, *109*, 3928; g) W. J. Evans. D. K. Drummond, *J. Am. Chem. Soc.* **1989**, *111*, 3329; h) W. J. Evans, R. A. Keyer, G. W. Rabe, D. K. Drummond, J. W. Ziller, *Organometallics* **1993**, *12*, 4664; i) W. J. Evans, J. W. Grate, R. J. Doedens, *J. Am. Chem. Soc.* **1985**, *107*, 1671; j) W. J. Evans, T. A. Ulibarri, *J. Am. Chem. Soc.* **1987**, *109*, 4292; k) W. J. Evans, J. W. Grate, L. A. Hughes, H. Zhang, J. L. Atwood, *J. Am. Chem. Soc.* **1985**,*107*, 3728; l) W. J. Evans, D. K. Drummond, *J. Am. Chem. Soc.* **1988**, *110*, 2772; m) W. J. Evans, D. K. Drummond, *Organometallics* **1988**, *7*, 797; n) W. J. Evans, D. K. Drummond, L. R. Chamberlain, R. J. Doedens, S. G. Bott, H. Zhang, J. L. Atwood, *J. Am. Chem. Soc.* **1988**, *110*, 4983; o) W. J. Evans, D. K. Drummond, *J. Am. Chem. Soc.* **1986**, *108*, 7440; p) W. J. Evans, J. T. Leman, J. W. Ziller, *Inorg. Chem.* **1996**, *35*, 4283.

[2] a) W. J. Evans, M. A. Hozbor, *J. Organomet. Chem.* **1987**, *326*, 299, and references therein; b) C. J. Schaverien, *Adv. Organomet. Chem.* **1994**, *36*, 283, and references therein; c) T. J. Marks, R. D. Ernst in *Comprehensive Organometallic Chemistry*, Pergamon, Oxford, **1982**, chapt. 21; d) W. Evans, *Adv. Organomet. Chem.* **1985**, *24*, 131; e) M. Ephritikhine, *Chem. Rev.* **1997**, *97*, 2193; f) L. G. Hubert-Pfalzgraf, *New J. Chem.* **1995**, *19*, 727.

[3] a) R. D. Ernst, T. J. Marks, *J. Organomet. Chem.* **1987**, *318*, 29; b) R. D. Ernst, *J. Organomet. Chem.* **1990**, *392*, 51; c) J. A. Meesemarktscheffel, L. Esser, H. Schumann, *Chem. Rev.* **1995**, *95*, 865.

[4] See for example: a) F. Nief, L. Ricard, *J. Organomet. Chem* **1997**, *529*, 357; b) Z. Hou, A. Fujita, T. Yoshimura, A. Jesorka, Y. Zhang, H. Yamazaki, Y. Wakatsuki, *Inorg. Chem.* **1996**, *35*, 7190; c) G. W. Rabe, J. Riede, A. Schier, *Organometallics* **1996**, *15*, 439; d) R. Minhas, Y. Ma, S. Gambarotta, *Inorg. Chem.* **1996**, *35*, 1866; e) J.-I. Song, S. Gambarotta, *Angew. Chem.* **1995**, *107*, 2319; *Angew. Chem. Int. Ed. Engl.* **1995**, *34*, 2141; f) K. Mashima, Y. Nakayama, T. Shibahara, H. Fukumoto, A. Nakamura, *Inorg. Chem.* **1996**, *35*, 93; g) A. Sen, V. Chebolu, A. L. Rheingold, *Inorg. Chem.* **1987**, *26*, 1821; h) G. Rabe, A. Schier, *Inorg. Chem.* **1996**, *35*, 2680.

[5] a) J. Takats, X. W. Zhang, *Organometallics* **1993**, *12*, 4286; b) Z. Xie, K. Chiu, B. Wu, T. C. W. Mak, *Inorg. Chem.* **1996**, *35*, 5957; c) J. Takats, X. Zhang, G. R. Lopnow, R. McDonald, *J. Am. Chem. Soc.* **1995**, *117*, 7828; d) W. J. Evans, D. K. Drummond, H. Zhang, J. L. Atwood, *Inorg. Chem.* **1988**, *27*, 575; e) D. L. Reger, S. J. Knox, J. A. Lindeman, L. Leboida, *Inorg. Chem.* **1990**, *29*, 416; f) A. Recknagel, A. Steiner, M. Noltemeyer, S. Brooker, D. Stalke, F. T. Edelmann, *J. Organomet. Chem.* **1991**, *414*, 327; g) H. Schumann, M. R. Keitsch, J. Winterfeld, J. Demtschuk, *J. Organomet. Chem.* **1996**, *525*, 279; h) S. J. Swamy, J. Leobel, H. Schumann, *J. Organomet. Chem.* **1989**, *379*, 51.

