Monatshefte für Chemie 129, 689–696 (1998)

Monatshefte für Chemie
Chemical Monthly

Printed in Austria

Diels-Alder Reactions of Push-Pull Olefins I. Reactions of Dicyanovinyl Acylates with Cyclopentadiene, 1,3-Cyclohexadiene, and Anthracene[a]

Martin Dees and **Hans-Hartwig Otto***

Institut für Pharmazie, Universität Greifswald, D-17487 Greifswald, Bundesrepublik Deutschland

Summary. The reaction between 2,2-dicyanoethenyl acylates and cyclopentadiene affords 2-acyloxy-3,3-dicyano-5-norbornene derivatives with significant stereoselectivity. Reactions between the less reactive 1,3-cyclohexadiene and anthracene require elevated temperatures and extended reaction times. Stereoselectivity of the reactions with 1,3-cyclohexadiene is higher than of those with cyclopentadiene.

Keywords. *Diels-Alder*; Push-Pull Olefins; Stereoselectivity.

***Diels-Alder*-Reaktionen von Push-Pull-Olefinen, 1. Mitt. Reaktionen von Dicyanovinylestern mit Cyclopentadien, 1,3-Cyclohexadien und Anthracen**

Zusammenfassung. Reaktionen zwischen 2,2-Dicyanoethenylcarbonsäureestern und Cyclopentadien ergeben mit signifikanter Stereoselektivität 2-Acyloxy-3,3-dicyan-5-norbornenderivate. Analoge Reaktionen mit den weniger reaktiven Dienen 1,3-Cyclohexadien und Anthracen erfordern höhere Temperaturen und längere Reaktionszeiten; die Stereoselektivität der Reaktionen mit 1,3-Cyclohexadien ist deutlich größer.

Introduction

The *Diels-Alder* reaction is one of the most valuable tools for the construction of six-membered rings in synthetic chemistry [1]. Wether the reaction proceeds normaly or with inverse electron demand depends on the electron donating or withdrawing properties of the substituents of the dienes and dienophiles. However, only few attention has been paid so far to the use of push-pull substituted olefins as dienophiles [2]. We have investigated *Diels-Alder* reactions between some push-pull olefins and symmetrical as well as unsymmetrical dienes. Our main goals were to study the influence of the substitution pattern on the reactivity of the

[a] From the thesis of Martin Dees, University of Freiburg, 1995

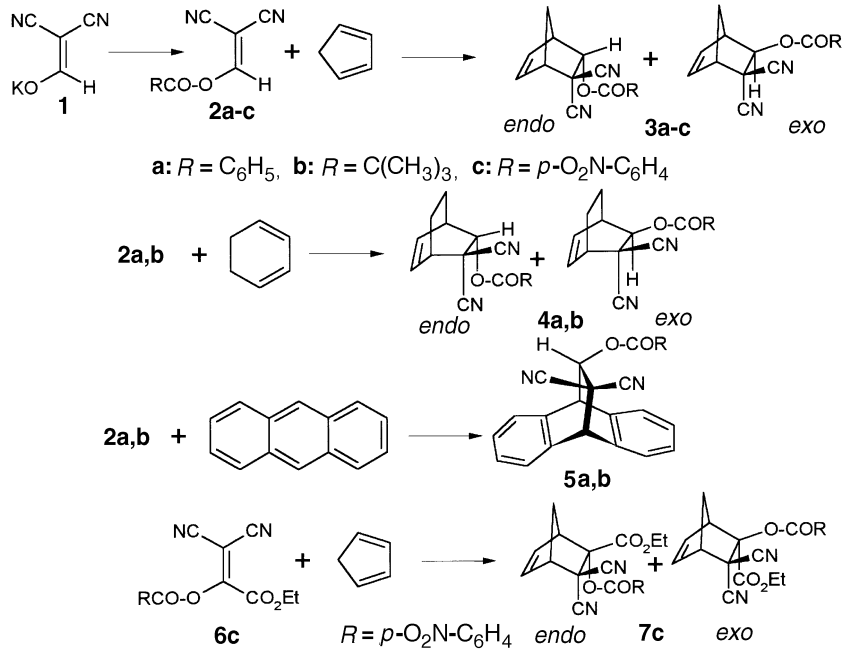
* Corresponding author

dienophiles, the regioselectivity of reactions with unsymmetrical dienes, and the stereoselectivity of these reactions.

