Addition Reactions of 2-Amino-4-methoxypenta-2,4-dienenitrile with Electrophiles Containing Electron-deficient Multiple Bonds

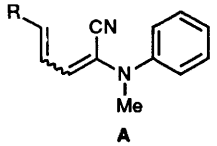
Yu-Wen Wang,[b] Jim-Min Fang,*[,a] Yu-Ker Wang,[a] Mei-Huei Wang,[a] Teng-Yao Ko[a] and Yie-Jia Cherng[a]

[a] *Department of Chemistry, National Taiwan University, Taipei, Taiwan 10764, Republic of China*

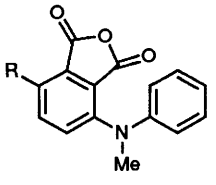
[b] *Department of Mathematics & Physics Education, Taiwan Provincial Chiayi Teachers College, Taiwan, Republic of China*

The title compound **1** underwent an insertion reaction with dichlorocarbene selectively at the C-4 double bond. The [4 + 2]cycloadditions of **1** with benzoquinone and naphthoquinone proceeded by subsequent dehydrocyanation and oxidative aromatization under mild conditions to give the diarylamines **6** and **7**. The cycloaddition of **1** and *N*-phenylmaleimide in a sealed tube proceeded with reinsertion of the cyanide ion to give the diarylamine **8**. The homologation of **1** with chlorosulfonyl isocyanate (CSI) and tetracyanoethylene (TCNE), giving the dienoate **9** and the triene **10**, was unusual compared with commonly observed [2 + 2]cycloadditions of CSI and TCNE. The reaction of **1** with dimethyl acetylenedicarboxylate proceeded *via* an intermediate cyclobutene and tandem ring-opening afforded the triene **11**. The reaction of **1** with ethyl propiolate produced two diarylamines **12a** and **12b**. Formation of **12a** might involve cyanide reinsertion on the intermediate derived from the [4 + 2]cycloaddition, whereas an opening of the [2 + 2]intermediate followed by an electrocyclization would yield the isomer **12b**.

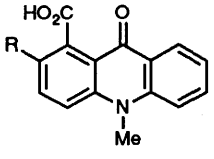
Although the α-aminoalkenenitriles have been used as acceptors in Michael reactions[1] and as dienophiles in Diels–Alder reactions,[2] we have reported that the related dienes **A**



A

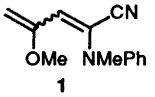


B



C

(R = Me, Et and Ph) function as nucleophiles in cycloaddition with electron-deficient double bonds and in insertions with dichlorocarbene.[3] The diarylamines **B**, obtained by the reaction of **A** and maleic anhydride, are useful precursors for the acridones **C** formed by acid-catalysed cyclisations. We report here the reactions of 2-(*N*-methylanilino)-4-methoxypenta-2,4-dienenitrile **1**, whose reactivity toward electrophiles was

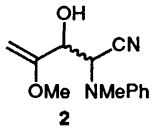


1

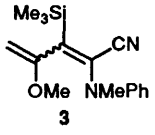
expected to be enhanced by the presence of the methoxy group. During the course of this study, we observed some unusual reactions of **1** owing to the effect of the methoxy group.

Results and Discussion

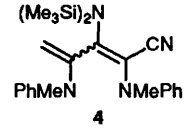
The allylic alcohol **2** was obtained in 90% yield by the reaction



2



3

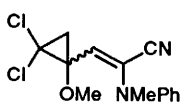


4

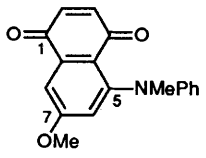
of the anion of 2-(*N*-methylanilino)acetonitrile with 2-methoxyacrylaldehyde. The methanesulfonate of the alcohol **2** was treated with Bu^{t}OK to afford the desired diene **1** in 64% yield. Conversion of the allylic alcohol **2** to corresponding chloride ($POCl_3$, pyridine) or acetate (Ac_2O, pyridine), followed by elimination with various bases 1,4-diazabicyclo[2.2.2]octane, 1,5-diazabicyclo[4.3.0]non-5-ene, 1,8-diazabicyclo[5.4.0]undec-7-ene or Bu^{t}OK) gave lower yields of **1**. Unlike other stable α-aminodienenitriles, compound **1** decomposed partially on a silica gel column, however, pure diene **1** was obtained by chromatography on neutral alumina. Although the *E*- and *Z*-isomers of **1** were isolated for analytical purpose, the *E*/*Z* mixture (predominating in the *Z*-isomer) was routinely used in subsequent reactions with a number of electrophiles. We also attempted to synthesise the diene **1** by using Peterson's method.[3] The reaction did not yield the diene **1**, it gave instead the silylated derivative **3** accompanied by a self-condensation product **4**.

Treatment of the diene **1** (*Z*-configuration) with dichlorocarbene, generated from $CHCl_3$ and NaOH by ultrasonication in the presence of a phase-transfer catalyst,[4] yielded a cyclopropanation product **5** with the *Z*-configuration. However, the compound when dissolved in $CDCl_3$ gradually became a mixture of the *E*,*Z*-isomers.