[6] P. A. Gale, J. L. Sessler, V. Král, V. Lynch, *J. Am. Chem. Soc.* **1996**, *118*, 5140.

[7] J. Jubb, S. Gambarotta, *J. Am. Chem. Soc.* **1994**, *116*, 4477.

[8] a) W. J. Evans, K. M. Coleson, S. C. Engerer, *Inorg. Chem.* **1981**, *20*, 4320; b) W. J. Evans, S. C. Engerer, A. C. Neville, *J. Am. Chem. Soc.* **1978**, *100*, 331; c) P. H. Kasai, D. McLeod, Jr., T. Watanabe, *J. Am. Chem. Soc.* **1977**, *99*, 3521; d) C. J. Burns, R. A. Andersen, *J. Am. Chem. Soc.* **1987**, *109*, 915; e) W. J. Evans, T. A. Ulibarri, J. W. Ziller, *J. Am. Chem. Soc.* **1990**, *112*, 219; f) W. J. Evans, T. A. Ulibarri, J. W. Ziller, *J. Am. Chem. Soc.* **1990**, *112*, 2314.

[9] a) J. Jubb, S. Gambarotta, R. Duchateau, J. Teuben, *J. Chem. Soc. Chem. Commun.* **1994**, 2641; b) H. C. Aspinall, M. R. Tillotson, *Inorg. Chem.* **1996**, *35*, 2163; c) W. J. Evans, R. Dominguez, T. P. Hanusa, *Organometallics* **1986**, *5*, 1291; d) J. Jubb, S. Gambarotta, *Inorg. Chem.* **1994**, *33*, 2503; e) J. Jubb, S. Gambarotta, *J. Am. Chem. Soc.* **1993**, *115*, 10410; f) T. Dube, S. Gambarotta, G. P. A. Yap, *Organometallics* **1998**, *17*, 3967; g) S. De Angelis, E. Solari, C. Floriani, A. Chiesi-Villa, *J. Chem. Soc. Dalton Trans.* **1994**, 2467.

[10] a) C. Floriani, E. Solari, A. Chiesi-Villa, C. Rizzoli, *Angew. Chem.* **1998**, *110*, 2367; *Angew. Chem. Int. Ed.* **1998**, *37*, 2245, and references therein; b) G. Solari, E. Solari, C. Floriani, A. Chiesi-Villa, C. Rizzoli, *Organometallics* **1997**, *16*, 508.

[11] Crystal structure: T. Dube, S. Gambarotta, G. P. A. Yap, unpublished results.

[12] W. J. Evans, D. M. DeCoster, J. Greaves, *Macromolecules* **1995**, *28*, 7929, and references therein.

Directed Metalation Linked to Transition Metal Catalyzed Cascade Reactions: Two Total Syntheses of Plicadin, the Alleged Coumestan from *Psoralea plicata***

Brian A. Chauder, Alexey V. Kalinin, Nicholas J. Taylor, and Victor Snieckus*

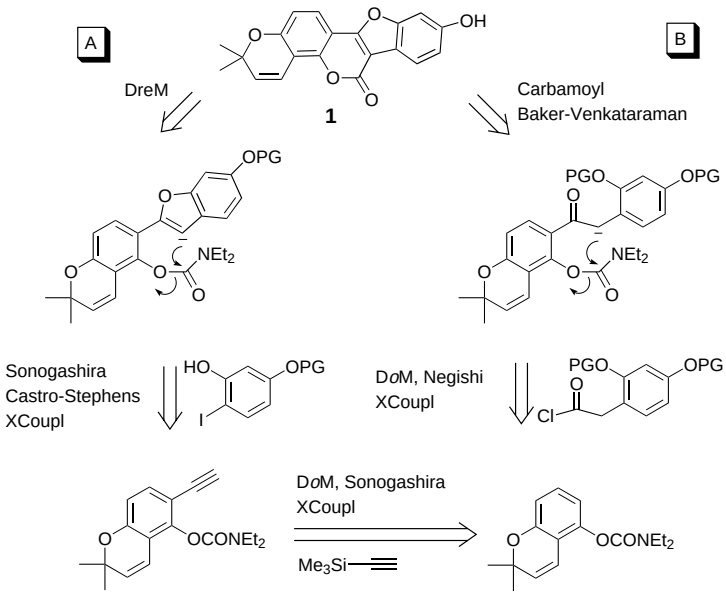
Plicadin, isolated in 1991 from the herb *Psoralea plicata*[1] and assigned structure **1** (see Scheme 1),[2] has a compact, oxygen-rich heterocyclic structure that poses a synthetic challenge from the perspective of combined directed *ortho* metalation/directed remote metalation (D*o*M/DreM) and transition metal catalyzed coupling strategies, a current theme in our laboratories.[3] Herein we report two syntheses of plicadin (**1**) which incorporate effective use of the following sequences: a) D*o*M/DreM, Sonogashira, and Castro – Stephens reactions (Scheme 1, retrosynthesis A), and b) D*o*M, Negishi, and carbamoyl Baker – Venkataraman reactions[4] (retrosynthesis B). We also demonstrate inconsistencies between physical and spectral data of the synthetic material and those reported for the natural product isolated from *Psoralea*