In this paper, on some reactions between carboxylates of 2,2-dicyanoethenol and the highly reactive cyclopentadiene, the less reactive cyclohexa-1,3-diene, and anthracene. Furthermore, the *Diels-Alder* reaction between a dienophile bearing a third electron withdrawing group and having therefore both push-pull and captodative properties [3] and cyclopentadiene is described. A *Diels-Alder* reaction between 2,2-dicyanoethenyl acetate and cyclopentadiene has been reported [4], and some cycloadditions employing acyloxymethylenemalonates without and with *Lewis* acid catalysis have been studied by *Katagiri* and coworkers [5]. In these experiments, the *exo*-acyloxy compound is the predominating stereoisomer at elevated temperatures, and the *endo*-derivative under *Lewis* acid catalysis; the *endo*/*exo* ratio depends on the *Lewis* acid and the temperature.

Results and Discussion

2,2-Dicyanovinyl benzoate (**2a**), pivalate (**2b**), and *p*-nitrobenzoate (**2c**) were prepared from the potassium salt of hydroxymethylidenemalononitrile (**1**, [6]) in analogy to the rather crude literature procedure described for the corresponding acetate [7] or by a more convenient pathway from hydroxymethylidenemalononitrile [8]. We found tetrahydrofuran to be the solvent of choice for this reaction. 2,2-Dicyano-1-(ethoxycarbonyl)vinyl *p*-nitrobenzoate (**6c**) was prepared in a similar manner from the potassium salt of ethyl 3,3-dicyano-2-hydroxyacrylate [6] and *p*-nitrobenzoyl chloride. Especially **2a** and **2b** are very interesting and



Scheme

useful compounds because of their ease of preparation and their stability. The corresponding acetate decomposes within a few days, even if stored at −20°C under a nitrogen atmosphere.

At room temperature, the reactions between **2a–c** and cyclopentadiene are completed within 45 min. The yields are nearly quantitative, and all products are isolated as crystalline compounds. The ^{1}H NMR spectra of the crude products **3a–c** show two signals between 4.8 and 5.8 ppm with a ratio of about 2:1 corresponding to 2-H of the *endo*- and *exo*-acyloxy diastereomers. The more intense signal which is shifted downfield has a coupling constant of $J \approx 4$ Hz, whereas the minor signal shows a coupling constant of $J \approx 4$ Hz. According to the *Karplus-Conroy* relation, the signal with $J = 4$ Hz should correspond to the equatorial 2-H of the *endo*-diastereomers of **3a–c**, spreading a dihedral angle of about 60° with the bridgehead hydrogen atom 1-H. The dihedral angle of 2-H axial with 1-H of the *exo*-diasteromers amounts to about 90°, resulting in a smaller coupling constant.

The *endo*-diastereomers of **3a** and **b** be separated by fractionated crystallization in *ca.* 40% yield, whereas the isolation of small amounts of the better soluble *exo*-isomer succeed only in the case of **3b**. Compound **3c** is obtained as a diastereomeric mixture (*endo*:*exo* ≈ 2:1).

Compound **6c**, the push-pull captodative olefin, also reacts with cyclopentadiene at room temperature. The ethoxycarbonyl group, however, does not enhance the reactivity of **6c** significantly compared to **2a–c**. At least, no exothermic reaction is observed as might be expected from a reaction of cyclopentadiene with a much more reactive olefine. The *endo*- and *exo*-diastereomers of **7c** are formed in a ratio of about 1:1 (TLC). The diastereomer which is more soluble in apolar solvents was separated by column chromatography and identified as the *endo*-ethoxycarbonyl-*exo*-(*p*-nitrobenzoyloxy) diastereomer *exo*-**7c** by an NOE experiment.