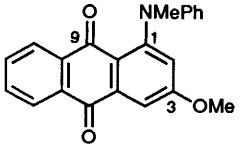
The reaction of **1** and *p*-benzoquinone occurred readily at room temperature to give a diarylamine **6**. This reaction probably involved a dipolar process to give a [4 + 2]-cycloaddition intermediate **D**,[5] which subsequently lost HCN and underwent oxidative aromatization.[3] Compared with the analogous reaction of the diene **A**, which must be effected in refluxing xylene, the diene **1** appeared to be more reactive toward electrophiles. The similar reaction with 1,4-naphthoquinone also gave a high yield of the diarylamine **7**. When a benzene solution of the diene **1** and *N*-phenylmaleimide was



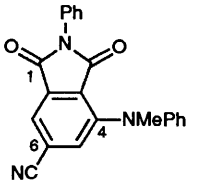
5



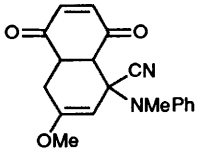
6



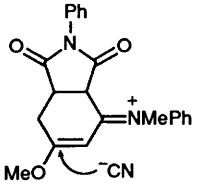
7



8



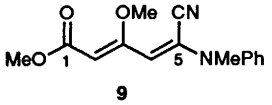
D



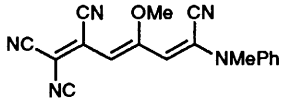
E

heated in a sealed tube, the diarylamine **8** with a cyano group replacing the methoxy substituent was obtained as the exclusive product. The characteristic IR absorption at 2235 cm^{-1} and the ^{13}C resonance at δ 117 clearly indicated the presence of cyano group, and the parent ion at m/z 353.115 supported the structural assignment of **8**. The reaction presumably involved counterattack of a cyanide ion on the conjugated iminium intermediate (**E**) followed by elimination of the methoxy group.

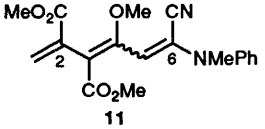
The reaction of diene **1** with chlorosulfonyl isocyanate CSI, followed by treatment with sodium methoxide, afforded the methyl dienoate **9**. This result was in agreement with our



9

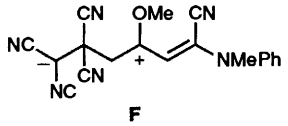


10

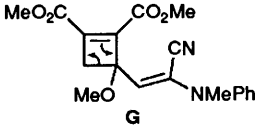


11

previous report for homologation of the dienes **A** by adding to CSI instead of forming β-lactams.[6] Compound **1** reacted readily with tetracyanoethylene TCNE in THF at −78 °C to give a quantitative amount of the triene **10**. This reaction appeared to follow an addition–elimination mechanism.[7] However, attempts to intercept the presumed zwitterion intermediate **F**[8] with MeOH failed. The result was different



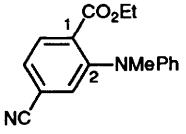
F



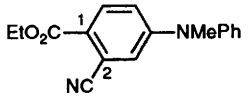
G

from the [2 + 2]cycloadditions of the analogous dienes **A** with TCNE.[3,8] The reaction of **1** with dimethyl acetylenedicarboxylate in refluxing benzene gave an 88% yield of the triene **11**. By a DEPT technique, the ^{13}C resonance at δ 129.2 was shown to be the olefinic methylene carbon (H_2C=), it was presumed that the initially formed cyclobutene intermediate **G** readily underwent a ring rupture to give the thermodynamically stable product.[9]

A toluene solution of **1** and ethyl propiolate in a sealed tube was refluxed for 16 h to give two diarylamines **12a** (51%) and

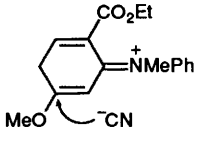


12a

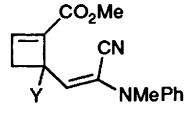


12b

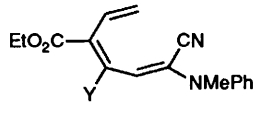
12b (10%). The major compound **12a** showed an IR absorption at 2227 cm^{-1} for the cyano group. The ^1H NMR spectrum revealed the absence of a methoxy group and the resonances of 5-H, 3-H and 6-H appeared at δ 6.84 (dd, J 9, 3 Hz), 6.98 (d, J 3 Hz) and 7.90 (d, J 9 Hz) as an ABX pattern. The ^{13}C resonances of **12a** were in agreement with the theoretical values calculated for the assigned structure.[10] The structure of **12b** was inferred from the ^1H and ^{13}C NMR spectrum, however, we were unable to obtain pure **12b** without contamination by **12a**. Formation of **12a** was considered to involve a cyanide ion counterattack on the iminium intermediate **H** as in the pathway proposed for



H



I (Y = OMe or CN)



J (Y = OMe or CN)

compound **8**. On the other hand, ring opening of the cyclobutene intermediate **I** might give **J**,[9] and subsequent electrocyclization would eventually lead to product **12b**.[11]

In summary, the α-aminodienenitrile **1** having a methoxy group at C-4 exerted remarkable nucleophilicity toward various substrates containing double or triple bonds. Compound **1** followed the similar pathway of analogous α-amino dienenitriles **A** in reactions with *p*-benzoquinone, 1,4-naphthoquinone, dichlorocarbene and chlorosulfonyl isocyanate, while **1** reacted unusually with TCNE and dimethyl acetylenedicarboxylate. It was noted that the reactions with *N*-phenylmaleimide and ethyl propiolate in sealed tubes caused counterattack of the cyanide ion to replace the methoxy group.