[*] Prof. V. Snieckus,[+] B. A. Chauder,[+] A. V. Kalinin, N. J. Taylor
Guelph-Waterloo Centre for Graduate Work in Chemistry
University of Waterloo
Waterloo, ON, N2L 3G1 (Canada)

[+] Current address:
Department of Chemistry
Queen's University
Kingston, ON, K7L 3N6 (Canada)
Fax: (+1) 613-533-2837
E-mail: snieckus@chem.queensu.ca

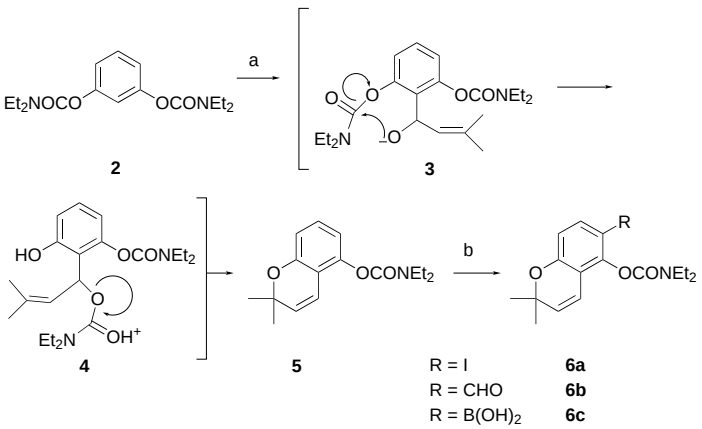
[**] We warmly acknowledge NSERC and Monsanto Canada for support under the Industrial Research Chair and Research Grant programs. We are especially grateful to Costa Metallinos for comradeship in providing the X-ray analysis of plicadin. A.V.K. thanks NSERC/NATO for a Science Fellowship.

  1433-7851/99/3810-1435 $ 17.50+.50/0



Scheme 1. Retrosynthetic analysis and strategies for the total synthesis of plicadin (**1**). XCoupl = cross-coupling, PG = protecting group.

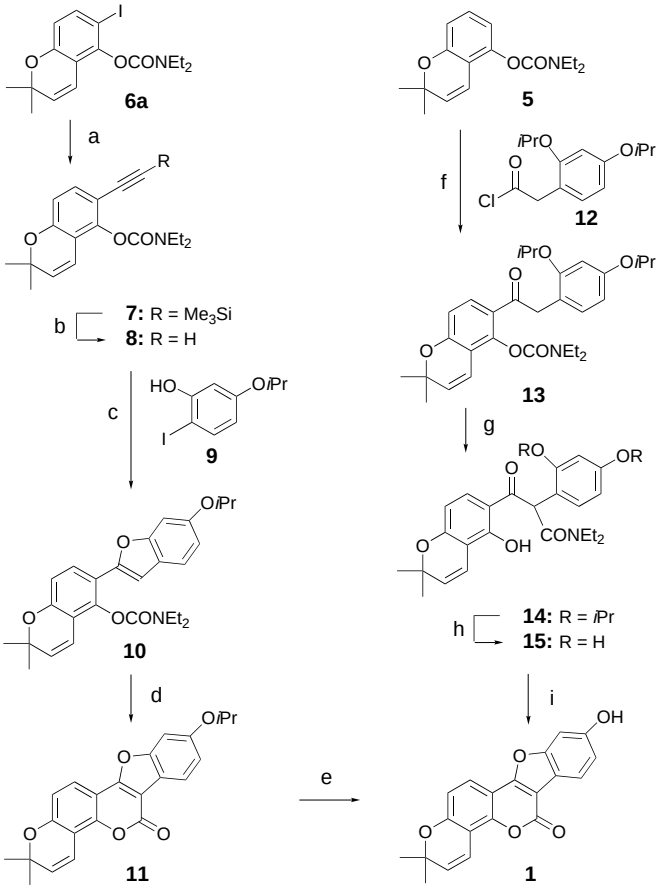
plicata and named plicadin. In addition to presenting short and didactic routes which diverge broadly from classical construction modes for coumestans,[2] this work suggests new synthetic methodologies of potentially general value: a) a regiospecific synthesis of chromenes not based on a Friedel–Crafts reaction (**2** → **5**); b) original carbamate metalation chemistry (**5** → **6**), and c) metalation, Sonogashira, and Castro–Stephens cascade reactions (Scheme 2).