For a successful reaction of **2a** or **2b** with the rather unreactive cyclohexa-1,3-diene, the reactants were refluxed in carbon tetrachloride for 48 h. The reactions yield about 60–70% of the cycloadducts **4a** and **4b**, both isolated as diastereomeric mixturer in a ratio of 95:5. In the crude reaction mixture, the ratio was determined to be about 9:1. The protons at C-1 and C-2 of the bicyclo[2.2.2]oct-5-ene derivatives **4a** and **4b** spread a dihedral angle of about 60° in the *endo*- as well as in the *exo*-diastereomers. MMX calculations of the minimum energy conformations using the program PCMODEL, Serena Software, show dihedral angles of 63.65° for the *endo*- and −55.35° for the *exo*-isomer.

NOE experiments show a positive NO effect between 2-H and one of the protons of the C-7/C-8 bridge (most propably 7-H$_{syn}$) of the main diastereomers. This indicates that in the main diastereomers of **4a** and **4b** the acyloxy group is *endo*-oriented. Thus the *endo*/*exo* preference in these reactions between 2,2-dicyanvinyl carboxylates and 1,3-cyclohexadiene is about 9:1, significantly higher than in the reactions with cyclopentadiene where it is about 2:1.

Refluxing **2a** or **2b** with anthracene in xylene always leads to an incomplete formation of the reaction products **5a**, **b**. Neither a reaction time up to 3 days nor lowering the reaction temperature to 80°C and extending at the same time the reaction time to one week improves the yields. The addition products, however, could easily be separated from unchanged starting material and decomposition

products by column chromatography in about 20% yield. The presumption that in these reactions with anthracene under the applied conditions an equilibrium between *Diels-Alder* and *retro-Diels-Alder* reaction with an equilibrium constant of about 0.2 is reached can be demonstrated by refluxing **5a** in xylene, leading to the decomposition into **2a** and anthracene (TLC).

The ^{1}H NMR spectra of **5a** and **5b** show two doublets ($\delta = 4.73/4.63$ and 5.51/5.27 ppm, $J = 3$ Hz) and one singulet at $\delta = 4.90$ ppm. The latter indicates the bridgehead proton 9-H; the assignment of the doublets can only be performed by NOE experiments, showing that the signals shifted downfield arise from the proton of the ethano bridge, 11-H.

In the reaction of cyclopentadiene with the dienophiles **2a–c** we found a 2:1 preference for the formation of the *endo*-diastereomers. Assuming the reactions are kinetically controlled, this is not to be expected. Since all isolated diastereomers are stable compounds, at least under our reaction conditions (room temperature, aprotic solvent), the reactions between the 2,2-dicyanovinyl carboxylates and cyclopentadiene should be kinetically controlled. Usually, the *endo*-preference in kinetically controlled *Diels-Alder* reactions is explained by a secondary orbital overlap between the frontier orbitals, thereby lowering the energy of the transition state. This type of attracting forces normally is described as an interaction between the π-system of the diene and a group of the dienophile which is π-conjugated to its olefinic double bond. As the push-pull olefins **2** do not show this π-conjugation, we postulate a secondary orbital overlap between the π-system of the diene and the *n*-electrons of the acyloxy group of the dienophile. To the best of our knowledge, this type of interaction has not been reported until today.

Regarding reaction temperature and time in the reactions of 1,3-cyclohexadiene with **2a** and **2b**, one might come to the conclusion that the *endo*-products **4a** and **4b** are thermodynamically more stable than the *exo* products. This would lead to their preferred formation under thermodynamically controlled reaction conditions. Force field calculations (MMX), however, showed no significant difference in the stability of the *endo*- and *exo*-diastereomers. Thus, it is more likely that, as with cyclopentadiene, the reaction of 2,2-dicyanovinyl carboxylates with 1,3-cyclohexadiene proceeds kinetically controlled and that the preferred formation of *endo*-acyloxy products is caused by a transition state lower in energy than that leading to the *exo* products.

Experimental

General

All configurations are relative; m.p.: Linström apparatus (uncorr.); IR spectra: Perkin-Elmer IR 841, KBr if not noted otherwise; ^{1}H NMR spectra: Varian T60, Bruker WP80, Bruker WH90, Varian U300, Bruker AM400, internal *TMS*, δ in ppm, values for 60 MHz spectra in $CDCl_3$ if not noted otherwise; ^{13}C NMR spectra: Varian U300 (75.43 MHz), internal *TMS*, δ in ppm; elemental analyses: Pharmazeutisches Institut or Chemisches Laboratorium der Universität Freiburg. Tetrahydrofuran (*THF*) was dried over KOH, refluxed with benzophenone and sodium, and then distilled. Dimethylformamid (*DMF*) was dried over P_4O_{10} and distilled from CaH_2. Other solvents were dried/purified according to literature procedures.