Experimental

M.p.s are not corrected. ^1H NMR spectra were recorded at 200 or 300 MHz while ^{13}C NMR recorded at 50 or 75 MHz (J values in Hz). Mass spectra were recorded at an ionizing voltage of 70 eV. Merck silica gel 60F sheets were used for analytical TLC. HPLC was performed on a μ-Porasil column (0.78 × 25 cm) using the indicated eluent with 5 cm^3 min^{-1} flow rate. 2-(*N*-Methylanilino)acetonitrile was prepared by the Strecker's method.[12] 2-Methoxyacrylaldehyde was prepared from formaldehyde and 2-methoxyacetaldehyde.[13]

4-Methoxy-2-(N-methylanilino)penta-2,4-dienenitrile **1**.—Under an atmosphere of nitrogen, BuLi (1.6 mol dm^{-3} solution in hexane; 0.69 cm^3, 1.1 mmol) was added dropwise to a solution

of diisopropylamine (0.17 cm^3, 1.2 mmol) in tetrahydrofuran (THF) (2 cm^3) at −10 °C. The solution was stirred for 10 min, and a solution of 2-(*N*-methylanilino)acetonitrile (153 mg, 1.05 mmol) in THF (1 cm^3) was added dropwise. After 15 min, the solution was cooled to −78 °C, and a solution of 2-methoxyacrylaldehyde (126 mg, 1.05 mmol) in THF (0.5 cm^3) was added dropwise. The reaction mixture was warmed to room temp. and quenched by addition of acetic acid (1.2 cm^3). The volatile components were removed under reduced pressure and the residue was partitioned between EtOAc and water. The aqueous phase was extracted (2 × EtOAc). The combined organic phase was washed with brine, dried (Na_2SO_4), and concentrated to give the allylic alcohol **2** (220 mg, 0.95 mmol) (two diastereoisomers). A mixture of the alcohol **2** (220 mg) and triethylamine (0.3 cm^3) in CH_2Cl_2 (2 cm^3) was treated with methanesulfonyl chloride (0.1 cm^3, 1.3 mmol) at 0 °C. The reaction mixture was slowly warmed to room temp. over a period of 2 h and then heated to 40 °C for 16 h. An HCl solution (5%) was added, and the mixture was extracted (3 × EtOAc). The combined extracts were washed with brine, dried and concentrated to give the corresponding methanesulfonate (284 mg). To a THF solution (5 cm^3) of Bu^{t}OK (110 mg, 1 mmol) cooled to −78 °C, was added dropwise a THF solution (1 cm^3) of the above prepared methanesulfonate. The mixture was stirred for 30 min, and then a solution of AcOH (3 mmol) in THF was added. The mixture was concentrated under reduced pressure, and the residue was chromatographed on Al_2O_3 90 (neutral, activity I) by elution with 5% EtOAc in hexane to give the *diene* **1** (134 mg, 60% overall yield).

Z-Isomer (major): yellow oil; ν_{max}(neat)/cm^{-1} 2949, 2214 (CN), 1595, 1362, 1192, 824 and 754; δ_H($CDCl_3$; 300 MHz) 3.14 (3 H, s, NMe), 3.32 (3 H, s, OMe), 4.34 (1 H, d, *J* 2.6, 5-H), 4.43 (1 H, d, *J* 2.6, 5-H), 6.12 (1 H, s, 3-H), 6.62 (2 H, m), 6.69 (1 H, m) and 7.27 (2 H, m); δ_C($CDCl_3$; 75 MHz) 38.7 (NMe), 54.8 (OMe), 91.6 (C-5), 115.7 (2 C, C-2′, C-6′), 117.0 (CN), 118.9 (C-2), 120.5 (C-4′), 129.0 (2 C, C-3′, C-5′), 129.6 (C-3), 145.5 (C-1′) and 156.1 (C-4); *m*/*z* 214 (M^+, 67%), 213 (M^+ − 1, 100), 199 (M^+ − 15, 75), 172 (19) and 77 (68) (M^+, 214.1114. *M*, 214.1106).

E-Isomer: yellow oil; ν_{max}(neat)/cm^{-1} 2950, 2210 (CN), 1595, 1360, 1160, 840 and 770; δ_H($CDCl_3$; 300 MHz) 3.11 (3 H, s, NMe), 3.38 (3 H, s, OMe), 4.09 (1 H, s, 3-H), 4.50 (1 H, d, *J* 2.5), 4.59 (1 H, d, *J* 2.5), 7.11 (2 H, m), 7.15 (1 H, m) and 7.27 (2 H, m); *m*/*z* 214 (M^+, 77%), 213 (M^+ − 1, 100), 199 (M^+ − 15, 62), 172 (20), 144 (19), 106 (14), 82 (24) and 77 (69) (M^+, 214.1114. *M*, 214.1106).