Scheme 2. Synthesis and metalation of chromene **5**. a) *t*BuLi (1.1 equiv), THF ($c = 0.5$ M), −78 °C/30 min; then $Me_2C{=}CHCHO$ (1.3 equiv), −78 °C/15 min → 25 °C/1 h; then HOAc (3 equiv), 0 → 25 °C/1 h, 58%; b) *s*BuLi(1.2 equiv), THF ($c = 0.25$–0.5 M), −78 °C/1 h; **6a**: then I_2 (1.3 equiv), → 25 °C/1 h, 82%; **6b**: then DMF (4 equiv), → 25 °C/1 h, 85%; **6c**: then $B(OMe)_3$ (3 equiv), → 25 °C/1 h, quantitative.

The chromene carbamate **5**, which is common to both routes, was readily constructed in good yield from resorcinol dicarbamate **2** by a quench experiment with *t*BuLi and senecialdehyde followed by acetic acid catalyzed cyclization (Scheme 2). This one-pot sequence takes advantage of regiospecific cooperative D*o*M[3a] and intramolecular O-to-O carbamoyl transfer (**3**) to facilitate formal S_N2' carbamate expulsion (**4**) and provide a substituted chromene (**5**), which cannot be obtained regioselectively by classical tactics based on electrophilic aromatic substitution.[5]

A second D*o*M on **5** with *s*BuLi followed by an electrophilic quench furnished substituted derivatives **6a**–**c** regiospecifically and in high yields. Sonogashira coupling of **6a** under conditions of $[PdCl_2(PPh_3)_2]$/CuI catalysis[6] led to **7**, which upon desilylation gave the acetylenic chromene **8** (Scheme 3).



Scheme 3. Syntheses of **1**. a) $Me_3SiC{\equiv}CH$ (2 equiv), $[PdCl_2(PPh_3)_2]$ (0.05 equiv), CuI (0.05 equiv), NEt_3/MeCN (4/1), 50 °C, 2 h, 92%; b) K_2CO_3 (0.1 equiv), MeOH, 25 °C, 3 h, 86%; c) **9** (1.1 equiv), $[Pd(OAc)_2(PPh_3)_2]$ (0.05 equiv), CuI (0.05 equiv), DMF/NEt_3 (1/1), 80 °C, 45 h, 44%; d) LDA (3.5 equiv), THF, 0 °C, 15 min, then HOAc, reflux, 10 min, 84%; e) BCl_3 (7.7 equiv), CH_2Cl_2 (c=0.005 M), 25 °C, 10 h, 50%; f) *s*BuLi (1.2 equiv), THF, −78 °C, 1 h, then $ZnCl_2$ (1.2 equiv), −78 °C, 15 min, then **12** (1.4 equiv), $[PdCl_2(PPh_3)_2]$ (0.05 equiv), DIBALH (0.1 equiv), toluene, 0 °C, 2 h, 25 °C, 1 h, 74% (85% based on recovered **5**); g) NaH (2.5 equiv), toluene, reflux, 2 h, 88%; h) BCl_3 (5 equiv), CH_2Cl_2 ($c = 0.05$ M), −78 → −10 °C, 1 h, then MeOH quench at −78 °C, 25 °C, Rochell's salt workup, 99%; i) PTSA (2 equiv), MeOH, reflux, 6 h, 49%. LDA = lithium diisopropylamide, DIBALH = diisobutylaluminum hydride; PTSA = *p*-toluenesulfonic acid.