Thin layer chromatography (TLC): DC-Alufolien silica gel 60 F254 (Merck Nr. 5554), detection with UV light (254 nm and 366 nm) or with phosphomolybdato ammonium cerium(IV) sulfate (1.0 g of ammonium cerium(IV) sulfate-2-hydrate and 2.5 g of phosphomolybdic acid are dissolved in 8 ml of conc. sulfuric acid, water is added to 100 ml, and after 2 h the solution is filtered); column chromatography (CC): silica gel 60 (0.063–0.200 mm, Merck Nr. 7734).

(Hydroxymethylidene) malononitrile (**1**): see Refs. [9, 10].

Acylation of **1**, *General Procedure*

a) 5.10 g (50 mmol) of triethylamine is added dropwise to an ice-cooled soln. of 50 mmol of **1** and 50 mmol of the acide chloride in 200 ml of *THF*; the mixture is stirred for 1 h at 0°C, then 15 h at room temp. The precipitate is separated, washed twice with 50 ml of *THF* each, the combined org. layers are dried over sodium sulfate, the solvent is evaporated, and the residue is purified as specified.

b) 20 mmol of the sodium or potassium salt of **1** is dissolved in 150 ml of *THF*; 20 mmol of the acide chloride is added, and the mixture is refluxed as noted. Then the solvent is evaporated, 150 ml of dichloromethane are added to the residue, and after filtration, the solvent is again evaporated. The residue is purified as specified.

2,2-Dicyanovinyl benzoate (**2a**)

From 3.75 g (40 mmol) of **1**, 5.65 g (40 mmol) of benzoyl chloride, and 4.05 g (40 mmol) of triethylamine, method *a*; from 6.60 g (50 mmol) of **1** (potassium salt) and 7.00 g (50 mmol) of benzoyl chloride, time 2 h, method *b*.

Yield: *a*) 6.10 g (77%), b) 8.55 g (86%); colorless crystals; m.p.: 154°C (dec., *n*-hexane); IR: $\nu = 3056$ (CH), 2244 (CN), 1771 (CO), 1617 (C=C) cm^{-1}; ^1H NMR: $\delta = 7.66$–8.50 (m, 5H, aromatic H), 8.87 (s, 1H, olefin. H) ppm; $C_{11}H_6N_2O_2$ (198.2); calcd.: C 66.67, H 3.05, N 14.14; found: C 66.87, H 3.08, N 14.26.

2,2-Dicyanovinyl pivaloate (**2b**)

From 5.30 g (40 mmol) of **1** (potassium salt) and 4.85 g (40 mmol) of pivaloyl chloride, time 2 h, method *b*.

Yield: 5.30 g (74%); colorless crystals; m.p.: 85°C (*n*-hexane); IR: $\nu = 3053$, 2983, 2942, 2915, 2879 (CH), 2249 (CN), 1801 (CO), 1620 (C=C) cm^{-1}; ^1H NMR: $\delta = 1.37$ (s, 9H, CH_3), 8.48 (s, 1H, olefin. H) ppm; $C_9H_{10}N_2O_2$ (178.2); calcd.: C 60.67, H 5.66, N 15.72; found: C 60.58, H 5.71, N 15.59.

2,2-Dicyanovinyl p-nitrobenzoate (**2c**)

From 2.65 g (20 mmol) of **1** (potassium salt) and 3.7 g (20 mmol) of *p*-nitrobenzoyl chloride, time 2 h, method *b*.

Yield: 0.55 g (11%); light yellow crystals; m.p.: 166°C (dec., CCl_4); IR: $\nu = 3106$, 3058 (CH), 2249 (CN), 1776 (CO), 1624 (C=C), 1534, 1356 (NO_2) cm^{-1}; ^1H NMR: $\delta = 8.47$ (s, 4H, arom. H), 8.80 (s, 1H, olefin. H) ppm; $C_{11}H_5N_3O_4$ (243.2); calcd.: C 54.33, H 2.07, N 17.28; found: C 54.46, H 2.09, N 17.22.

