Anionic Cyclization of (*N*,*N*-Dimethylamino)[2-(prop-2-yn-1-yloxy)aryl]-acetonitriles

Tadeusz Zdrojewski, Joanna Musielak, Andrzej Jończyk*

Warsaw University of Technology, Faculty of Chemistry, Koszykowa St. 75, 00-662 Warszawa, Poland
Fax +48(22)6282741; E-mail: anjon@ch.pw.edu.pl

Received 6 February 2009; revised 13 February 2009

Abstract: The cyclization of (*N*,*N*-dimethylamino)[2-(prop-2-yn-1-yloxy)aryl]acetonitriles is carried out under phase-transfer conditions using powdered sodium hydroxide and benzyltriethylammonium chloride as catalyst in dimethyl sulfoxide to afford mixtures of a methylenechromane and a methylchromene via favored 6-*exo*-dig and 6-*endo*-dig processes, respectively. Several of the chromenes rearranged into benzofuranone derivatives during column chromatography on alumina and the formation of these is rationalized.

Key words: phase-transfer catalysis, carbanions, cyclizations, heterocycles, intramolecular vinylation

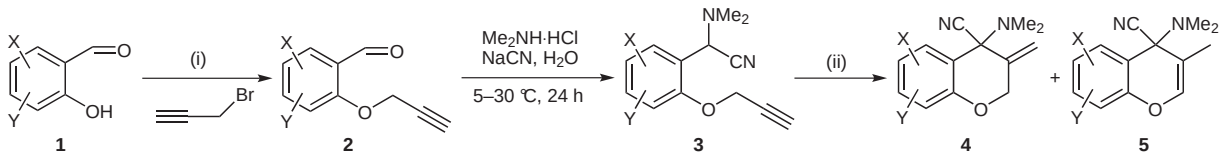
Compounds which possess both an acidic site and a suitably located carbon–carbon triple bond, on treatment with a base, generate anions which can undergo intramolecular addition to the triple bond via *exo*- and/or *endo*-dig cyclization[1] leading to the formation of carbo- or heterocyclic products.

There are several examples in the literature of such carbanionic cyclizations. These include cyclizations of substituted derivatives of malonic[2–5] and acetoacetic acid esters,[2,5–7] α-substituted methyl acetate derivatives,[5] alkynyl ketones,[7–9] *o*-alkynyl-[10] and *o*-propargyloxyacetophenones,[11] propargyl ethyl malonates,[12] ethyl *N*-(2-ethynyloxyphenyl)malonamate[13] and nitro-substituted compounds.[14] The one-pot reaction of dimethyl 2-oxo-cycloalkane-1,3-dicarboxylates with 1,4-dibromobut-2-yne produced substituted dihydrofurans in 92–100% yield.[15] Cyclizations of α-cyanocarbanions generated from suitably substituted α-aminonitriles using lithium diisopropylamide (followed by oxidation of the crude intermediates with 2,3-dichloro-5,6-dicyano-1,4-benzoquinone),[16] or from phenylacetonitrile, or ω-ethynylalkyl-α-substituted-benzylsulfones, using catalytic amounts of cesium hydroxide,[17] produced either mixtures of substituted pyrroles and azetidines,[16] or 2-*exo*-methylenecyclopentanes or hexanes,[17] respectively.

It has been reported that 2-(dialkylamino)phenylacetonitriles can be alkylated in the presence of a mixture of concentrated aqueous and solid sodium hydroxide and benzyltriethylammonium chloride (TEBAC) as a phase-transfer catalyst (PTC system[18–20]), at elevated temperature.[21] On the other hand, efficient intermolecular addition of 2-phenylalkanenitriles to ethynes occurred on treatment with solid sodium hydroxide, benzyltriethylammonium chloride as the catalyst and dimethyl sulfoxide[22] or cesium *tert*-butoxide in *N*-methyl-2-pyrrolidinone.[17] The former conditions were also suitable for intermolecular vinylation of 2-(dialkylamino)arylacetonitriles[23–25] and 2-substituted *N*-(benzylidene)glycinonitriles.[26] Based on the above,[21–26] we have investigated the phase-transfer-catalyzed intramolecular addition reactions of aminonitriles **3**, which are easily prepared from salicylic aldehydes **1a**–**e** (Scheme 1 and Table 1).

Aldehydes **1** were O-alkylated with propargyl bromide under phase-transfer conditions (10% aqueous sodium hydroxide, benzyltriethylammonium chloride, toluene) to give alkynes **2** which were converted into the required aminonitriles **3** via the Strecker reaction. Subsequent anionic cyclization of compounds **3** was carried out in the presence of powdered sodium hydroxide, benzyltriethylammonium chloride as the catalyst and dimethyl sulfoxide (solid–liquid system), under mild conditions, to give chromanes **4** or mixtures of **4** and chromenes **5** (Scheme 1).