Reaction with the *o*-iodophenol **9**[7] under $[Pd(OAc)_2(PPh_3)_2]$/CuI catalysis resulted in a sequential Sonogashira/Castro–Stephens process[8] to give the benzofuran **10** in acceptable overall yield. Delightfully, the sequence of DreM, carbamoyl migration, and acid-catalyzed cyclization[3] proceeded in 84% yield to give the coumestan **11**. Deprotection of **11** with BCl_3[9]

  1433-7851/99/3810-1436 $ 17.50+.50/0 *Angew. Chem. Int. Ed.* **1999**, *38*, No. 10

concluded the synthesis of plicadin (**1**) according to retrosynthesis A in seven steps from **2** in 6.8% overall yield.

Retrosynthesis B (Scheme 1) was commenced by Negishi acylative cross-coupling of chromene carbamate **5** with protected acid chloride **12**, prepared by Willgerodt–Kindler reaction from the corresponding acetophenone,[10] to give the ketone **13**. Carbamoyl Baker–Venkataraman reaction under NaH conditions afforded the ketoamide **14**,[4] which was effectively deprotected with BCl_3 to yield triphenol **15**. Acid-catalyzed cyclization of **15** concluded the second synthesis of plicadin (**1**) in five steps from **2** in 20.5% overall yield.

Examination of the reported data for plicadin[1] showed several discrepancies with those obtained for the synthetic material. A melting point of 117 °C (EtOH/benzene) was reported for plicadin, whereas sublimation at 290 °C (EtOH/benzene) was observed for the synthetic material. With the exception of the splitting patterns for three signals in the ^{1}H NMR spectrum (see Table 1), which may be a result of inadvertent inversion in the assignment, all signals and coupling constants are in agreement within experimental error with those reported (Table 1).[1] The structure of the synthetic material was fully confirmed by an X-ray crystallographic analysis (Figure 1).[11]

Table 1. ^{1}H NMR data observed for synthetic **1** and reported for plicadin.[a]

δ(**1**)[b]	δ(plicadin)[c]
10.04 (s, 1H)	–[d]
7.71 (d, J = 8.5 Hz, 1H)	7.76 (d, J = 8.5 Hz, 1H)
7.68 (d, J = 8.4 Hz, 1H)	7.70 (d, J = 8.4 Hz, 1H)
7.14 (d, J = 2.0 Hz, 1H)	7.12 (d, J = 1.8 Hz, 1H)
6.93 (dd, J = **8.4**, **2.0 Hz**, 1H)*	7.00 (d, J = **10 Hz**, 1H)***
6.87 (d, J = **8.5 Hz**, 1H)**	6.88 (dd, J = **8.5**, **1.8 Hz**, 1H)*
6.78 (d, J = **10 Hz**, 1H)***	6.80 (d, J = **8.5 Hz**, 1H)**
5.94 (d, J = 10 Hz, 1H)	5.81 (d, J = 10 Hz, 1H)
1.44 (s, 6H)	1.49 (s, 6H)

[a] The asterisks indicate the shifts for which there are discrepancies between the data reported for plicadin and those obtained for the synthetic material. [b] Measured at 500 MHz in [D$_6$]DMSO. [c] Measured at 400 MHz in [D$_6$]DMSO. [d] Not reported.

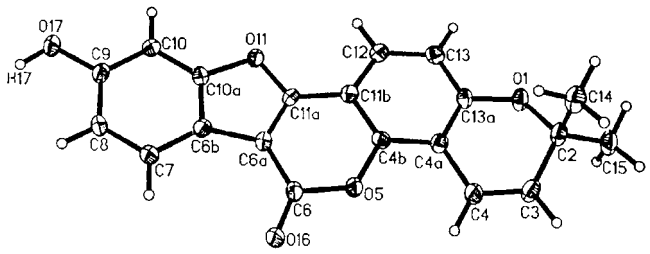


Figure 1. Crystal structure of **1**.

The discrepancy in the melting points cannot be explained and requires clarification by Amad, Malik, and co-workers. Additional comparison by ^{13}C NMR spectroscopy was not feasible owing to the absence of this data in the original report.[1, 12] Therefore, the structure of the compound isolated from *Psoralea plicata* and named plicadin remains uncertain.

