

Synthesis of novel diaryloxocyclopentanethiocarboxylates by electrochemical reduction of cinnamic acid thioesters

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Jonas Gruber* and Fernanda Ferraz Camilo

Instituto de Química da Universidade de São Paulo, Caixa Postal 26077 - CEP 05599-970, São Paulo - SP - Brazil

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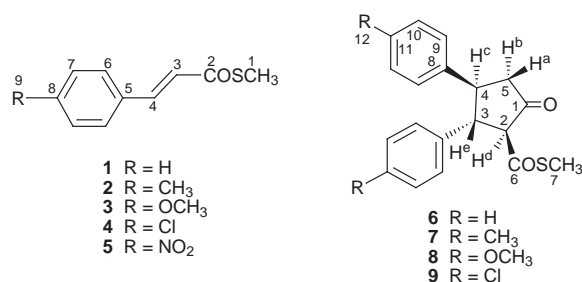
The cathodic cyclic electrohydrodimerisation of a series of *para*-substituted (*E*)-methyl thiocinnamates in a polar aprotic solvent is presented. Only the all-*trans* (\pm)-3,4-diaryl-1-oxocyclopentane-2-thiocarboxylates are formed, as shown by assignments of ^1H NMR coupling constants.

Introduction

The electrohydrodimerisation (EHD) of alkenes, activated towards cathodic reduction by electron-withdrawing groups such as CO_2R , COR , CN , NO_2 and $\text{C}=\text{NR}$, is a successful carbon-carbon bond-forming reaction.^{1,2} The best known example is the EHD of acrylonitrile ($\text{CH}_2=\text{CHCN}$) to give adiponitrile $[\text{NC}(\text{CH}_2)_4\text{CN}]$ ^{3,4} and which was developed into a commercial process.⁵

The cathodic reduction of alkyl cinnamates in relatively aprotic media was early recognised to involve EHD followed by Dieckmann condensation under the alkaline electrolysis conditions.⁶ Only the all-*trans* esters of (\pm)-3,4-diaryl-1-oxocyclopentane-2-carboxylic acids are formed as could be firmly established by assignment of ^1H NMR coupling constants⁷ and later confirmed by X-ray crystallography.⁸

In this paper we report our investigations concerning the cyclic EHD of a series of *para*-substituted (*E*)-methyl thiocinnamates **1–5** carried out in DMF containing residual water. Compounds **1–4** gave, in good yields, exclusively the cyclic hydromers, methyl (\pm)-3,4-diaryl-1-oxocyclopentane-2-thiocarboxylates **6–9** in which the ring substituents are all-*trans*.



Compounds **1–9** with non-systematic NMR numbering schemes.

Results and discussion

The thiocinnamates

The preparation of the thioesters of (substituted) cinnamic acids, compounds **1–5**, was achieved by reaction of commercial *para*-substituted (*E*)-cinnamic acids with thionyl dichloride in anhydrous diethyl ether followed by treatment with liquefied methanethiol at low temperature. Full details of a typical preparation have been described⁹ in an earlier paper and key physical data of the new compound **2** are presented in the Experimental section.

Table 1 Cyclic voltammetric^a experiments

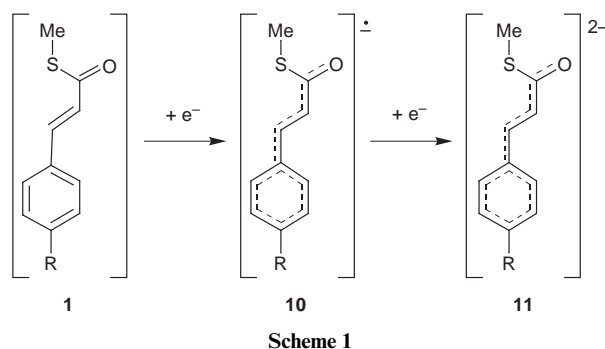
Thiocinnamate ester	$-E_{\text{pc}}(\text{I})^{b,c}$	$-E_{\text{pc}}(\text{II})^{b,d}$
1 (R = H)	1.13	1.64
2 (R = Me)	1.20	1.69
3 (R = OMe)	1.19	1.67
4 (R = Cl)	1.06	1.56
5 (R = NO ₂)	0.88	1.21

^a Thioester concentration 2–4 mmol dm⁻³. ^b V vs. Ag/AgBr. ^c Quasi-reversible. ^d Irreversible; pc = potential peak, cathodic.