According to Baldwin's rules,[1] formation of *exo* products **4** should occur by way of favored 6-*exo*-dig cyclization, while *endo* products **5** are formed by a favored 6-*endo*-dig process (Scheme 2). Production of *exo*-**4** occurs through straightforward carbanion attack on the carbon–carbon triple bond of **3** to generate **4**$^-$, yet a similar process leading to *endo*-**5** requires propargyl to allenyl ether rearrangement in **3**, prior to cyclization. Alternatively, the



Scheme 1 *Reagents and conditions*: (i) 10% aq NaOH, toluene, TEBAC, 60 °C, 3–10 h; (ii) powdered NaOH, DMSO, TEBAC, 35 °C, 2 h.

SYNTHESIS 2009, No. 12, pp 2029–2034
Advanced online publication: 27.04.2009
DOI: 10.1055/s-0028-1088061; Art ID: Z02009SS

Table 1 2-Propargyloxyarylcarbaldehydes **2**, Aminonitriles **3**, and the Anionic Cyclization Products **4** and **5**

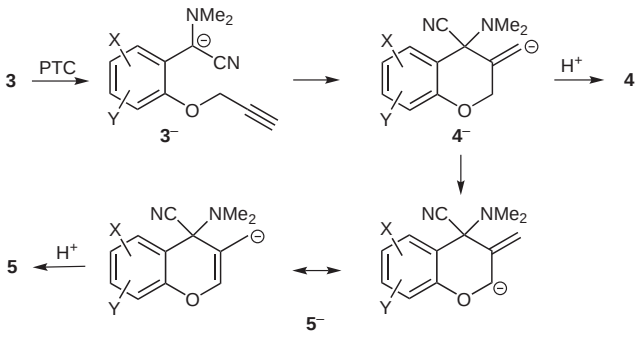
Compd	X, Y	Time (h)[a]	Yield (%) of **2**	Yield (%) of **3**	Yield (%) of **4**	Yield (%) of **5**	Ratio of **4**:**5**[b]
1a	H, H	3	88	80	32	44	1:2
1b	5-Cl, H	4	83	82	48	30	2:1
1c	5-Br, H	5	79	77	36	–[c]	5:1
1d	H, 3-MeO	4	85	48	21[d]		1:0
1e	5,6-$(CH)_4$	10	55	73	30	–[c]	5:1

[a] Reaction time for the conversion of **1** into **2**.
[b] Determined on the basis of ^{1}H NMR spectroscopy.
[c] Decomposed with the formation of **9** during column chromatography.
[d] Competitive oxidation of **3d**$^-$ decreased the yield of the cyclization product.

highly basic vinyl anion **4**$^-$ may undergo a [1,3]-proton shift to yield allyl anion **5**$^-$ which gives **5** on protonation.

The compositions of the crude reaction mixtures of **4** and **5**, after cyclization, were determined by integration of the signals of the dimethylamino groups in the ^{1}H NMR spectra.

Attempted isolation of cyclic products **4** and **5** by column chromatography on alumina led to pure *exo*-**4** while *endo*-**5** was transformed into heterocycle **9**. Two possible routes 'a' and 'b' leading from **5** to **9** are shown in Scheme 3.

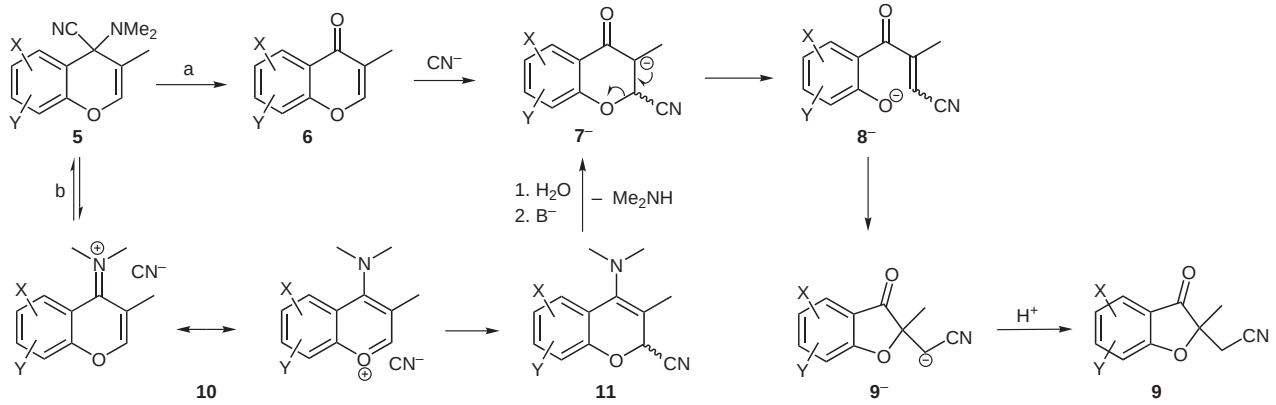


Scheme 2 Intramolecular cyclization leading to chromanes **4** and chromenes **5**