4-*Methoxy*-2-(N-*methylanilino*)-3-*trimethylsilylpenta*-2,4-*dienenitrile* **3** *and* 2,4-*Bis*(N-*methylanilino*)-3-[*bis*(*trimethylsilyl*)*amino*]*but*-2-*enenitrile* **4**.—A lithium diisopropylamide (LDA) solution (11 mmol) was prepared at −10 °C, and a solution of 2-(*N*-methylanilino)acetonitrile (1.46 g, 10 mmol) in THF (7 cm^3) was added dropwise. The solution was stirred for 30 min, cooled to −78 °C, and chlorotrimethylsilane (1.6 cm^3, 10 mmol) was added dropwise. The mixture was stirred for 30 min after which additional LDA solution (10 mmol) was added. After 1 h, a solution of 2-methoxyacrylaldehyde (1.23 g, 10 mmol) in THF (5 cm^3) was added dropwise. The reaction mixture was warmed to room temp. for 16 h, and then quenched with saturated aqueous NH_4Cl (15 cm^3). The volatiles were removed under reduced pressure and the residue was extracted (3 × EtOAc). The combined extracts were washed with brine, dried and concentrated to give a crude oil, which was chromatographed on a SiO_2 column by elution with 2% EtOAc in hexane to afford the *silylated diene* **3**, (1.21 g, 43%), as a mixture of *E*- and *Z*-isomers (3:1) and a *side-product* **4** (0.65 g).

E-Isomer of **3**: colourless crystals, m.p. 60–61 °C; HPLC (2% EtOAc in hexane) t_R 4.9 min; ν_{max}(KBr)/cm^{-1} 2952, 2213, 1637, 1596, 1494, 1191, 995, 845 and 753; δ_H($CDCl_3$) 0.34 (9 H, s), 3.12 (3 H, s), 3.42 (3 H, s), 3.84 (1 H, d, *J* 2.7), 3.96 (1 H, d, *J* 2.7), 6.80 (2 H, m), 6.89 (1 H, m) and 7.27 (2 H, m); δ_C($CDCl_3$) −1.3 (q, 3 C, Me_3Si), 38.9 (q, NMe), 54.6 (q, OMe), 82.5 (t, C-5), 116.2 (d, 2 C), 116.6 (s, CN), 120.4 (d), 126.6 (s, C-3), 129.0 (2 C), 145.8 (s, C-2), 147.4 (s) and 159.0 (s, C-4); *m*/*z* 286 (M^+, 17%), 271 (56), 181 (24), 167 (22), 89 (27) and 77 (100) (Found: C, 67.1; H, 7.8; N, 9.9). $C_{16}H_{22}N_2OSi$ requires C, 67.09; 7.74; N, 9.78%.

Z-Isomer of **3**: colourless crystals, m.p. 71–72 °C; HPLC (2% EtOAc in hexane) t_R 6.8 min; ν_{max}(KBr)/cm^{-1} 2955, 2200, 1595, 1491, 1154, 994, 846 and 757; δ_H($CDCl_3$) 0.09 (9 H, s), 3.04 (3 H, s), 3.63 (3 H, s), 4.27 (1 H, d, *J* 2.7), 4.32 (1 H, d, *J* 2.7), 6.80 (2 H, m), 6.90 (1 H, m) and 7.27 (2 H, m); δ_C($CDCl_3$) −1.2 (q, 3 C, Me_3Si), 39.4 (q, NMe), 55.1 (q, OMe), 85.1 (t, C-5), 114.2 (s, CN), 114.8 (d, 2 C), 120.3 (d), 127.9 (s, C-3), 129.1 (s), 129.2 (2 C), 147.1 (s) and 160.5 (s, C-4); *m*/*z* 286 (M^+, 14%), 271 (51), 181 (20), 158 (22) and 77 (100) (Found: C, 67.0; H, 7.8; N, 10.0. $C_{16}H_{22}N_2OSi$ requires C, 67.09; H, 7.74; N, 9.78%).

Nitrile **4**: Colourless platelets, m.p. 97.5–98.5 °C (hexane); ν_{max}(KBr)/cm^{-1} 2954, 2204, 1598, 1498, 1256, 902 and 843; δ_H($CDCl_3$) 0.30 (18 H, s, 2 × Me_3Si), 2.91 (3 H, s, NMe), 3.13 (3 H, s, NMe), 3.98 (2 H, s) and 6.67–7.30 (10 H); δ_C($CDCl_3$) 2.88 (Me_3Si), 39.8 (NMe), 40.5 (NMe), 55.8 (CH_2), 112.2 (s), 112.7 (d), 114.6 (d), 116.1 (s), 116.3 (s), 116.9 (d), 118.7 (s), 120.0 (d), 128.8 (d), 129.2 (d), 147.1 (s) and 149.8 (s); *m*/*z* 436 (M^+, 36%), 421 (5), 330 (90), 300 (22), 275 (12), 274 (15) and 120 (110) (Found: C, 65.9; H, 8.2; N, 12.95. $C_{24}H_{36}N_4Si_2$ requires C, 66.0; H, 8.31; N, 12.83%).

3-(2,2-*Dichloro*-1-*methoxycyclopropyl*)-2-(N-*methylanilino*)-*prop*-2-*enenitrile* **5**.—To a mixture of the diene **1** (*Z*-isomer; 178 mg, 0.83 mmol) and benzyltriethylammonium chloride (5 mg) in $CHCl_3$ (2 cm^3) was added dropwise aqueous KOH (60%; 1 cm^3) at 0 °C. The viscous mixture was sonicated for 3.5 h while the temperature was kept at 0–5 °C. The mixture was diluted with water (5 cm^3) and extracted (3 × $CHCl_3$). The combined organic phase was dried, concentrated, and purified by a short silica gel column by elution with EtOAc to give compound **5**, (232 mg, 0.78 mmol, 94%), (*Z*-form) which became the *E*/*Z* mixture with time.