Synthesis of **3**, *General Procedure*

The dienophile is dissolved in an appropriate solvent, 1.2–2 equiv. of cyclopentadiene (freshly distilled) are added, the mixture is stirred at r.t. for 15 h, the solvent is evaporated, and the residue is purified as specified.

3,3-Dicyanobicyclo[2.2.1]hept-5-en-2-yl benzoate (**3a**)

From 1.00 g (5.05 mmol) of **2a** and 0.60 g (9.1 mmol) of cyclopentadiene in CH_2Cl_2. 60 ml of *n*-hexane is added to the residue.

Yield: 1.03 g (77%); mixture of isomers, *endo*/*exo* = 2:1; colorless crystals.

endo-**3a**

From the mixture by two cristallizations from CCl_4; yield: 0.49 g (37%); colorless crystals; m.p.: 130°C (CCl_4); IR: $\nu = 3081, 3060, 3005, 2994, 2951, 2880$ (CH), 2247 (CN), 1712 (CO), 1600, 1583 (arom.), 1274, 1107 (C–O) cm^{-1}; ^1H NMR (80 MHz): $\delta = 1.80–2.05$ (m, 2H, 7-H_{syn}, 7-H_{anti}), 3.38–3.60 (m, 1H, 1-H), 3.60–3.78 (m, 1H, 4-H), 5.75 (d, $J = 4$ Hz, 1H, 2-H), 6.40–6.63 (m, 2H, 5-H, 6-H), 7.23–7.73, 7.93–8.10 (2 m, 5H, arom. H) ppm; $C_{16}H_{12}N_2O_2$ (264.3); calcd.: C 72.72, H 4.58, N 10.60; found: C 72.70, H 4.66, N 10.68.

3,3-Dicyanobicyclo[2.2.1]hept-5-en-2-yl pivalate (**3b**)

From 1.80 g (10.1 mmol) of **2b** and 0.90 g (13.6 mmol) of cyclopentadiene in CCl_4. The precipitate (*endo*-**3b**) is separated before the solvent is evaporated.

endo-**3b**: Yield: 1.00 g (40%); colorless crystals; m.p.: 128°C (CCl_4); IR: $\nu = 3072, 2985, 2975, 2933, 2907, 2874$ (CH), 2245 (CN), 1730 (CO), 1688 (C=C), 1146, 1132 (C–O) cm^{-1}; ^1H NMR (80 MHz): $\delta = 1.23$ (s, 9 H, $C(CH_3)_3$), 1.75–1.98 (m, 2H, 7-H_{syn}, 7-H_{anti}), 3.25–3.48 (m, 1H, 1-H), 3.53–3.73 (m, 1H, 4-H), 5.40 (d, $J = 4$ Hz, 1H, 2-H), 6.30–6.53 (m, 2H, 5-H, 6-H) ppm; $C_{14}H_{16}N_2O_2$ (244.3); calcd.: C 68.83, H 6.60, N 1147; found: C 68.55, H 6.77, N 11.38.

exo-**3b**: By fractionated crystallization from *n*-hexane; yield 0.07 g (2.8%); colorless crystals; m.p.: 68°C (*n*-hexane); IR: $\nu = 3075, 2995, 2980, 2937, 2907, 2878$ (CH), 2252 (CN), 1736 (CO), 1662 (C=C), 1130 (C–O) cm^{-1}; ^1H NMR (80 MHz): $\delta = 1.28$ (s, 9H, $C(CH_3)_3$), 2.00–2.18 (m, 2H, 7-H_{syn}, 7-H_{anti}), 3.05–3.23 (m, 1H, 1-H), 3.55–3.70 (m, 1H, 4-H), 4.80 (d, $J = 2$ Hz, 1H, 2-H), 6.30–6.53 (m, 2H, 5-H, 6-H).

3,3-Dicyanobicyclo[2.2.1]hept-5-en-2-yl p-nitrobenzoate (**3c**)

From 1.00 g (4.1 mmol) of **2c** and 0.50 g (7.6 mmol) of cyclopentadiene in *THF*.