According to route 'a', the latent carbonyl group in aminonitrile **5** is unmasked during column chromatography giving chromone **6** which undergoes addition of cyanide to form **7**$^-$. The latter affords the heterocyclic product **9** via a ring-opening/ring-closing process. The base-induced ring-opening of chromenes has been described previously.[27,28] In route 'b', aminonitrile **5** can exist in equilibrium with the strongly electrophilic immonium salt **10** which can easily add a cyanide anion to form enamine **11**. Hydrolysis of the latter gives a β-cyanoketone which after deprotonation produces **7**$^-$, which is further transformed into **9** via the processes described above. Some of the steps presented in route 'b' have already been reported in the reactions of vinylaminonitriles.[24]

Products **4** and **5** contain a masked carbonyl group and hence are precursors of the corresponding 3-methylene-chroman-4-ones and 3-methylchromone derivatives **6**. However, attempted unmasking of the carbonyl groups[23] in **4** and **5** under typical conditions (benzene–aqueous copper sulfate solution, or water–ethanolic copper sulfate solution) failed; a complex mixture of products was obtained instead.

In conclusion, we have demonstrated that a phase-transfer catalytic system can be used to achieve anionic cyclization of aminonitriles **3**. Some of the chromenes **5** proved to be unstable during column chromatography on alumina and underwent rearrangement into benzofuranones **9**.



Scheme 3 Possible routes leading to the formation of heterocycle **9**

Column chromatography was carried out on Fluka 5016A aluminum oxide (basic) using EtOAc–hexane (1:5 v/v) as eluent. Gas chromatography (GC) was performed using an Agilent 6850 Series GC System fitted with a HP–50+ (30 m) column. ^{1}H NMR (400 MHz, $CDCl_3$) and ^{13}C NMR (100 MHz, $CDCl_3$) spectra were recorded on a Varian Mercury 400BB spectrometer; chemical shifts (δ) are given in ppm relative to tetramethylsilane (TMS); coupling constants (*J*) are given in Hz. MS and HRMS spectra were obtained using an AMD 604 (Intectra) apparatus. Elemental analyses were performed on a Perkin Elmer 2400 Series II CHNS/O microanalyzer. Melting points were measured on a capillary apparatus and are uncorrected. Aldehydes **1** and propargyl bromide (80 wt% solution in toluene) were commercial grade (Aldrich).

(Prop-2-yn-1-yloxy)benzaldehydes and (Prop-2-yn-1-yloxy)naphthaldehyde 2; General Procedure

To a stirred solution of aldehyde **1** (50 mmol) and TEBAC (0.11 g, 0.5 mmol) in toluene (70 mL) was added a solution of NaOH (2.4 g, 0.06 mol) in H_2O (22 mL). The mixture was stirred (ca. 0.5 h) and then propargyl bromide (55 mmol, 80 wt% in toluene) was added dropwise. Stirring was continued at 60 °C until aldehyde **1** was no longer detected by GC (3–10 h, Table 1). The reaction mixture was allowed to cool and the organic phase was separated. The aq phase was extracted with toluene (3 × 20 mL) and the combined organic phase was washed with H_2O (30 mL) and dried ($MgSO_4$). Following evaporation of the solvent, the crude product was crystallized from C_6H_6 or from a mixture of C_6H_6–cyclohexane.

2-(Prop-2-yn-1-yloxy)benzaldehyde (2a)

Mp 66–69 °C (Lit.[29] 66–68 °C).

^{1}H NMR: δ = 2.56 (t, *J* = 2.4 Hz, 1 H, CCH), 4.80 (d, *J* = 2.4 Hz, 2 H, CH_2), 6.94–7.89 (m, 4 H, ArH), 10.46 (s, 1 H, CHO).

^{13}C NMR: δ = 56.0, 76.4, 77.5, 113.1, 121.5, 125.3, 128.3, 135.7, 159.7, 189.5.

Anal. Calcd for $C_{10}H_8O_2$: C, 74.99; H, 5.03. Found: C, 75.13; H, 4.99.

5-Chloro-2-(prop-2-yn-1-yloxy)benzaldehyde (2b)

Mp 75–76 °C.

^{1}H NMR: δ = 2.59 (t, *J* = 2.4 Hz, 1 H, CCH), 4.81 (d, *J* = 2.4 Hz, 2 H, CH_2), 7.07 (d, *J* = 9.2 Hz, 1 H, ArH), 7.49 (dd, *J* = 9.2, 2.8 Hz, 1 H, ArH), 7.78 (d, *J* = 2.8 Hz, 1 H, ArH), 10.38 (s, 1 H, CHO).

^{13}C NMR: δ = 56.6, 76.9, 77.1, 114.9, 126.3, 127.3, 128.0, 135.1, 158.0, 188.1.