Z-Isomer: ν_{max}(neat)/cm^{-1} 2933, 2233, 1591, 1493, 1351, 1250, 1007, 855 and 699; δ_H($CDCl_3$) 1.78 (1 H, d, *J* 11.3, 3′-H), 1.77 (1 H, d, *J* 11.3, 3′-H), 3.32 (3 H, s, NMe), 3.35 (3 H, s, OMe), 5.85 (1 H, s, 3-H), 6.96 (3 H, m) and 7.34 (2 H, m); δ_C($CDCl_3$) 34.1 (q, NMe), 39.2 (t, C-3′), 55.9 (q, OMe), 63.8 (s, C-2′), 64.8 (s, C-1′), 115.7 (s, CN), 117.2 (d, 2 C, C-2″, C-6″), 121.8 (d, C-3), 124.4 (s, C-2), 125.2 (d, C-4″), 129.1 (d, 2 C, C-3″, C-5″) and 144.7 (s, C-1″); *m*/*z* 297 (M^+ + 1, 9%), 296 [M^+ (^{35}Cl), 8%], 262 (34), 261 (86), 260 (30), 225 (100), 210 (9), 199 (13), 185 (48), 142 (23), 107 (47) and 77 (79) (M^+, 296.0466. *M*, 296.0483).

E-Isomer: δ_H($CDCl_3$) 1.95 (1 H, d, *J* 13.5), 2.01 (1 H, d, *J* 13.5), 3.22 (3 H, s, NMe), 3.46 (3 H, s, OMe), 5.58 (1 H, s, 3-H), 7.16 (3 H, m) and 7.37 (2 H, m); δ_C($CDCl_3$) 33.2 (q, NMe), 40.6 (t, C-3′), 55.1 (q, OMe), 63.8 (s, C-2′), 65.0 (s, C-1′), 111.2 (d, C-3), 113.4 (s, CN), 122.0 (s, C-2), 124.1 (d, 2 C, C-2″, C-6″), 125.8 (d, C-4″), 129.4 (d, 2 C, C-3″, 5″) and 145.2 (s, C-1″).

7-*Methoxy*-5-(N-*methylanilino*)-1,4-*naphthoquinone* **6**.—A benzene solution (3 cm^3) of the diene **1** (*E*/*Z* mixture; 60 mg, 0.28 mmol) and *p*-benzoquinone (40 mg, 0.37 mmol) was stirred at room temp. for 16 h. The solvent was removed, and the residue was chromatographed on SiO_2 by elution with gradients of EtOAc in hexane to give *compound* **6** (74 mg, 90%), as purple crystals, m.p. 99–101 °C; TLC (5% EtOAc in hexane) R_f 0.14; ν_{max}(KBr)/cm^{-1} 2938, 1660 (C=O), 1583, 1464, 1268, 1184, 1085, 990, 845 and 749; δ_H ($CDCl_3$; 300 MHz) 3.25 (3 H,

s, NMe), 3.89 (3 H, s, OMe), 6.75 (5 H, m), 7.07 (1 H, d, *J* 2.9), 7.19 (2 H, m) and 7.47 (1 H, d, *J* 2.9); δ_C($CDCl_3$; 75 MHz), 40.3 (q, NMe), 55.9 (q, OMe), 109.2 (d, C-6), 115.5 (d, 2 C, C-2′, C-6′), 119.2 (d, C-8), 120.1 (d, C-4′), 129.0 (d, 2 C, C-3′, C-5′), 135.8 (d, C-3), 136.6 (s, C-5), 141.2 (d, C-2), 148.4 (s, C-10), 150.9 (s, C-9), 164.0 (s, C-7), 182.0 (s, C=O) and 185.2 (s, C=O); *m/z* 293 (M^+, 80%), 276 (100) and 261 (28) (Found: C, 73.3; H, 5.2; N, 4.9. $C_{18}H_{15}NO_3$ requires C, 73.71; H, 5.15; N, 4.78%).

3-*Methoxy*-1-(N-*methylanilino*)-9,10-*anthraquinone* **7**.—A benzene solution (10 cm^3) of the diene **1** (*E*/*Z* mixture, 489 mg, 2.3 mmol) and 1,4-naphthoquinone (370 mg, 2.4 mmol) was heated at 60 °C for 16 h. The solvent was removed, and the residue was chromatographed on SiO_2 by elution with gradients of EtOAc in hexane to give *compound* **7**, (641 mg, 82%), as purple crystals, m.p. 197–198 °C; TLC (1% EtOAc in hexane) R_f 0.21; ν_{max}(KBr)/cm^{-1} 3441, 1731w, 1667s, 1584, 1300 and 884; δ_H($CDCl_3$; 300 MHz) 3.31 (3 H, s, NMe), 3.93 (3 H, s, OMe), 6.76 (3 H, m), 7.16 (3 H, m), 7.69 (3 H, m), 8.11 (1 H, m) and 8.21 (1 H, m); δ_C ($CDCl_3$; 75 MHz) 40.2 (q, NMe), 55.9 (q, OMe), 109.6 (d, C-2), 114.9 (d, 2 C, C-2′, C-6′), 118.7 (d, C-4), 121.3 (d, C-4′), 126.6 (d, C-5), 127.2 (d, C-8), 129.0 (d, 2 C, C-3′, C-5′), 133.0 (d, C-6), 134.3 (d, C-7), 135.0 (s, C-1′), 138.2 (s, C-1), 148.5 (s, 2 C, C-11, C-12), 151.4 (s, 2 C, C-13, C-14), 164.1 (s, C-3), 180.3 (s, C=O) and 183.4 (s, C=O); *m/z* 343 (M^+, 90%), 326 (100), 251 (16), 106 (12) and 77 (10) (Found: C, 76.4; H, 4.95; N, 3.8. $C_{22}H_{17}NO_3$ requires C, 76.95; H, 4.99; N, 4.08%).

