A New Synthesis of Trimethyl Aconitate by Palladium-catalysed Triple Carbonylation of Propynyl Alcohol

Bartolo Gabriele,[a] Mirco Costa,[b] Giuseppe Salerno[a] and Gian Paolo Chiusoli[b]

[a] *Dipartimento di Chimica, Università della Calabria, I-87100 Arcavacata di Rende, Italy*
[b] *Istituto di Chimica Organica dell'Università, Viale delle Scienze, I-43100 Parma, Italy*

A two-step palladium-catalysed carbonylation, consisting of an oxidative carbonylation of propynyl alcohol, followed by a substitutive carbonylation, leads to *E* and *Z* aconitic trimethyl esters in high yield.

We report an efficient triple carbonylation of propynyl alcohol, which takes place in two steps at 25–40 °C and 1.5–6.0 MPa of CO to afford trimethyl aconitate **2** as the main product, according to eqn. (1).

$$HC{\equiv}CCH_2OH + 2CO + 2MeOH + 1/2O_2 \xrightarrow{PdI_2\text{–}KI} MeO_2CCH{=}C(CO_2Me)CH_2OH \quad (\mathbf{1})$$

$$\xrightarrow[CO,MeOH]{[Pd(tu)_4]I_2} MeO_2CCH{=}C(CO_2Me)CH_2CO_2Me \quad (\mathbf{2}) +$$

$$MeO_2CCH_2C(CO_2Me){=}CH_2 \quad (\mathbf{3}) \quad (1)$$

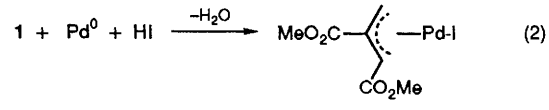
The first step (oxidative carbonylation) occurs in methanol at 20 °C, 1.5 MPa of CO and 0.5 MPa of air under the catalytic action of either a PdI_2 + 10KI or a Pd/C + KI[1] system and leads to compound **1**, while the second step is catalysed by the ionic $[Pd(tu)_4]I_2$† complex[2] at 40 °C and 6.0 MPa of CO and leads to compound **2** (through substitutive carbonylation) and **3** (through hydrogenolysis) in a 4 : 1 ratio.

Thus PdI_2, KI and propynyl alcohol in a 1 : 10 : 150 molar ratio were dissolved in methanol (1.7×10^{-3} mol dm^{-3} of PdI_2) and kept at 20 °C under CO/air pressure for 15 h. Compound **1** (77% *Z*, 23% *E*) was formed in 96% yield. The methyl ether of **1** (3%) and the lactone derived from *E*-**1** (1%) were also obtained.

The same solution was then added to the $[Pd(tu)_4]I_2$ complex (1 mol per 20 mol of **1**), adjusted with methanol to 3.2×10^{-3} mol dm^{-3} of the palladium complex, and stirred under CO pressure (6.0 MPa) for 48 h. A 73% yield of **2** (57% *E*, 16% *Z*, 70% overall yield on propynyl alcohol) and an 18% yield of **3** were obtained. The use of $[Pd(tu)_4]Cl_2$[3] in place of the iodide gave poor results.

A lower concentration of the substrate and a higher CO pressure are required in the second step to cause carbonylation to predominate over hydrogenolysis to **3**. On the other side a higher concentration of the catalyst is needed to assure an acceptable reaction rate.

The presence of zero-valent palladium is required to attack compound **1**, (see for example ref. 4) probably through formation of an allyl iodide [from HI or iodide species present in solution, eqn. (2)].



(2)

Accordingly, palladium(0) under the form of Pd/C in conjunction with tu and iodide ions was proved to be effective for the conversion of **1** to **2**.