In summary, the purported plicadin (**1**) has been obtained by two efficient and comparable syntheses. The syntheses are showcases for directed *ortho* and remote metalation and transition metal catalyzed reactions (Negishi, Sonogashira, and Castro–Stephens) and demonstrate the tactical advantages of tandem sequencing.

Experimental Section

5: To a cooled (−78 °C) solution of **2** (14.92 g, 48.2 mmol) in THF (100 mL, c = 0.5 M) was added *t*BuLi (34 mL, 57.5 mmol, c = 1.71 M in pentane) over 1 h; the internal temperature was kept below −75 °C. The reaction mixture was stirred for 15 min, 3-methyl-2-butenal (6.3 mL, 65 mmol) was added over 30 min (internal temperature below −74 °C), and the mixture was stirred for 1 h at −78 °C. The reaction mixture was allowed to warm to room temperature, stirred for 1 h, cooled to 0 °C, sequentially treated with acetic acid (7.2 mL, 125 mmol) and brine solution (100 mL), and stirred for 1 h at room temperature. The organic phase was separated, the aqueous phase was extracted with Et_2O (3 × 50 mL), and the combined organic extracts were evaporated under vacuum. Excess aldehyde was removed under high vacuum, the residue was dissolved in Et_2O (150 mL), and the solution was dried (Na_2SO_4), passed through a plug of silica gel, and distilled to provide **5** as a thick yellow oil (7.16 g, 54%); b.p. (bath temp) 120–140 °C (0.1–0.25 Torr). IR (neat): $\tilde{\nu}$ = 2977, 1722, 1638, 1611, 1460, 1418, 1277, 1225, 1156, 1116, 1060, 758 cm^{-1}; ^{1}H NMR (250 MHz, $CDCl_3$): δ = 7.06 (t, J = 8.1 Hz, 1H), 6.64 (d, J = 8.1 Hz, 1H), 6.63 (d, J = 8.1 Hz, 1H), 6.38 (d, J = 10.0 Hz, 1H), 5.62 (d, J = 10.0 Hz, 1H), 3.47-3.37 (m, 4H), 1.43 (s, 6H), 1.29-1.17 (m, 6H); ^{13}C NMR (50.3 MHz, $CDCl_3$): δ = 153.8, 153.6, 147.1, 130.8, 128.5, 116.4, 114.7, 114.4, 113.3, 75.9, 42.2, 41.8, 27.8, 14.3, 13.3; MS (EI): m/z (%): 275 (26) [M^+], 261 (18), 260 (46), 161 (22), 160 (25), 101 (15), 100 (100), 72 (40); HR-MS (EI): calcd for $C_{16}H_{21}NO_3$: 275.1521, found: 275.1523. (Carrying out the same reaction on a 20-mmol scale and at a concentration of 0.2 M gave **5** in 58% yield.)

6a: To a cooled (−78 °C) solution of **5** (3.79 g, 13.73 mmol) in THF (30 mL, c = 0.46 M) was added *s*BuLi (12.9 mL, 16.48 mmol, 1.28 M in cyclohexane) over 1 h; the internal temperature was kept below −75 °C. After stirring the mixture for 1 h at −78 °C, a solution of I_2 (4.53 g, 17.85 mmol) in THF (20 mL) was added and the reaction mixture was warmed to room temperature (6 h) and treated with saturated NH_4Cl solution (5 mL). THF was removed under vacuum, Et_2O (50 mL) and H_2O (20 mL) were added, and the organic layer was separated, dried (Na_2SO_4), and concentrated under vacuum. The residue was purified by flash column chromatography (EtOAc/hexanes 3/17) to afford **6a** as a yellow oil (4.50 g, 82%). IR (neat): $\tilde{\nu}$ = 2947, 1726, 1415, 1270, 1051 cm^{-1}; ^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.17–1.35 (m, 6H), 1.40 (s, 6H), 3.36–3.49 (m, 4H), 5.62 (d, J = 10.0 Hz, 1H), 6.30 (d, J = 10.0 Hz, 1H), 6.47 (d, J = 8.6 Hz, 1H), 7.44 (d, J = 8.6 Hz, 1H); ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 153.7, 152.1, 147.0, 137.2, 131.4, 116.6, 116.5, 115.7, 80.1, 76.1, 42.1, 41.9, 27.6, 14.3, 13.1; MS (EI): m/z (%): 401 (75) [M^+], 386 (70), 274 (75), 100 (100), 72 (97); HR-MS (EI): calcd for $C_{16}H_{20}INO_3$: 401.0489, found: 401.0494.