Cyclic voltammetry

Single-sweep voltammetry at a mercury-coated platinum bead cathode in DMF–Et₄NBr (TEAB) (0.1 mol dm⁻³) at 0.30 V s⁻¹ revealed for all thiocinnamates two reduction peaks (Table 1). The first, quasi-reversible, one corresponds to the formation of the radical anion and the second, irreversible, peak to that of the dianion.

The differences in the first reduction peak potentials [$|E_{\text{pc}}(\text{2}) - |E_{\text{pc}}(\text{5})| = 0.32$ V], as well as in the second ones (0.48 V), are substantial and probably reflect a difference in the standard reduction potentials (E°). These potentials are less negative in the case of an electron-withdrawing substituent (R = NO₂, **5**) and more negative for electron-donating substituents (R = Me, **2**; R = OMe, **3**). The observed peak values for the *p*-Cl thioester **4** suggests that the withdrawal inductive effect of the Cl atom is more effective than its donating mesomeric one in stabilising both the radical anion **10** and the dianion **11** (Scheme 1). Plots of the first and second E_{pc} against



σ_{p}^- , but not against σ_{p} , show linear relationships (Fig. 1), which reflect a direct conjugation between the substituents and the electron-rich centre.

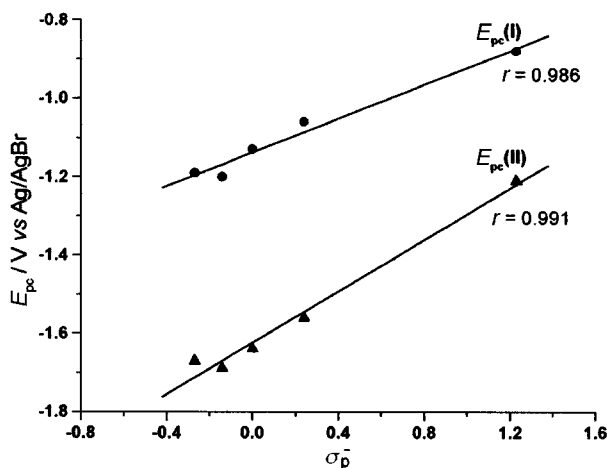


Fig. 1 Linear relationships between E_{pc} and σ_p^- .

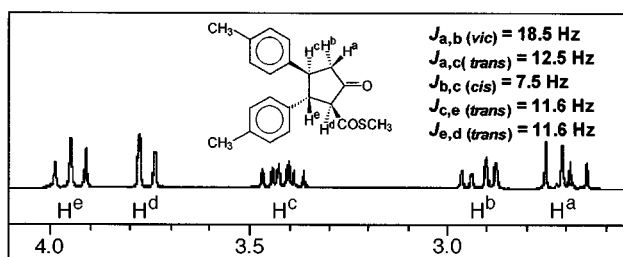


Fig. 2 Part of ^1H NMR spectrum of compound 7.

Controlled-potential electrolyses

These were typically carried out on a 0.3–0.5 g scale, at the first reduction peak potentials [$E_{pc}(I)$ in Table 1] referred to above, in a conventional cell equipped with a magnetically stirred mercury pool cathode, a reference electrode (Ag/AgBr), a graphite anode and an efficient microporous divider. The solvent was DMF containing 0.1 mol dm^{-3} TEAB as supporting electrolyte. The cathode compartment was continually flushed with a slow stream of dry nitrogen.

Methyl thiocinnamates 1–4 were converted to the corresponding cyclic hydrodimers 6–9 and the reactions were complete after the passage of ~ 1 faraday mol^{-1} , at which point the current had fallen to the background level. The nitro derivative 5 did not show similar behaviour and even after 2 faradays mol^{-1} the current was still high. A complex mixture of products was obtained and could not be properly identified. Probably, reduction of the nitro group had occurred concomitantly.

Stereochemistry of the cyclic hydrodimers

Only the all-*trans* isomers could be observed both in the crude and purified products 6–9. Their ^1H NMR spectra (e.g. 7, Fig. 2) had shown that the neighbouring protons (H^a , H^c , H^e and H^d) on the cyclopentanone ring, had typical *trans* coupling constants of ~ 12 Hz, whilst protons H^b and H^c had *cis* coupling constants of ~ 7.5 Hz. These observations are consistent with the reported⁸ coupling constants for an analogous ester cyclic hydrodimer of which X-ray crystallography confirmed the structure.