Yield: 1.01 g (79%); mixture of isomers, *endo*/*exo* = 2:1; light yellow crystals; m.p.: 173°C (CCl_4); IR: $\nu = 3110, 3078, 3055, 3001, 2949, 2881$ (CH), 2249 (CN), 1722 (CO), 1529, 1350 (NO_2), 1263, 1100 (C–O) cm^{-1}; ^1H NMR: $\delta = 1.90–2.10$ (m, 2H×2/3, 7-H_{syn}, 7-H_{anti}), 2.10–2.33 (m, 2H×1/3, 7-H_{syn}, 7-H_{anti}), 3.30–3.95 (m, 2H, 1-H, 4-H), 5.20 (br.s, 1H×1/3, 2-H), 5.83 (d, $J = 4$ Hz, 1H×2/3, 2-H), 6.43–6.73 (m, 2H, 5-H, 6-H), 8.10–8.50 (m, 4 H, arom. H) ppm; $C_{16}H_{11}N_3O_4$ (309.3); calcd.: C 62.14, H 3.58, N 13.59; found: C 62.19, H 3.66, N 13.50.

Synthesis of **4**, *General Procedure*

The dienophile and the equivalent amount of cyclohexa-1,3-diene are refluxed in 50 ml of CCl_4 for 48 h. Then the solvent is evaporated, and the residue is redissolved in CH_2Cl_2 and filtered through silica gel. The filtrate is evaporated, and the residue is crystallized as specified.

endo-3,3-Dicyanobicyclo[2.2.2]oct-5-en-2-yl benzoate (**4a**)

From 1.0 g (5.1 mmol) of **2a** and 1.0 g (12.5 mmol) of cyclohexa-1,3-diene.

Yield: 0.67 g (48%); light yellow crystals; m.p.: 167°C (CCl_4); IR: $\nu = 3057, 2984, 2959, 2880$ (CH), 2248 (CN), 1720 (CO), 1283, 1266, 1097 (C–O) cm^{-1}; ^1H NMR (300 MHz): $\delta = 1.45–1.59$

(m, 2H, 7-H_{anti}, 8-H_{anti}), 1.74–1.87 (m, 1H, 7-H_{syn}), 2.05–2.18 (m, 1H, 8-H_{syn}), 3.04–3.11 (m, 1H, 1-H, 3.32–3.38 (m, 1H, 4-H), 5.33 (d, $J = 2.44$ Hz, 1H, 2-H), 6.44–6.58 (m, 2H, 5-H, 6-H), 7.41–7.63, 8.03–8.09 (2m, 5H, arom. H) ppm; $C_{17}H_{14}N_2O_2$ (278.3); calcd.: C 73.37, H 5.07, N 10.07; found: C 73.15, H 5.04, N 10.21.

endo-3,3-Dicyanobicyclo[2.2.2]oct-5-en-2-yl pivalate (**4b**)

From 1.00 g (5.6 mmol) of **2b** and 1.10 g (13.7 mmol) of cyclohexa-1,3-diene.

Yield: 0.98 g (68%); colorless crystals; m.p.: 114°C (*n*-hexane); IR: $\nu = 3075$, 3056, 2977, 2940, 2875 (CH), 2246 (CN), 1728 (CO), 1610 (C=C), 1144 (C–O) cm^{-1}; ^1H NMR (300 MHz): $\delta = 1.22$ (s, 9H, $C(CH_3)_3$), 1.36–1.52 (m, 2H, 7-H_{anti}, 8-H_{anti}), 1.65–1.78 (m, 1H, 7-H_{syn}), 1.99–2.12 (m, 1H, 8-H_{syn}), 2.85–2.94 (m, 1H, 1-H), 3.24–3.32 (m, 1H, 4-H), 4.97 (d, $J = 2.4$ Hz, 1H, 2-H), 6.38–6.49 (m, 2H, 5-H, 6-H) ppm; $C_{15}H_{18}N_2O_2$(258.3); calcd.: C 69.74, H 7.02, N 10.84; found: C 69.50, H 6.94, N 10.99.

Synthesis of **5**, *General Procedure*

The dienophile and the equivalent amount of anthracene are refluxed in 50 ml of xylene for 48 h. Then, the solvent is evaporated, and the residue is purified by CC. First, anthracene is separated by extraction with chloroform, then the product is obtained by elution with dichloromethane (TLC control).