The way by which palladium(0) is formed reveals an important role of the tu ligand, which is carbonylated according to eqn. (3), as shown by the isolation of thioallophanic methyl ester.

$$H_2NC(S)NH_2 + CO + MeOH + PdI_2 \rightarrow H_2NC(S)NHCO_2Me + 2HI + Pd \quad (3)$$

The palladium(0) thus formed remains coordinated (possibly giving rise to an H–Pd–I species) and does not precipitate from the solution. The use of the PdI_2–tu system to effect both steps in one gave poor selectivities because of the adverse effect of oxygen in the second step (oxidation of palladium).

The achievement in the first step of a high yield oxidative carbonylation, preserving the hydroxymethyl group of

† Thiourea = tu.

propynyl alcohol is unprecedented. Hydroxymethylbutenedioate **1** can exist as the *Z* or *E* stereoisomer. Although the latter is briefly mentioned in the literature[5] as a minor product, resulting from photochemical addition of methanol to acetylenedicarboxylic diester, it turns out to be the *Z* stereoisomer. In our case too the major product has *Z* stereochemistry. Both isomers have been fully characterized.‡

The high selectivity towards **2** is also remarkable in view of the competition between substitutive carbonylation and hydrogenolysis. The reaction of propynyl alcohol or propynyl halides with CO has been reported to give itaconic esters with $Ni(CO)_4$[6] and itaconic and aconitic esters with $PdCl_2$.[7] The latter could not be obtained in a yield higher than 10%, however, under increased temperature and pressure.

Trimethyl aconitate has interesting applications in polyester chemistry.[8] It also can be transformed into citric acid salts according to a known technique.[9]

This work has been supported by Consiglio Nazionale delle Ricerche, Progetto Finalizzato Chimica Fine 2.

Received, 23rd April 1992; Com. 2/02093I

References

1 G. P. Chiusoli, M. Costa and S. Reverberi, *Synthesis*, 1989, 282.
2 M. Costa, B. Gabriele, G. P. Chiusoli and G. Salerno, *J. Mol. Catal.*, in the press.
3 N. S. Kurnakov, *J. Prakt. Chem.* [2], 1894, **50**, 485.
4 W. D. Baugh and J. H. Murib (Quantum. Chem. Corp.), US Pat. 4,801,743, 1989.
5 E. Grovenstein, Jr., T. C. Campbell and T. Shibata, *J. Org. Chem.*, 1969, **34**, 2418.
6 G. P. Chiusoli, *Chim Ind.*, (*Milan*), 1959, **41**, 513; *Angew Chem.*, 1960, **72**, 74.
7 J. Tsuji and T. Nogi, *Tetrahedron Lett.*, 1966, 1801; *Tetrahedron*, 1969, **25**, 4099.
8 *Kirk-Othmer Encyclopedia of Chemical Technology*, Wiley, New York, 3rd edn., 1982, vol. 18, p. 577.
9 V. Lamberti and E. N. Gutierrez (Lever Brothers Co), US Pat. 4,056,567, 1977.

‡ Both isomers are oily compounds; typical spectroscopic data are in accord with the reported structure; **1**-*Z*: ^1H NMR δ_H (300 MHz; $CDCl_3$): 3.68 (s, 3H, OMe), 3.75 (s, 3H, OMe), 4.29 (d, 2H, *J* 2.0 Hz, CH_2), 6.12 (t, 1H, *J* 2.0 Hz, =CH); MS, *m/z*: 174 (M^+, absent), 159(6), 145(18), 143(75), 142(60), 115(34), 113(100), 110(72), 83(66), 59(53), 55(54); **1**-*E*: ^1H NMR δ_H (300 MHz; $CDCl_3$): 3.37 (s, 6H, 2OMe), 4.35 (d, 2H, *J* 2.0 Hz, CH_2), 6.89 (t, 1H, *J* 2.0 Hz, =CH); MS, *m/z*: 174 (M^+, absent), 159(6), 145(20), 143(22), 142(35), 141(30), 115(18), 114(26), 113(53), 110(36), 83(100), 59(64), 55(78). Elemental analyses were satisfactory.