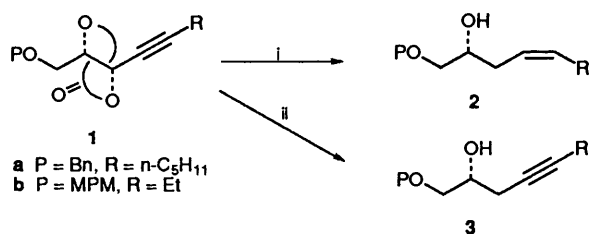


Synthesis of (*Z*)-Homoallylic Alcohols and Homoprop-2-ynylic Alcohols via Palladium-catalysed Hydrogenolysis of Prop-2-ynylic Cyclic Carbonates

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The decarboxylation–hydrogenolysis of prop-2-ynylic cyclic carbonates which have an internal acetylenic bond with ammonium formate in the presence of a catalytic amount of $[\text{Pd}(\text{acac})_2]$ and Bu^n_3P afforded (*Z*)-homoallylic alcohols or homoprop-2-ynylic alcohols depending on the reaction conditions, however, hydrogenolysis of terminal prop-2-ynylic cyclic carbonates gave homoallylic alcohols; using (*Z*)-homoallylic alcohol **2b** as a chiral synthon, the male sex pheromone of the pyralid moth *Aphomia gularis* has been synthesized.

Optically active (*Z*)-homoallylic and homoprop-2-ynylic alcohols are versatile chiral synthons in organic synthesis. In the literature, stereoselective synthesis of (*Z*)-homoallylic alcohols by addition of crotylstannanes to aromatic aldehydes has been reported.¹ We report here a convenient one-pot synthetic method for the highly stereoselective preparation of (*Z*)-homoallylic alcohols **2** and homoprop-2-ynylic alcohols **3** utilizing palladium-catalysed selective hydrogenolysis,^{2,3} details of which are shown in Scheme 1 and Table 1.

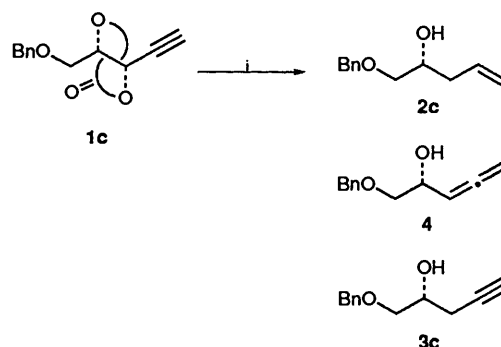


Scheme 1 Reagents and conditions: i, HCO_2NH_4 (4 equiv.), $[\text{Pd}(\text{acac})_2]\text{-Bu}^n_3\text{P}$ (cat.), PhH, reflux; ii, HCO_2NH_4 (1 equiv.), $[\text{Pd}(\text{acac})_2]\text{-Bu}^n_3\text{P}$ (cat.), PhH, room temp. (MPM = *p*-methoxyphenylmethyl)

The internal prop-2-ynylic cyclic carbonate **1a** reacted with 4 equiv. of ammonium formate in the presence of $[\text{Pd}(\text{acac})_2]$ (acac = acetylacetonate) and Bu^n_3P as catalysts in benzene at reflux for 3 h to afford the (*Z*)-homoallylic alcohol **2a** in 76% yield, the structure of which was confirmed by ^1H NMR (300 MHz) coupling constants of the olefinic protons (entry 1). It is presumed that Pd-catalysed decarboxylation–hydrogenolysis gives the homoprop-2-ynylic alcohol **3a** as an intermediate (checked by TLC), which is subsequently reduced with excellent stereoselectivity (>99%) to the (*Z*)-homoallylic alcohol **2a** by ammonium formate as a hydrogen donor in the presence of Pd-catalyst.⁴ As indirect evidence for the intermediary of alcohol **3a**, the reaction of the carbonate **1a** with 1 equiv. of $[\text{Pd}(\text{acac})_2]$ and Bu^n_3P afforded the homoprop-2-ynylic alcohol **3a** in 93% yield (entry 2).[†] It is notable that under the same conditions, with benzene as solvent, stirring at room temperature afforded **3a** in 97% yield (entry 3). This conversion was applied to the prop-2-ynylic cyclic carbonate **1b** and thus the (*Z*)-homoallylic alcohol **2b** and the homoprop-2-ynylic alcohol **3b** were obtained (entries 4 and 5).