12,12-Dicyano-9,10-dihydro-9,10-ethanoanthracen-11-yl benzoate (**5a**)

From 1.10 g (5.6 mmol) of **2a** and 0.99 g (5.6 mmol) of anthracene.

Yield: 0.38 g (18%); colorless crystals; m.p.: 199°C (dec.); IR: $\nu = 3069$, 3045, 3029, 2986, 2957 (CH), 2256 (CN), 1726 (CO), 1264, 1099 (C–O) cm^{-1}; ^1H NMR (80 MHz): $\delta = 4.73$ (d, $J = 3$ Hz, 1H, 10-H), 4.90 (s, 1H, 9-H), 5.51 (d, $J = 3$ Hz, 1H, 11-H), 7.30–7.59 (m, 11H, 1-H-8-H, benzoyl 3-H-5-H), 7.85–7.89 (m, 2H, benzoyl 2-H, 6-H) ppm; $C_{25}H_{16}N_2O_2$ (376.4); calcd.: C 79.77, H 4.28, N 7.44; found: C 79.73, H 4.37, N 7.32.

12,12-Dicyano-9,10-dihydro-9,10-ethanoathracen-11-yl pivalate (**5b**)

From 0.89 g (5.0 mmol) of **2b** and 0.89 g (5.0 mmol) of anthracene.

Yield: 0.38 g (21%); colorless crystals; m.p.: 149°C; IR: $\nu = 3073$, 3048, 3030, 2972, 2931, 2906, 2873, (CH), 2247 (CN), 1730 (CO), 1140 (C–O) cm^{-1}; ^1H NMR: $\delta = 1.17$ (s, 9H, $C(CH_3)_3$), 4.63 (d, $J = 3$ Hz, 1H, 10-H), 4.90 (s, 1H, 9-H), 5.27 (d, $J = 3$ Hz, 1H, 11-H), 7.20–7.80 (m, 8H, 1-H – 8-H) ppm; $C_{23}H_{20}N_2O_2$ (356.4); calcd.: C 77.51, H 5.66, N 7.86; found: C 77.71, H 5.72, N 7.77.

Ethyl 3,3-dicyano-2-(4-nitrobenzoyloxy)acrylate (**6c**)

2.05 g (10 mmol) ethyl 3,3-dicyano-2-hydroxyacrylate, potassium salt [11] and 1.90 g (10 mmol) *p*-nitrobenzoyl chloride in 150 ml of *THF* are refluxed for 3.5 h. The solvent is evaporated, and the residue is redissolved in 50 ml of benzene at room temperature and filtered. This procedure is repeated once. *n*-Hexane (*ca.* 100 ml) is added to the filtrate until a slight opalescent solution is formed. This solution is stored at −20°C until the crystallization is completed (3–5 days). The crystals are separated without warming.

Yield: 0.90 g (29%); light yellow crystals; m.p.: 75–76°C (*n*-hexane); IR: $\nu = 3112$, 3082, 3060, 2997, 2945 (CH), 2246 (CN), 1766, 1752 (CO), 1620 (C=C), 1526, 1351 (NO_2) cm^{-1}; ^1H NMR:

$\delta = 1.43$ (t, $J = 7$ Hz, 3H, CH_3), 4.53 (q, $J = 7$ Hz, 2H, CH_2), 8.20–8.50 (m, 4H, arom. H) ppm; $C_{14}H_9N_3O_6$ (315.2); calcd.: C 53.34, H 2.88, N 13.33; found: C 53.63, H 2.99, N 13.09.

Ethyl 3,3-dicyano-2-(p-nitrobenzoyloxy)bicyclo[2.2.1]hept-5-ene-2-carboxylate (**7c**)

From 1.50 g (4.8 mmol) of **6c** and 0.50 g (7.6 mmol) of cyclopentadiene in *THF* as described for **2**.