1: A solution of triphenol **15** (350 mg, 0.82 mmol) and *p*-toluenesulfonic acid monohydrate (313 mg, 1.65 mmol) in MeOH (30 mL) was heated under reflux for 6 h and concentrated under vacuum to about 10 mL. The resulting precipitate was collected by filtration, washed with cold MeOH (2 × 5 mL), and dried under vacuum to provide **1** as a yellow-green solid (136 mg, 0.41 mmol, 49%). Recrystallization gave yellow crystals; m.p. 289–290 °C (sublim, EtOH); m.p. 290 °C (sublim, EtOH/benzene). IR (KBr): $\tilde{\nu}$ = 3379 (br), 1717, 1645, 1628, 1601 cm^{-1}, ^{13}C NMR (62.9 MHz, [D$_6$]DMSO): δ = 159.0, 157.2, 156.9, 156.0, 155.1, 148.4, 131.8, 121.2, 120.6, 114.3, 114.2, 114.0, 113.5, 109.1, 105.5, 102.5, 98.6, 77.4, 27.6; MS (EI): m/z (%): 334 (29) [M^+], 320 (22), 319 (100), 318 (7), 160 (8); HR-MS (EI): calcd for $C_{20}H_{14}O_5$: 334.0841, found: 334.0854.

Received: November 9, 1998 [Z12637IE]
German version: *Angew. Chem.* **1999**, *111*, 1528–1530

Keywords: cross-coupling · domino reactions · lithiation · rearrangements · total synthesis

  1433-7851/99/3810-1437 $ 17.50+.50/0

[1] N. Rasool, A. Q. Khan, V. U. Ahmad, A. Malik, *Phytochemistry* **1991**, *30*(8), 2803 – 2805.
[2] Structure **1** is a member of the large and bioactivity-rich class of naturally occurring coumestans: a) W. Stadlbauer, T. Kappe, *Heterocycles* **1993**, *35*, 1425 – 1440; b) J. D. Hepworth in *Comprehensive Heterocyclic Chemistry, Vol. 4* (Ed.: A. R. Katritzky), Pergamon, New York, **1984**, pp. 995 – 998; c) F. M. Dean in *The Total Synthesis of Natural Products*, *Vol. 1* (Ed.: J. ApSimon), Wiley, New York, **1973**, pp. 485 – 548; d) A. Mustafa in *The Chemistry of Heterocyclic Compounds*, *Vol. 23* (Ed.: A. Weissberger), Wiley, New York, **1967**, pp. 243 – 255.
[3] a) V. Snieckus, *Chem. Rev.* **1990**, *90*, 879 – 933; b) J.-M. Fu, M. J. Sharp, V. Snieckus, *Tetrahedron Lett.* **1988**, *29*, 5459 – 5462; c) X. Wang, V. Snieckus, *Tetrahedron Lett.* **1991**, *32*, 4879 – 4882; d) J.-M. Fu, B.-P. Zhao, M. J. Sharp, V. Snieckus, *J. Org. Chem.* **1991**, *56*, 1683 – 1685; e) J.-M. Fu, B.-P. Zhao, M. J. Sharp, V. Snieckus, *Can. J. Chem.* **1994**, *72*, 227 – 236; f) W. Wang, V. Snieckus, *J. Org. Chem.* **1992**, *57*, 424 – 426; g) for application of this remote anionic Fries reaction to the synthesis of gilvocarcins, see C. A. James, V. Snieckus, *Tetrahedron Lett.* **1997**, *38*, 8149 – 8152, and for its generalization to arylfuryl and arylthiophenyl for construction of coumestans, see C. A. James, PhD thesis, University of Waterloo (Canada), **1998**.
[4] For further scope of this two-step procedure in the synthesis of 4-hydroxycoumarins, some of which are inaccessible by classical Friedel – Crafts and Lewis acid catalyzed Fries rearrangement reactions, see A. V. Kalinin, A. J. M. da Silva, C. C. Lopes, R. S. C. Lopes, V. Snieckus, *Tetrahedron Lett*. **1998**, *39*, 4995 – 4998; A. V. Kalinin, V. Snieckus, *Tetrahedron Lett*. **1998**, *39*, 4999 – 5002.
[5] B. A. Chauder, C. C. Lopes, R. S. C. Lopes, A. J. M. da Silva, V. Snieckus, *Synthesis* **1998**, 279 – 282, and references therein.
[6] K. Sonogashira, Y. Tohda, N. Hagihara, *Tetrahedron Lett.* **1975**, 4467 – 4470.
[7] Prepared according to D. E. Janssen, C. V. Wilson, *Org. Synth. Coll. Vol. IV* **1963**, 547 – 549.
[8] a) R. D. Stephens, C. E. Castro, *J. Org. Chem.* **1963**, *28*, 3313 – 3315; b) C. E. Castro, E. J. Gaughan, D. C. Owsley, *J. Org. Chem.* **1966**, *31*, 4071 – 4078; c) for a survey of palladium-based routes to benzofurans, see R. C. Larock, E. D. Yum, M. J. Doty, K. K. C. Sham, *J. Org. Chem.* **1995**, *60*, 3270 – 3271.
[9] Upon treatment with BCl_3, EtSNa, or LiCl, the corresponding methyl ether of **11** did not afford plicadin but gave product mixtures, indicating chromene and lactone ring opening.
[10] Prepared according to F. E. King, K. G. Neill, *J. Chem. Soc.* **1952**, 4752 – 4756; also see J. O. Amupitan, *Synthesis* **1983**, 730, and references therein.
[11] Crystallographic data (excluding structure factors) for the structure reported in this paper have been deposited with the Cambridge Crystallographic Data Center as supplementary publication no. CCDC-101777. Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK (fax: (+44) 1223-336-033; e-mail: deposit@ccdc.cam.ac.uk).
[12] Despite numerous attempts, we were unable to obtain an authentic sample, a copy of the original ^{1}H NMR spectrum, and ^{13}C NMR data from the authors.