In contrast to the internal prop-2-ynylic cyclic carbonate, decarboxylation–hydrogenolysis of the terminal prop-2-ynylic carbonate **1c**,⁵ with 2 equiv. of ammonium formate in the presence of a catalytic amount of $[\text{Pd}(\text{acac})_2]$ and Bu^n_3P in tetrahydrofuran (THF) at reflux for 30 min, provided the

homoallylic alcohol **2c** as the sole product (entry 6).[‡] Presumably, the allenic alcohol **4** and the homoprop-2-ynylic alcohol **3c** are the intermediates. As indirect evidence for this, treatment of **1c** with 1 equiv. of ammonium formate in the presence of $[\text{Pd}(\text{acac})_2]$ and Bu^n_3P in THF at reflux provided mixtures of the allenic alcohol **4** and the homoprop-2-ynylic alcohol **3c** (Scheme 2; entry 7).[§] It is notable that the reaction of



Scheme 2 Reagents and conditions: i, HCO_2NH_4 (1 equiv.), $[\text{Pd}(\text{acac})_2]\text{-Bu}^n_3\text{P}$ (cat.), THF, reflux, 30 min

1c with 1 equiv. of ammonium formate in the presence of $[\text{Pd}(\text{acac})_2]$ and Bu^n_3P in benzene at room temperature afforded the allenic alcohol **4** as the major product (entry 8).

The results of the palladium-catalysed hydrogenolysis of prop-2-ynylic cyclic carbonates are summarized in Table 1.

Using (*Z*)-homoallylic alcohol **2b** as a chiral synthon, the male sex pheromone of the pyralid moth *Aphomia gularis* **7**⁶ was synthesized (Scheme 3). The homoallylic alcohol **2b** was protected as methoxymethyl (MOM) ether and then the *p*-methoxyphenylmethyl (MPM) protecting group was removed to furnish the alcohol **5**, $[\alpha]_D^{25} -24$ (c 0.46, CHCl_3). The alcohol **5** was oxidized and Wittig olefination gave the α,β -unsaturated ester **6** (*Z*:*E* = 1.3:1). The (*Z*)- α,β -unsaturated ester **6** was subjected to deprotection, followed by lactonization

[†] $[\text{Pd}_2(\text{dba})_3]\text{-CHCl}_3$ (5 mol%) can be used instead of $[\text{Pd}(\text{acac})_2]$.

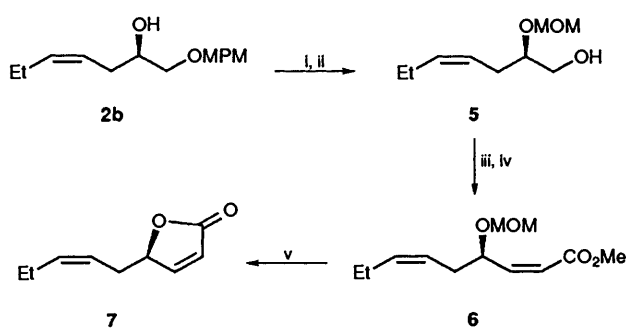
[‡] In our hands, using $[\text{Pd}(\text{PPh}_3)_4]$ (5 mol%) in THF at reflux did not furnish the product. However, with $[\text{Pd}(\text{PPh}_3)_4]$ in MeCN at reflux for 40 min, the product **2c** was obtained in 79% yield.

[§] Treatment of **1c** with $[\text{Pd}_2(\text{dba})_3]\text{-CHCl}_3$ (5 mol%), Bu^n_3P (5 mol%), HCO_2NH_4 (1 equiv.) in THF at reflux for 30 min gave **4** and **3c** in a ratio of 1:2.4. Under the same conditions, with 2 equiv. of HCO_2NH_4 , the reaction of **1c** gave the homoallylic alcohol **2c** in 73% yield.

Table 1 Pd⁰-Catalysed hydrogenolysis of prop-2-ynyl cyclic carbonates

Entry	Substrate	HCO ₂ NH ₄ (mol)	Solvent	Conditions ^a		Product ^b	Yield (%) ^d
				Temp. (°C)	Time (h)		
1	1a	4	Benzene	80	3	2a	76
2	1a	1	THF	65	0.5	3a	93
3	1a	1	Benzene	25	2	3a	97
4	1b	4	Benzene	80	3	2b^c	74
5	1b	1	Benzene	80	0.2	3b	86
6	1c	2	THF	65	0.5	2c	82
7	1c	1	THF	65	0.5	4 + 3c (1:1)	93
8	1c	1	Benzene	25	2	4 + 3c (5.92:1)	97

^a All the reactions were run in the presence of [Pd(acac)₂] (5 mol%) and Buⁿ₃P (5 mol%). ^b [α]_D²⁵ Values in CHCl₃: **2a**, -4.4 (c 4.6); **3a**, -10.7 (c 1.5); **2b**, -2.4 (c 2.3); **3b**, -8.0 (c 3.0); **2c**, -6.6 (c 2.1). ^c The selectivity was checked by GLC analysis of the acetate of **2b** using a Hewlett-Packard 5880 GC system [column: ultra-2 (5% pheugl), 0.2 × 12 m oven temp. 180–280 °C, carrier gas. He 0.6 cm³ min⁻¹. The retention time of the acetate of **2b** was 7.15 min. ^d Yields are isolated yields.