6-*Cyano*-4-(N-*methylanilino*)-N-*phenylphthalimide* **8**.—A benzene solution (5 cm^3) of the diene **1** (*E*/*Z* mixture, 326 mg, 1.5 mmol) and *N*-phenylmaleimide (263 mg, 1.5 mmol) was refluxed at 80 °C in a sealed tube for 16 h. The solvent was removed, and the residue was chromatographed on SiO_2 by elution with gradients of EtOAc in hexane to give *compound* **8** (386 mg, 72%), as orange crystals, m.p. 164–165 °C; HPLC (20% EtOAc in hexane) t_R 5.8 min; ν_{max}(KBr)/cm^{-1} 2235 (CN), 1770, 1720 (C=O), 1571, 1493, 1127, 979, 842 and 754; δ_H ($CDCl_3$; 300 MHz) 3.57 (3 H, s, NMe), 7.08–7.17 (3 H, m), 7.32–7.39 (5 H, m), 7.44–7.51 (2 H, m), 7.54 (1 H, s, 4-H) and 7.68 (1 H, s, 7-H); δ_C($CDCl_3$; 75 MHz) 42.7 (q, NMe), 117.0 (s, CN), 118.2 (d, C-5), 121.0 (s, C-6), 121.8 (d, 2 C, C-2″, C-6″), 124.6 (d), 126.6 (d, 2 C, C-2′, C-6′), 128.4 (d), 129.2 (d, 2 C, C-3″, C-5″), 129.9 (d, 2 C, C-3′, C-5′), 131.3 (s, C-1′), 132.4 (d, C-7), 135.5 (s, C-4), 147.1 (s, C-9), 148.2 (s, C-8), 164.5 (s, C=O) and 165.3 (s, C=O); *m/z* 353 (M^+, 100%), 324 (7), 308 (10), 276 (15), 205 (14), 177 (18), 106 (21), 77 (35), (M^+, 353.1147. *M*, 353.1164).

Methyl 5-*Cyano*-3-*methoxy*-5-(N-*methylanilino*)*penta*-2,4-*dienoate* **9**.—To a solution of the diene **1** (*E*/*Z* mixtue, 892 mg, 4.2 mmol) in CH_2Cl_2 (10 cm^3) at −78 °C was added chlorosulfonyl isocyanate (0.4 cm^3, 4.5 mmol). The mixture was stirred for 1 h, after which sodium methoxide (675 mg, 12.5 mmol) was added and stirring continued for a further 15 min. After addition of MeOH (5 cm^3), the reaction mixture was concentrated under reduced pressure, and the residue was separated by chromatography on SiO_2 column by elution with gradients of EtOAc in hexane to give the *ester* **9** (613 mg, 54%), as a brownish-yellow oil; TLC (2% EtOAc in hexane) R_f 0.27; ν_{max}(neat)/cm^{-1} 3180, 2943, 2229, 1710, 1688, 1510, 1320 and 870; δ_H($CDCl_3$; 300 MHz) 3.30 (3 H, s, NMe), 3.66 (3 H, s, OMe), 3.73 (3 H, s, OMe), 5.04 (1 H, s, 2-H), 7.18 (1 H, s, 4-H), 7.23 (3 H, m) and 7.34 (2 H, m); δ_C($CDCl_3$; 75 MHz) 41.5 (q, NMe), 50.9 (q, OMe), 55.2 (q, OMe), 90.0 (d, C-2), 107.8 (d, C-4), 114.0 (s, CN), 124.6 (s, C-5), 125.5 (d, 2 C, C-2′, C-6′), 126.6 (d, C-4′), 129.4 (d, 2 C, C-3′, C-5′), 145.3 (s, C-1′), 165.4 (s, C-3) and 167.9 (s, C=O); *m/z* 272 (M^+, 48%), 271 (64), 225 (33), 213 (100), 169 (14), 128 (15) and 77 (27). (M^+, 272.1143. *M*, 272.1161).