Anal. Calcd for $C_{10}H_7ClO_2$: C, 61.72; H, 3.63; Cl, 18.22. Found: C, 61.54; H, 3.60; Cl, 18.13.

5-Bromo-2-(prop-2-yn-1-yloxy)benzaldehyde (2c)

Mp 93–95 °C (Lit.[29] 89–91 °C).

^{1}H NMR: δ = 2.59 (t, *J* = 2.4 Hz, 1 H, CCH), 4.82 (d, *J* = 2.4 Hz, 2 H, CH_2), 7.02 (d, *J* = 9.2 Hz, 1 H, ArH), 7.63 (dd, *J* = 9.2, 2.4 Hz, 1 H, ArH), 7.93 (d, *J* = 2.4 Hz, 1 H, ArH), 10.38 (s, 1 H, CHO).

^{13}C NMR: δ = 56.6, 76.7, 77.3, 114.6, 115.3, 126.7, 131.1, 138.0, 158.5, 188.1.

Anal. Calcd for $C_{10}H_7BrO_2$: C, 50.24; H, 2.95; Br, 33.42. Found: C, 50.09; H, 2.99; Br, 33.60.

3-Methoxy-2-(prop-2-yn-1-yloxy)benzaldehyde (2d)

Mp 43–44 °C.

^{1}H NMR: δ = 2.48 (t, *J* = 2.4 Hz, 1 H, CCH), 3.91 (s, 3 H, OCH_3), 4.89 (d, *J* = 2.4 Hz, 2 H, CH_2), 7.16–7.20 (m, 2 H, ArH), 7.44–7.49 (m, 1 H, ArH), 10.50 (s, 1 H, CHO).

^{13}C NMR: δ = 56.0, 60.8, 76.9, 78.2, 117.7, 118.8, 124.9, 131.0, 149.4, 152.8, 190.6.

Anal. Calcd for $C_{11}H_{10}O_3$: C, 69.46; H, 5.30. Found: C, 69.50; H, 5.38.

2-(Prop-2-yn-1-yloxy)-1-naphthaldehyde (2e)

Mp 107–110 °C.

^{1}H NMR: δ = 2.58 (t, *J* = 2.4 Hz, 1 H, CCH), 4.95 (d, *J* = 2.4 Hz, 2 H, CH_2), 7.36–7.49 (m, 2 H, ArH), 7.59–7.68 (m, 1 H, ArH), 7.79 (d, *J* = 8.0 Hz, 1 H, ArH), 8.07 (d, *J* = 9.2 Hz, 1 H, ArH), 9.27 (d, *J* = 8.0 Hz, 1 H, ArH), 10.91 (s, 1 H, CHO).

^{13}C NMR: δ = 57.0, 76.5, 79.4, 108.3, 124.5, 126.5, 127.7, 127.9, 129.0, 129.8, 130.6, 138.9, 157.8, 190.0.

Anal. Calcd for $C_{14}H_{10}O_2$: C, 79.98; H, 4.79. Found: C, 79.90; H, 4.82.

(*N*,*N*-Dimethylamino)[2-(prop-2-yn-1-yloxy)aryl]acetonitriles 3; General Procedure

To a stirred, chilled (ca. 5 °C) suspension of aldehyde **2** (25 mmol) and dimethylamine hydrochloride (3.1 g, 38 mmol) in MeCN (25 mL), a solution of NaCN (1.9 g, 38 mmol) in H_2O (2 mL) was added dropwise whilst maintaining the temperature of the reaction mixture below 10 °C. The mixture was stirred for ca. 24 h at 30 °C until aldehyde **2** could no longer be detected by GC. The reaction mixture was cooled, diluted with H_2O (25 mL) and extracted with C_6H_6 (5 × 20 mL). The combined extracts were washed with H_2O (10 mL) and dried ($MgSO_4$). After evaporation of the solvent the crude residue was distilled and/or crystallized from Et_2O or a mixture of C_6H_6–cyclohexane.

(*N*,*N*-Dimethylamino)[2-(prop-2-yn-1-yloxy)phenyl]acetonitrile (3a)

Bp 107–108 °C (0.1 Torr); mp 35–36 °C.

^{1}H NMR: δ = 2.35 [s, 6 H, $N(CH_3)_2$], 2.52 (X of ABX, $J_{AX} = J_{BX}$ = 2.4 Hz, 1 H, CCH), 4.75, 4.81 (AB of ABX, J_{AB} = 16 Hz, 2 H, CH_2), 5.16 (s, 1 H, CH), 7.03–7.50 (m, 4 H, ArH).

^{13}C NMR: δ = 41.6 (2C), 56.4, 56.8, 75.9, 77.9, 113.0, 115.2, 121.2, 122.5, 129.5, 130.2, 154.7.

Anal. Calcd for $C_{13}H_{14}N_2O$: C, 72.87; H, 6.59; N, 13.07. Found: C, 72.81; H, 6.52; N 13.14.