Scheme 3 Reagents and conditions: i, MOMCl, Prⁱ₂NEt, 0 °C → room temp., 2 h (85%); ii, 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ), CH₂Cl₂, H₂O (18:1), 30 min (96%); iii, (COCl)₂, dimethyl sulfoxide (DMSO), Et₃N, CH₂Cl₂, -78 °C; iv, Ph₃PCHCO₂Me, MeOH, 0 °C, 5 h (30% overall); v, trifluoroacetic acid (TFA), CH₂Cl₂-H₂O (10:1) (80%)

to afford (4*R*,2*Z*,6*Z*)-nona-2,6-dien-4-olide, **7**, [α]_D²⁵ -160 (c 0.2, CHCl₃) {lit.,⁶ [α]_D²⁵ -162 (c 0.650, CHCl₃)}.*

Experimental

Typical Procedures.—**Preparation of 2a.** [Pd(acac)₂] and Buⁿ₃P (5 mol%) were mixed in a 1:1 ratio in dry benzene (5 cm³) to form a pale yellow solution. Then prop-2-ynyl cyclic carbonate **1a** (303 mg, 1.00 mmol) in dry benzene (5 cm³) was added followed by ammonium formate (2.52 mg, 4.0 mmol) and the mixture was stirred for 3 h at reflux. The benzene was evaporated and then the residue was separated by SiO₂ column chromatography (EtOAc-hexanes, 1:3, R_f 0.60) to afford alcohol **2a** (199 mg, 76%), [α]_D²⁵ † -4.4 (c 4.6, CHCl₃); δ_H(300 MHz; CDCl₃ ‡) 0.90 (3 H, t, J 7.0), 1.30 (6 H, m), 2.05 (2 H, m), 2.26 (2 H, m), 3.34 (1 H, m), 3.50 (1 H, m), 3.85 (1 H, m), 4.55

* **7**: δ_H(300 MHz, CDCl₃) 0.96 (3 H, t, J 7), 2.04 (2 H, m), 2.50 (2 H, m), 5.09 (1 H, m), 5.36 (1 H, m), 5.60 (1 H, m), 6.14 (1 H, dd, J 6 and 2.1) and 7.45 (1 H, dd, J 6 and 1.6); ν_{max}(neat)/cm⁻¹ 2950, 2926, 2850, 1755, 1450, 1250, 1240, 1160, 1100, 830, 740 and 700.

† [α]_D Values are given in units of 10⁻¹ deg cm² g⁻¹.

‡ J Values are given in Hz.

(2 H, s), 5.37 (1 H, dt, J 11 and 7.3), 5.48 (1 H, dt, J 11 and 7.3), 7.32 (5 H, s); ν_{max}(neat)/cm⁻¹ 3400 and 1620; m/z 262 (M⁺) and 91 (base peak) (Found: C, 77.5; H, 10.0. C₁₇H₂₆O₂ requires C, 77.86; H, 9.92%).

Preparation of 3a. [Pd(acac)₂] and Buⁿ₃P (5 mol%) were mixed in a 1:1 ratio in dry benzene (5 cm³) to form a pale yellow solution. Then prop-2-ynyl cyclic carbonate **1a** (303 mg, 1.00 mmol) in dry benzene (5 cm³) was added followed by ammonium formate (63 mg, 1.0 mmol) and the mixture was stirred for 2 h at room temperature. The THF was evaporated and the residue was separated by SiO₂ column chromatography (EtOAc-hexanes, 1:4, R_f 0.56) to afford alcohol **3a** (252 mg, 97%), [α]_D²⁵ -10.7 (c 1.5, CHCl₃); δ_H(300 MHz; CDCl₃) 0.90 (3 H, t, J 7.1), 1.32 (4 H, m), 1.47 (2 H, m), 2.15 (2 H, m), 2.43 (2 H, m), 3.50 (1 H, dd, J 9.6 and 6.7), 3.61 (1 H, dd, J 9.6 and 4.0), 3.93 (1 H, m), 4.58 (2 H, s) and 7.34 (5 H, s); m/z 260 (M⁺), 189 (19%), 91 (base peak) and 79 (11) (Found: C, 78.15; H, 9.3. C₁₇H₂₄O requires C, 78.46; H, 9.23).

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