4-*Methoxy*-6-(N-*methylanilino*)*hexa*-1,3,5-*triene*-1,1,2,6-*tetracarbonitrile* **10**.—A THF solution (5 cm^3) of the diene **1** (*E*/*Z* mixture, 96 mg, 0.45 mmol) and tetracyanoethylene (58 mg, 0.45 mmol) was stirred at −78 °C for 1.5 h. The solvent was removed, and the residue was chromatographed on SiO_2 by elution with gradients of EtOAc in hexane to give the *triene* **10** (130 mg, 92%), as a purple oil; TLC (15% EtOAc in hexane) R_f 0.13; ν_{max}(neat)/cm^{-1} 2946, 2212, 1526, 1487, 1307, 1132, 768 and 699; δ_H($CDCl_3$; 300 MHz) 3.50 (3 H, s, NMe), 3.94 (3 H, s, OMe), 5.87 (1 H, s, 3-H), 6.35 (1 H, s, 5-H), 7.23 (2 H, m), 7.39 (1 H, m) and 7.45 (2 H, m); δ_C($CDCl_3$; 75 MHz) 42.6 (q, NMe), 57.1 (q, OMe), 97.8 (d, C-3), 100.0 (d, C-5), 112.2 (s, CN), 112.3 (s, CN), 113.1 (s, CN), 113.9 (s, CN), 125.8 (s, C-6), 125.9 (d, 2 C, C-2′, C-6′), 129.0 (d, C-4′), 130.2 (d, 2 C, C-3′, C-5′), 130.6 (s, C-2), 134.8 (s, C-1′), 143.3 (s, C-1) and 169.0 (s, C-4); *m/z* 315 (M^+, 46%), 314 (100), 300 (23), 213 (20), 106 (35) and 77 (97) (M^+, 315.1109. *M*, 315.1120).

Dimethyl 6-*Cyano*-4-*methoxy*-6-(N-*methylanilino*)*hexa*-1,3,5-*triene*-2,3-*dicarboxylate* **11**.—A benzene solution (5 cm^3) of the diene **1** (*E*/*Z* mixture, 120 mg, 0.56 mmol) and dimethyl acetylenedicarboxylate (80 mg, 0.56 mmol) was refluxed at 80 °C for 16 h. The solvent was removed, and the residue was chromatographed on SiO_2 by elution with gradients of EtOAc in hexane to give *compound* **11** (175 mg, 88%), as a mixture of (3*E*,5*Z*)- and (3*E*,5*E*)-isomers (3:1). The analytical sample of the *Z*-isomer was obtained by HPLC, eluting with 2% EtOAc in hexane.

Z-Isomer: yellow oil; ν_{max}(neat)/cm^{-1} 2947, 2840, 2227, 1721, 1569, 1431, 1077, 994, 879 and 766; δ_H($CDCl_3$; 300 MHz) 3.32 (3 H, s, NMe), 3.63 (3 H, s, OMe), 3.67 (3 H, s, OMe), 3.74 (3 H, s, OMe), 5.74 (1 H, d, *J* 1.2), 6.46 (1 H, d, *J* 1.2 Hz), 6.80 (1 H, s, 5-H), 7.24 (3 H, m) and 7.36 (2 H, m); δ_C-($CDCl_3$; 75 MHz) 41.5 (q, NMe), 51.7 (q, OMe), 52.2 (q, OMe), 60.2 (q, OMe), 110.4 (d, C-5), 114.1 (s, CN), 124.5 (s, C-6), 125.1 (s, C-3), 125.4 (d, 2 C, C-2′, C-6′), 125.7 (s, C-2), 126.8 (d, C-4′), 129.2 (t, $=CH_2$), 129.5 (d, 2 C, C-3′, C-5′), 135.6 (s, C-1′), 145.1, (s, C-4), 164.4 (s, C=O) and 167.3 (s, C=O); *m/z* 356 (M^+, 67%), 355 (100), 341 (18), 297 (93), 265 (51), 237 (30), 169 (20) and 77 (97) (M^+, 356.1366. *M*, 356.1372).

E-Isomer (mixed with the *Z*-isomer): yellow oil; ν_{max}-(neat)/cm^{-1} 2947, 2840, 2222 (CN), 1722, 1574, 1490, 1130, 1077, 991 and 759; δ_H($CDCl_3$; 300 MHz) 3.30 (3 H, s, NMe), 3.59 (3 H, s, OMe), 3.68 (3 H, s, OMe), 3.69 (3 H, s, OMe), 5.74 (1 H, d, *J* 1.6), 5.85 (1 H, s, 5-H), 6.52 (1 H, d, *J* 1.6), 7.00 (2 H, m), 7.18 (1 H, m) and 7.34 (2 H, m); δ_C($CDCl_3$; 75 MHz) 40.1 (q, NMe), 52.0 (q, OMe), 52.4 (q, OMe), 59.1 (q, OMe), 117.0 (d, C-5), 118.1 (s, CN), 118.9 (d, 2 C, C-2′, C-6′), 123.6 (d, C-4′), 123.8 (s, C-3), 125.5 (s, C-2), 129.3 (t, $=CH_2$), 131.8 (d, 2 C, C-3′, C-5′), 145.1 (s, C-1′) and 158.2 (s, C-4).

Ethyl 4-*Cyano*-2-(N-*methylanilino*)*benzoate* **12a** *and Ethyl* 2-*Cyano*-4-(N-*methylanilino*)*benzoate* **12b**.—A toluene solution (5 cm^3) of the diene **1** (*E*/*Z* mixture, 167 mg, 0.78 mmol) and ethyl propiolate (0.08 cm^3, 0.86 mmol) was refluxed at 110 °C in a sealed tube for 16 h. The solvent was removed, and the residue was chromatographed on SiO_2 by elution with 2% EtOAc in hexane to give **12a** (53 mg) followed by a mixture of **12a, b** (3:1, 80 mg).