[5-Chloro-2-(prop-2-yn-1-yloxy)phenyl](*N*,*N*-dimethylamino)acetonitrile (3b)

Mp 68–70 °C.

^{1}H NMR: δ = 2.35 [s, 6 H, $N(CH_3)_2$], 2.53 (X of ABX, $J_{AX} = J_{BX}$ = 2.4 Hz, 1 H, CCH), 4.72, 4.78 (AB of ABX, J_{AB} = 16 Hz, 2 H, CH_2), 5.08 (s, 1 H, CH), 7.00 (d, *J* = 8.8 Hz, 1 H, ArH), 7.33 (dd, *J* = 8.8, 2.4 Hz, 1 H, ArH), 7.46 (d, *J* = 2.4 Hz, 1 H, ArH).

^{13}C NMR: δ = 41.6 (2C), 56.4, 56.8, 75.9, 77.9, 113.0, 115.2, 121.2, 122.5, 129.5, 130.2, 154.7.

Anal. Calcd for $C_{13}H_{13}ClN_2O$: C, 62.78; H, 5.27; N, 11.26; Cl, 14.25. Found: C, 62.79; H, 5.25; N, 11.23; Cl, 14.31.

[5-Bromo-2-(prop-2-yn-1-yloxy)phenyl](*N*,*N*-dimethylamino)acetonitrile (3c)

Mp 66–69 °C.

^{1}H NMR: δ = 2.36 [s, 6 H, $N(CH_3)_2$], 2.53 (X of ABX, $J_{AX} = J_{BX}$ = 2.4 Hz, 1 H, CCH), 4.72, 4.79 (AB of ABX, J_{AB} = 16 Hz, 2 H, CH_2), 5.08 (s, 1 H, CH), 6.95 (d, *J* = 8.8 Hz, 1 H, ArH), 7.45 (dd, *J* = 8.8, 2.4 Hz, 1 H, ArH), 7.60 (d, *J* = 2.4 Hz, 1 H, ArH).

^{13}C NMR: δ = 41.8 (2C), 56.6, 56.8, 76.4, 77.3, 113.8, 114.8, 115.0, 124.9, 133.0, 154.0.

Anal. Calcd for $C_{13}H_{13}BrN_2O$: C, 53.26; H, 4.47; N, 9.56; Br, 27.26. Found: C, 53.21; H, 4.40; N, 9.54; Br, 27.36.

(*N*,*N*-Dimethylamino)[3-methoxy-2-(prop-2-yn-1-yloxy)phenyl]acetonitrile (3d)
Mp 64–67 °C.

^{1}H NMR: δ = 2.34 [s, 6 H, $N(CH_3)_2$], 2.51 (X of ABX, $J_{AX} = J_{BX}$ = 2.4 Hz, 1 H, CCH), 3.87 (s, 3 H, OCH_3), 4.71, 4.83 (AB of ABX, J_{AB} = 16 Hz, 2 H, CH_2), 5.23 (s, 1 H, CH), 6.95 (d, *J* = 8.8 Hz, 1 H, ArH), 6.94–7.14 (m, 2 H, ArH).

^{13}C NMR: δ = 41.6 (2C), 55.8, 57.5, 60.4, 75.4, 79.1, 113.3, 115.4, 120.7, 124.3, 128.5, 144.6, 152.7.

Anal. Calcd for $C_{14}H_{16}N_2O_2$: C, 68.83; H, 6.60; N, 11.47. Found: C, 68.72; H, 6.52; N, 11.43.

(*N*,*N*-Dimethylamino)[2-(prop-2-yn-1-yloxy)-1-naphthyl]acetonitrile (3e)
Mp 72–73 °C.

^{1}H NMR: δ = 2.42 [s, 6 H, $N(CH_3)_2$], 2.55 (X of ABX, $J_{AX} = J_{BX}$ = 2.4 Hz, 1 H, CCH), 4.85, 4.94 (AB of ABX, J_{AB} = 16 Hz, 2 H, CH_2), 5.32 (s, 1 H, CH), 7.37–7.67 (m, 3 H, ArH), 7.82 (d, *J* = 8.4 Hz, 1 H, ArH), 7.89 (d, *J* = 9.2 Hz, 1 H, ArH), 8.33 (d, *J* = 8.4 Hz, 1 H, ArH).

^{13}C NMR: δ = 43.5 (2C), 53.2, 56.8, 76.5, 79.4, 109.9, 113.5, 118.6, 122.9, 125.5, 125.7, 129.3, 130.1, 130.3, 137.2, 153.0.

Anal. Calcd for $C_{17}H_{16}N_2O$: C, 75.25; H, 6.10; N, 10.60. Found: C, 77.29; H, 6.12; N, 10.68.