Experimental

Chemicals

Most chemicals were used as received from Aldrich.

Commercial DMF was dried over anhydrous CuSO_4 for 2 days and then distilled at $44\text{--}45^\circ\text{C}$ (25 mmHg) through a 40 cm Vigreux column and stored over freshly baked 4 Å molecular sieves.

Commercial grade TEAB was baked at 150°C overnight before use.

Electrochemical experiments

Cyclic voltammetric experiments were carried out using a USP electronics workshop-constructed triangular wave generator/potentiostat with a PAR RE0074 XY recorder. Controlled-potential electrolysis experiments were carried out using a potentiostat¹⁰ with an electronic charge integrator¹¹ constructed in our laboratory.

Spectroscopic studies

^1H and ^{13}C NMR Fourier transform (FT) spectra were recorded on a Bruker AC-200 spectrometer using deuterated chloroform/TMS as solvent/reference.

FTIR spectra were recorded for samples as a KBr disc, on a Perkin-Elmer 1750 series grating. Only major or important absorptions are given.

Elemental analyses

These were carried out on a Perkin-Elmer Elemental Analyser 2400 CHN.

Syntheses of methyl thiocinnamates 1–5

These compounds were obtained following methods described in the literature.⁹

Properties of the new compound methyl 4-methyl(thio)cinnamate 2. Yield: 83%; mp $91\text{--}94^\circ\text{C}$ (from EtOH) (Found: C, 68.75; H, 6.2. $\text{C}_{11}\text{H}_{12}\text{OS}$ requires C, 68.7; H, 6.3%); $\nu_{\text{max}}/\text{cm}^{-1}$ 3041, 2923, 1662 (C=O thioester), 1613 (C=C alkene), 1513, 1415, 1304, 1000, 858 and 810; δ_{H} (200 MHz) 2.37 (3 H, s, 9- H_3), 2.42 (3 H, s, 1- H_3), 6.70 (1 H, d, J 16, 3-H), 7.20 (2 H, d, J 8, $2 \times 7\text{-H}$), 7.45 (2 H, d, J 8, $2 \times 6\text{-H}$) and 7.59 (1 H, d, J 16, 4-H); δ_{C} (50 MHz) 11.6 (C-1), 21.5 (C-9), 124 (C-3), 128 (C-6), 130 (C-7), 131 (C-5), 140 (C-4), 141 (C-8) and 190 (C-2).

Controlled-potential electrolyses of thiocinnamate esters

Conditions employed for electrolyses are described above. Work-up involved quenching of the catholyte in an excess of ice-water, acidification with aq. hydrochloric acid to pH 6, and extraction with methylene dichloride ($3 \times 40 \text{ cm}^3$). The methylene dichloride solution was washed (water, $4 \times 50 \text{ cm}^3$) and dried. The crude solid products were recrystallised from methanol.

Physical data for the cyclic hydrodimers 6–9 are given below.

Compound 6. Yield: 85%; mp $130\text{--}131^\circ\text{C}$ (Found: C, 73.3; H, 5.75. $\text{C}_{19}\text{H}_{18}\text{O}_2\text{S}$ requires C, 73.55; H, 5.8%); $\nu_{\text{max}}/\text{cm}^{-1}$ 3029, 2928, 1750 (C=O ketone), 1669 (C=O thioester), 1495, 1452, 1310, 859 and 761; δ_{H} (200 MHz) 2.32 (3 H, s, 7- H_3), 2.75 (1 H, dd, $J_{a,c}$ 12.5, $J_{a,b}$ 18.5, 5- H^a), 2.97 (1 H, td, $J_{b,d}$ 0.9, $J_{b,c}$ 7.5, $J_{a,b}$ 18.5, 5- H^b), 3.47 (1 H, td, $J_{b,c}$ 7.5, $J_{c,e}$ 11.6, $J_{a,c}$ 12.5, 4- H^c), 3.81 (1 H, dd, $J_{b,d}$ 0.8, $J_{e,d}$ 11.6, 2- H^d), 4.00 (1 H, t, $J_{e,c \text{ or } d}$ 11.6, 3- H^e) and 7.09–7.32 (10 H, m, ArH); δ_{C} (50 MHz) 12.1 (C-7), 47.2 (C-5), 47.5 (C-4), 53.6 (C-3), 70.9 (C-2), 127–129 (C arom), 138–139 (C-8), 195 (C-6) and 208 (C-1).