Isomer **12a**: Yellow oil; ν_{max}(neat)/cm^{-1} 2981, 2227 (CN), 1705 (C=O), 1581, 1490, 1361 and 1270; δ_H($CDCl_3$; 300 MHz) 1.38 (3 H, t, *J* 7.2), 3.35 (3 H, s, NMe), 4.37 (2 H, q, *J* 7.2), 6.84 (1 H, dd, *J* 8.8, 2.6, 5-H), 6.98 (1 H, d, *J* 2.6, 3-H), 7.19 (2 H, m), 7.27 (1 H, m), 7.43 (2 H, m) and 7.90 (1 H, d, *J* 8.8, 6-H); δ_C-($CDCl_3$; 75 MHz) 14.2 (q, Me), 40.2 (q, NMe), 61.3 (t, OCH_2), 114.0 (s, CN), 115.9 (d, C-3), 118.3 (s, C-4), 119.0 (d, C-4′), 119.8 (s, C-1), 126.5 (d, 2 C, C-2′, C-6′), 126.8 (d, C-5), 130.3 (d, 2 C, C-3′, C-5′), 132.5 (d, C-6), 146.1 (s, C-1′), 151.7 (s, C-2) and

164.3 (s, C=O); *m/z* 280 (M^+, 85%), 175 (14), 160 (32), 132 (100), 106 (62) and 77 (32). (M^+ 280.1210. *M*, 280.1212).

Isomer **12b** (mixed with **12a**): $\delta_H(CDCl_3$; 300 MHz) 1.40 (3 H, t, *J* 7.2 Hz), 3.87 (3 H, s, NMe), 4.40 (2 H, q, *J* 7.2), 7.10 (1 H, dd, *J* 9.3, 2.8), 7.22 (4 H, m), 7.43 (2 H, m) and 8.06 (1 H, d, *J* 9.3); $\delta_C(CDCl_3)$ 14.1 (q, Me), 55.9 (q, NMe), 61.8 (t, OCH_2), 114.0 (s, CN), 118.3 (s, C-2), 119.0 (C-4'), 119.8 (s, C-1), 119.9 (d, C-3, C-5), 126.5 (d, 2 C, C-2', C-6'), 130.3 (d, 2 C, C-3', C-5'), 133.1 (d, C-6), 146.1 (s, C-1'), 158.5 (s, C-4) and 162.6 (s, C=O).

Acknowledgements

We thank the National Science Council of the Republic of China for financial support of this work.

References

1 (*a*) H. Ahlbrecht and K. Pfaff, *Synthesis*, 1985, 421; (*b*) H. Ahlbrecht and M. Ibe, *Synthesis*, 1988, 210; (*c*) J. M. Fang and H. T. Chang, *J. Chem. Soc., Perkin Trans. 1*, 1988, 1945.

2 (*a*) J. L. Boucher and L. Stella, *Tetrahedron*, 1985, **41**, 875; (*b*) D. Dopp, H. R. Mamarian, C. Kruger and E. Rabbe, *Chem. Ber.*, 1989, **122**, 585.

3 (*a*) J. M. Fang and C. C. Yang, *J. Chem. Soc., Chem. Commun.*, 1985, 1356; (*b*) J. M. Fang, C. C. Yang and Y. W. Wang, *J. Org. Chem.*, 1989, **54**, 477.

4 F. Mohamadi and W. C. Still, *Tetrahedron Lett.*, 1986, **27**, 893.

5 (*a*) R. Gompper, *Angew. Chem., Int. Ed. Engl.*, 1969, **8**, 312; (*b*) M. Petrzilka and J. I. Grayson, *Synthesis*, 1981, 753; (*c*) P. W. Hickmott, *Tetrahedron*, 1982, **38**, 3363; (*d*) P. W. Hickmott, *Tetrahedron*, 1984, **40**, 2989.

6 (*a*) J. K. Rasmussen and A. Hassner, *Chem. Rev.*, 1976, **76**, 389; (*b*) J. R. Malpass and N. J. Tweddle, *J. Chem. Soc., Perkin Trans. 1*, 1977, 874.

7 (*a*) N. S. Isaacs, *J. Chem. Soc. B*, 1966, 1053; (*b*) Z. Rappoport, *J. Chem. Soc.*, 1963, 4498.

8 (*a*) R. Huisgen, *Acc. Chem. Res.*, 1977, **10**, 117; (*b*) R. Huisgen, *Acc. Chem. Res.*, 1977, **10**, 199.

9 J. Froborg and G. J. Magnusson, *J. Am. Chem. Soc.*, 1978, **100**, 6728.

10 E. Pretsch, J. Seibl, W. Simon and T. Clerc, *Table of Spectral Data for Structure Determination of Organic Compounds*, Springer-Verlag, Berlin, 1983, pp. C120–C125, H255–H260.

11 (*a*) C. W. Spangler, B. Keys and D. C. Bookbinder, *J. Chem. Soc., Perkin Trans. 2*, 1979, 810; (*b*) H. Y. Elnagar and W. H. Okamura, *J. Org. Chem.*, 1988, **53**, 3060.

12 J. H. Boyer and J. Kooi, *J. Am. Chem. Soc.*, 1976, **98**, 1099.

13 G. A. Russell and M. Ballenegger, *Synthesis*, 1973, 104.

Paper 2/00611A
Received 4*th February* 1992
Accepted 18*th February* 1992