Biodegradable Polymeric Materials—Not the Origin but the Chemical Structure Determines Biodegradability

Uwe Witt,* Motonori Yamamoto, Ursula Seeliger, Rolf-Joachim Müller, and Volker Warzelhan*

Dedicated to Professor Hans-Jürgen Quadbeck-Seeger on the occassion of his 60th birthday

Biodegradable polymeric materials (BPMs) are of ever increasing interest because of the many problems associated with solid wastes. As early as the end of the 1970s first attempts had been made to develop polymeric materials that combine good useage properties (such as thermoplastic processing ability for films, fibers and moulding) of conventional plastics and biodegradability by microorganisms.[1] In the meantime, such "bio-plastics" have become commercially available or are in the pre-marketing phase.[2] It is in principal possible to fall back on different sources of raw materials to produce such polymers. Thus, it is possible to distinguish between BPMs based on renewable or on petrochemical sources. Examples of such renewable sources are starch derivatives and starch blends, polyhydroxybutyrates, polylactic acid, cellophane, cellulose derivatives, caseine, and chitin polymers. BPMs produced from petrochemical resources are, for example, aliphatic polyesters such as polycaprolactone and polybutylene succinate, aromatic – aliphatic copolyesters, and polyester amides.

Whereas the biodegradability of BPMs based on renewable resources is plausible, there were doubts as to whether polymers based on petrochemical sources could also be mineralized by a natural process caused by microorganisms such as bacteria or fungi.

Aliphatic polyesters were extensively investigated as to their biodegradability.[3–5] The primary cleavage of the usually insoluble polymer chain takes place outside of the microorganisms and is catalyzed by specific enzymes that are produced in the cell and excreted by microorganisms such as bacteria or fungi. The microorganisms are then able to take up the fragments in their cells and utilize them as food.

Examinations of the biodegradability of aliphatic – aromatic copolyesters have only been known for a few years.[6–8] The chemical structure of such copolyesters examined in the literature is shown in Scheme 1. Such copolyesters are a very interesting class of substances in reference to the assessment of their biodegradation behavior because of their high aromatic component content. The introduction of the aromatic component is useful for improving physical and

[*] Dr. U. Witt, Dr. V. Warzelhan, M. Sc. M. Yamamoto
ZKT Kuntstofflaboratorium, BASF Aktiengesellschaft
D-67056, Ludwigshafen (Germany)
Fax: (+49) 621-60-41766.
E-mail: uwe.witt@basf.ag.de
Dr. U. Seeliger
KSS/BP Project Ecoflex, BASF Aktiengesellschaft, Ludwigshafen
Dr. R.-J. Müller
BVT/UVT Umweltverfahrenstechnik
Gesellschaft für Biotechnologische Forschung mbH
D-38124 Braunschweig (Germany)

  1433-7851/99/3810-1438 $ 17.50+.50/0