Intramolecular Vinylation of Aminonitriles 3; General Procedure
To a stirred (under nitrogen) solution of aminonitrile **3** (10 mmol) and TEBAC (50 mg, 0.2 mmol) in DMSO (15 mL), powdered NaOH (2.4 g, 60 mmol) was added in one portion, at r.t. A slight exotherm was observed and the temperature of the mixture increased to ca. 30 °C. Stirring was continued at 35 °C until aminonitrile **3** was no longer detected by GC (usually 2 h). The mixture was quenched with H_2O (50 mL) and extracted with C_6H_6 (5 × 10 mL). The combined organic extract was washed with H_2O (20 mL) and brine (20 mL), and then dried ($MgSO_4$). After removing the solvent, the resulting residue consisting of **4** and **5** was treated as described below.

Residue from 3a
The mixture of products **4a** and **5a** was distilled (Kugelrohr, 115-125 °C/0.2 Torr) to afford a yellowish oil which partially crystallized. The crystals were separated and were identified as being predominantly chromene **5a**. The oil containing mostly chromane **4a** was chromatographed on alumina to give pure **4a**; residual **5a** in the oil rearranged into **9a**.

4-(*N*,*N*-Dimethylamino)-3-methylenechromane-4-carbonitrile (4a)
Yellowish oil.

^{1}H NMR: δ = 2.27 [s, 6 H, $N(CH_3)_2$], 4.59, 4.96 (AB of ABMX, J_{AB} = 12 Hz, $J_{AX} = J_{BX}$ = 0.8 Hz, J_{BM} = 1.6 Hz, 2 H, CH_2), 5.39 (M of ABMX, J_{BM} = 1.6 Hz, 1 H, CH), 5.74 (X of ABMX, $J_{AX} = J_{BX}$ = 0.8 Hz, 1 H, CH), 6.84–6.97 (m, 2 H, ArH), 7.24–7.44 (m, 2 H, ArH).

^{13}C NMR: δ = 39.7 (2C), 66.6, 68.1, 114.1, 116.0, 117.5, 119.5, 119.8, 129.2, 131.0, 137.5, 153.1.

Anal. Calcd for $C_{13}H_{14}N_2O$: C, 72.87; H, 6.59; N, 13.07. Found: C, 72.77; H, 6.46; N, 12.86.

4-(*N*,*N*-Dimethylamino)-3-methyl-4*H*-chromene-4-carbonitrile (5a)
Yellowish crystals; mp 68–70 °C (cyclohexane).

^{1}H NMR: δ = 1.99 (d, *J* = 1.4 Hz, 3 H, CH_3), 2.21 [s, 6 H, $N(CH_3)_2$], 6.77 (q, *J* = 1.4 Hz, 1 H, CH), 7.03–7.54 (m, 4 H, ArH).

^{13}C NMR: δ = 14.9, 38.9 (2C), 61.2, 106.9, 114.0, 116.7, 118.0, 123.3, 128.9, 129.8, 139.8, 151.1.

Anal. Calcd for $C_{13}H_{14}N_2O$: C, 72.87; H, 6.59; N, 13.07. Found: C, 72.63; H, 6.55; N, 12.95.

(2-Methyl-3-oxo-2,3-dihydro-1-benzofuran-2-yl)acetonitrile (9a)
White powder; yield: 6%; mp 54–55 °C (C_6H_6).

^{1}H NMR: δ = 1.58 (s, 3 H, CH_3), 2.72, 2.87 (AB, J_{AB} = 16.8 Hz, 2 H, CH_2), 7.10–7.18 (m, 2 H, ArH), 7.64–7.73 (m, 2 H, ArH).

^{13}C NMR: δ = 21.0, 26.7, 84.6, 113.8, 115.0, 118.8, 122.8, 125.1, 139.1, 170.9, 200.3.

Anal. Calcd for $C_{11}H_9NO_2$: C, 70.58; H, 4.85; N, 7.48. Found: C, 70.52; H, 4.99; N, 7.29.

Residue from 3b
The sticky oil partially solidified and was triturated with cyclohexane (5 mL) to give pure isomer **5b**. The organic layer containing **4b** was filtered through alumina to remove tars.

6-Chloro-4-(*N*,*N*-dimethylamino)-3-methylenechromane-4-carbonitrile (4b)
White crystals; mp 69–71 °C (cyclohexane).

^{1}H NMR: δ = 2.27 [s, 6 H, $N(CH_3)_2$], 4.59, 4.95 (AB of ABMX, J_{AB} = 12 Hz, $J_{AX} = J_{BX}$ = 0.8 Hz, J_{BM} = 1.6 Hz, 2 H, CH_2), 5.42 (M of ABMX, J_{BM} = 1.6 Hz, 1 H, CH), 5.76 (X of ABMX, $J_{AX} = J_{BX}$ = 0.8 Hz, 1 H, CH), 6.80 (d, *J* = 8.8 Hz, 1 H, ArH), 7.23 (dd, *J* = 8.8, 2.4 Hz, 1 H, ArH), 7.39 (d, *J* = 2.4 Hz, 1 H, ArH).