Yield: 1.08 g (60%); mixture of isomers, *endo*/*exo* = 1:1; light yellow crystals; m.p.: 134°C (cyclohexane); IR: $\nu = 3111$, 3079, 3055, 2995, 2940, 2905 (CH), 2949 (CN), 1753 (CO), 1529, 1348 (NO_2), 1282, 1098 (C–O) cm^{-1}; ^1H NMR (80 MHz): $\delta = 1.26$ (t, $J = 7$ Hz, 3H×1/2, CH_3), 1.30 (t, $J = 7$ Hz, 3H×1/2, CH_3), 1.90–2.63 (m, 2H, 7-H_{syn}, 7-H_{anti}), 3.63–3.88, 4.00–4.20 (2 m, 1-H, 4-H), 4.29 (q, $J = 7$ Hz, 2H×1/2, CH_2), 4.38 (q, $J = \varepsilon$ 7 Hz, 2H×1/2, CH_2), 6.13–6.85 (m, 2H, 5-H, 6-H), 8.05–8.48 (m, 4H, arom. H) ppm; $C_{19}H_{15}N_3O_6$ (381.4); calcd.: C 59.84, H 3.96, N 11.02; found: C59.65, H 4.01, N 11.15.

exo-**7c**: Separation by CC (silica gel, diethyl ether/*n*-hexane = 1:1; TLC control); $R_f = 0.49$ (*endo*-**7c**: $R_f = 0.40$); yield: 0.021 g (21%); light yellow crystals; m.p.: 131°C; ^1H NMR (300 MHz): $\delta = 1.30$ (t, $J = 7.1$ Hz, 3H, CH_3), 2.09 (ddd, $J = 11.0$ Hz, 1.7 Hz, 1.7 Hz, 1H, 7-H_{anti}), 2.45 (dbr.s, $J = 11$ Hz, 1H, 7-H_{syn}), 3.77 (m, 1H, 4-H), 4.13 (m, 1H, 1-H), 4.38 (q, $J = 7.1$ Hz, 2H, CH_2), 6.29 (dd, $J = 5.6$ Hz, 3.2H_2, 1H, 6-H), 6.57 (dd, $J = 5.6$ Hz, 2.9 Hz, 1H, 5-H), 8.22–8.36 (m, 4H, arom. H).

Acknowledgements

Financial support provided by the *Fonds der Chemischen Industries*, Frankfurt, and *Ciba*, Basel, is gratefully appreciated. We thank *Volker Brecht* for recording of NMR spectra and *Ursula Predoiu* for experimental help.

References

[1] Curran DP (1993) Advances in Cycloaddition, vol 1–3, and Lautens M (1997) (ed), vol 4. Jai Press, Greenwich, CT
[2] a) Rudorf WD (1983) Wiss Z Univ Halle **32M**: H 1, 57; b) Lloyd D, McNab H (1976) Angew Chem **88**: 496
[3] Viehe HG, Janousek Z, Merényi R, Stella L (1985) Acc Chem Res **18**: 148
[4] Kölbl H, Gompper R, Behrenz W, Hammann I, Homeyer B, Herrmann G (1983) Ger Offen, DE 3, 141, 119; Chem Abstr (1983) **99**: P100974
[5] a) Katagiri N, Haneda T, Kaneko C (1986) Chem Pharm Bull **34**: 4875; b) Katagiri N, Haneda T, Hayasaka E, Watanabe N, Kaneko C (1988) J Org Chem **53**: 226; c) Katagiri N, Haneda T, Watanabe N, Hayasaka E, Kaneko C (1988) Chem Pharm Bull **36**: 3867; d) Katagiri N, Kurimoto A, Kaneko C (1992) Chem Pharm Bull **40**: 1737
[6] Schenck R, Finken H (1928) Liebigs Ann Chem **462**: 158
[7] Rubtsov IA, Balyakina MV, Zaitseva EV, Preobrazhenskii NA (1953) Trudy, Vsesoyuz, Nauch.-Issledovatel Vitamin Inst **4**: 20; Chem Abstr (1965) **50**: 4156 g
[8] DeGraw JI, Christie PH, Kisliuk RL, Gaumont Y, Sirotnak FM (1990) J Med Chem **33**: 673
[9] Diels O, Gärtner H, Kaack R (1922) Chem Ber **55**: 3439
[10] Libis B, Fleury JP (1965) Bull Soc Chim Fr 3323
[11] Dornow A, Grabhöfer H (1958) Chem Ber **91**: 1824

Received November 21, 1997. Accepted December 4, 1997