Compound 7. Yield: 70%; mp $120\text{--}125^\circ\text{C}$ (Found: C, 74.3; H, 6.5. $\text{C}_{21}\text{H}_{22}\text{O}_2\text{S}$ requires C, 74.55; H, 6.5%); $\nu_{\text{max}}/\text{cm}^{-1}$ 3023, 2918, 1752 (C=O ketone), 1665 (C=O thioester), 1516 and 818; δ_{H} (200 MHz) 2.26 (3 H*, s, 12- H_3), 2.27 (3 H*, s, 12'- H_3), 2.31 (3 H, s, 7- H_3), 2.70 (1 H, dd, $J_{a,c}$ 12.6, $J_{a,b}$ 18.5, 5- H^a), 2.92 (1 H, td, $J_{b,d}$ 0.9, $J_{b,c}$ 7.4, $J_{a,b}$ 18.5, 5- H^b), 3.41 (1 H, td, $J_{b,c}$ 7.4, $J_{c,e}$ 11.6, $J_{a,c}$ 12.5, 4- H^c), 3.78 (1 H, dd, $J_{b,d}$ 0.9, $J_{d,e}$ 11.6, 2- H^d), 3.95 (1 H, t, $J_{e,c \text{ or } d}$ 11.6, 3- H^e) and 6.98–7.12 (8 H, m, ArH);

δ_C (50 MHz) 12.2 (C-7), 21.0 (C-12), 47.1 (C-5), 47.5 (C-4), 53.1 (C-3), 70.9 (C-2), 127–129 (C-9,-10), 136–137 (C-8,-11), 195 (C-6) and 208 (C-1).

* These assignments may be reversed.

Compound 8. Yield: 67%; mp 100–105 °C (Found: C, 67.85; H, 5.9. $C_{21}H_{22}O_4S$ requires C, 68.1; H, 5.95%); ν_{max}/cm^{-1} 3059, 2967, 1692 (C=O ketone and thioester overlapped), 1513, 1251, 1030 and 827; δ_H (200 MHz) 2.30 (3 H, s, 7- H_3), 2.68 (1 H, dd, $J_{a,c}$ 12.5, $J_{a,b}$ 18.5, 5- H^a), 2.91 (1 H, dd, $J_{b,c}$ 7.4, $J_{a,b}$ 18.5, 5- H^b), 3.34–3.44 (1 H, m, 4- H^c), 3.74 (3 H*, s, 12- H_3), 3.75 (3 H*, s, 12'- H_3), 3.73–3.79 (1 H, m, 2- H^d), 3.88 (1 H, t, $J_{e,d}$ or c 11.6, 3- H^e), 6.74–6.85 (4 H, m, 4 × 10-H) and 7.00–7.08 (4 H, m, 4 × 9-H); δ_C (50 MHz) 12.1 (C-7), 46.9 (C-5), 47.2 (C-4), 53.1 (C-3), 55.2 (C-12), 71.0 (C-2), 114 (C-10), 128 (C-9), 131 (C-8), 158 (C-11), 195 (C-6) and 208 (C-1).

* These assignments may be reversed.

Compound 9. Yield: 73%; mp 125–128 °C (Found: C, 59.95; H, 4.2. $C_{19}H_{16}Cl_2O_2S$ requires C, 60.15; H, 4.2%); ν_{max}/cm^{-1} 3032, 2925, 1749 (C=O ketone), 1673 (C=O thioester), 1492, 827 and 774; δ_H (200 MHz) 2.31 (3 H, s, 7- H_3), 2.68 (1 H, dd, $J_{a,c}$ 12.5, $J_{a,b}$ 18.5, 5- H^a), 2.84 (1 H, dd, $J_{b,c}$ 7.5, $J_{a,b}$ 18.5, 5- H^b), 3.39–3.45 (1 H, m, 4- H^c), 3.75 (1 H, d, $J_{e,d}$ 11.6, 2- H^d), 3.91 (1 H, t, $J_{e,c}$ or d 11.6, 3- H^e) and 7.19–7.25 (8 H, m, ArH); δ_C (50 MHz) 12.1 (C-7), 46.9 (C-5), 49.8 (C-4), 55.4 (C-3), 70.5

(C-2), 128–129 (C-9,-10), 133 (C-11), 138 (C-8), 194 (C-6) and 207 (C-1).

Acknowledgements

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