^{13}C NMR: δ = 39.7 (2C), 66.8, 67.9, 113.7 116.8, 119.0, 120.9, 124.7, 128.6, 131.0, 136.9, 151.8.

Anal. Calcd for $C_{13}H_{13}ClN_2O$: C, 62.78; H, 5.27; N, 11.26. Found: C, 62.71; H, 5.29; N, 11.33.

6-Chloro-4-(*N*,*N*-dimethylamino)-3-methyl-4*H*-chromene-4-carbonitrile (5b)
Yellowish crystals; mp 120–124 °C (dec.; cyclohexane–C_6H_6).

^{1}H NMR: δ = 1.97 (d, *J* = 1.6 Hz, 3 H, CH_3), 2.21 [s, 6 H, $N(CH_3)_2$], 6.77 (q, *J* = 1.6 Hz, 1 H, CH), 7.00 (d, *J* = 8.8 Hz, 1 H, ArH), 7.30 (dd, *J* = 8.8, 2.4 Hz, 1 H, ArH), 7.49 (d, *J* = 2.4 Hz, 1 H, ArH).

^{13}C NMR: δ = 14.7, 38.8 (2C), 60.9, 106.7, 115.5, 117.6, 118.1, 128.3, 128.4, 129.9, 139.6, 149.6.

Anal. Calcd for $C_{13}H_{13}ClN_2O$: C, 62.78; H, 5.27; N, 11.26. Found: C, 62.74; H, 5.33; N, 11.20.

Residue from 3c
Column chromatography gave pure **4c** and **9c**. The NMR data for chromene **5c** are taken from the proton and carbon spectra of the mixture of crude **4c**/**5c** (5:1). No other data are presented for **5c**.

6-Bromo-4-(*N*,*N*-dimethylamino)-3-methylenechromane-4-carbonitrile (4c)
Yellow oil.

^{1}H NMR: δ = 2.24 [s, 6 H, $N(CH_3)_2$], 4.59, 4.94 (AB of ABMX, J_{AB} = 12 Hz, $J_{AX} = J_{BX}$ = 0.8 Hz, J_{BM} = 1.6 Hz, 2 H, CH_2), 5.42 (M of ABMX, J_{BM} = 1.6 Hz, 1 H, CH), 5.76 (X of ABMX, $J_{AX} = J_{BX}$ = 0.8 Hz, 1 H, CH), 6.75 (d, *J* = 8.8 Hz, 1 H, ArH), 7.36 (dd, *J* = 8.8, *J* = 2.4 Hz, 1 H, ArH), 7.51 (d, *J* = 2.4 Hz, 1 H, ArH).

^{13}C NMR: δ = 39.6 (2C), 66.6, 67.7, 111.6, 113.5, 116.7, 119.4, 121.3, 131.3, 133.8, 136.6, 152.2.

Anal. Calcd for $C_{13}H_{13}BrN_2O$: C, 53.26; H, 4.47; N, 9.56. Found: C, 52.89; H, 4.21; N, 9.39.

6-Bromo-4-(*N*,*N*-dimethylamino)-3-methyl-4*H*-chromene-4-carbonitrile (5c)

^{1}H NMR: δ = 1.97 [d, *J* = 1.6 Hz, 3 H, CH_3), 2.21 (s, 6 H, $N(CH_3)_2$], 6.75 (q, *J* = 1.6 Hz, 1 H, CH), 6.94 (d, *J* = 8.8 Hz, 1 H, ArH), 7.43 (dd, *J* = 8.8, 2.4 Hz, 1 H, ArH), 7.63 (d, *J* = 2.4 Hz, 1 H, ArH).

^{13}C NMR: δ = 14.7, 38.7 (2C), 60.7, 106.6, 115.4, 115.8, 117.5, 118.4, 131.1, 132.7, 139.5, 149.9.

(6-Bromo-2-methyl-3-oxo-2,3-dihydro-1-benzofuran-2-yl)acetonitrile (9c)

Yellow oil; yield: 15%.

^{1}H NMR: δ = 1.59 (s, 3 H, CH_3), 2.74, 2.88 (AB, J_{AB} = 16.8 Hz, 2 H, CH_2), 7.08 (dd, *J* = 8.8, 0.8 Hz, 1 H, ArH), 7.73–7.82 (m, 2 H, ArH).

^{13}C NMR: δ = 21.1, 25.7, 85.6, 114.7, 115.4, 115.6, 120.6, 127.6, 141.7, 169.8, 198.8.

Anal. Calcd for $C_{11}H_8BrNO_2$: C, 49.65; H, 3.03; N, 5.26. Found: C, 49.71; H, 2.93; N, 5.02.

Residue from 3d

Column chromatography afforded pure **4d** and the product of oxidation of carbanion **3d**$^-$: 3-methoxy-*N*,*N*-dimethyl-2-(prop-2-yn-1-yloxy)benzamide **3d′**.

4-(*N*,*N*-Dimethylamino)-8-methoxy-3-methylenechromane-4-carbonitrile (4d)

Yellow oil.

^{1}H NMR: δ = 2.27 [s, 6 H, $N(CH_3)_2$], 3.87 (s, 3 H, OCH_3), 4.72, 5.03 (AB of ABMX, J_{AB} = 12 Hz, J_{AX} = J_{BX} = 0.8 Hz, J_{BM} = 1.6 Hz, 2 H, CH_2), 5.41 (M of ABMX, J_{BM} = 1.6 Hz, 1 H, CH), 5.74 (X of ABMX, J_{AX} = J_{BX} = 0.8 Hz, 1 H, CH), 6.88–6.93 (m, 2 H, ArH), 7.01–7.07 (m, 1 H, ArH).

^{13}C NMR: δ = 39.8 (2C), 56.0, 67.0, 68.0, 112.4 114.2, 116.2, 119.5, 120.1, 121.0, 137.4, 142.8, 148.7.

Calcd for $C_{14}H_{16}N_2O_2$: C, 68.83; H, 6.60; N, 11.47. Found: C, 68.69; H, 6.64; N, 7.01.

3-Methoxy-*N*,*N*-dimethyl-2-(prop-2-yn-1-yloxy)benzamide 3d′

White crystals; yield: 44%; mp 54–55 °C (C_6H_6).

^{1}H NMR: δ = 2.48 (t, *J* = 2.5 Hz, 1 H, CCH), 2.87 (s, 3 H, NCH_3), 3.11 (s, 3 H, NCH_3), 3.87 (s, 3 H, OCH_3), 4.69 (s, 2 H, CH_2), 6.84 (dd, *J* = 7.6, 1.6 Hz, 1 H, ArH), 6.92 (dd, *J* = 8.2, 1.6 Hz, 1 H, ArH), 7.11 (dd, *J* = 8.2, 7.6 Hz, 1 H, ArH).

^{13}C NMR: δ = 34.8, 38.4, 55.8, 60.9, 75.1, 79.1, 112.8, 119.2, 125.2, 132.2, 142.7, 152.5, 168.5.

Anal. Calcd for $C_{13}H_{15}NO_3$: C, 66.94; H, 6.48; N, 6.00. Found: C, 66.97; H, 6.42; N, 5.90.

Residue from 3e

Column chromatography afforded pure compounds **4e** and **9e**. The NMR data for chromene **5e** are taken from the proton and carbon spectra of the mixture of crude **4e**/**5e** (5:1). No other data are presented for **5e**.

1-(*N*,*N*-Dimethylamino)-2-methylene-2,3-dihydro-1*H*-benzo[*f*]chromene-1-carbonitrile (4e)

White crystals; mp 86–92 °C (C_6H_6).

^{1}H NMR: δ = 2.41 [s, 6 H, $N(CH_3)_2$], 4.60, 4.68 (AB of ABMX, J_{AB} = 12 Hz, J_{AM} = 1.2 Hz, J_{BM} = 0.6 Hz, 2 H, CH_2), 5.65 (M of ABMX, J_{AM} = 1.2 Hz, J_{BM} = 0.6 Hz, 1 H, CH), 5.80 (s, X of ABMX, 1 H, CH), 7.06 (d, *J* = 9.2 Hz, 1 H, ArH), 7.37–7.80 (m, 4 H, ArH), 8.86 (d, *J* = 8.8 Hz, 1 H, ArH).

^{13}C NMR: δ = 39.4 (2C), 62.8, 68.7, 109.7, 118.5, 118.9, 124.1, 124.5, 127.1, 128.6, 129.8, 132.1, 132.3, 133.8, 153.7.

Anal. Calcd for $C_{17}H_{16}N_2O$: C, 77.25; H, 6.10; N, 10.60. Found: C, 77.22; H, 6.32; N, 10.51.

1-(*N*,*N*-Dimethylamino)-2-methyl-1*H*-benzo[*f*]chromene-1-carbonitrile (5e)

^{1}H NMR: δ = 2.01 (d, *J* = 1.6 Hz, 3 H, CH_3), 2.46 [s, 6 H, $N(CH_3)_2$], 6.80 (q, *J* = 1.6 Hz, 1 H, CH), the aromatic signals overlapped with those of **4e**.

(2-Methyl-1-oxo-1,2-dihydronaphtho[2,1-*b*]furan-2-yl)acetonitrile (9e)

White crystals; yield: 13%; mp 97–99 °C (C_6H_6).

^{1}H NMR: δ = 1.68 (s, 3 H, CH_3), 2.79, 2.96 (AB, J_{AB} = 16.8 Hz, 2 H, CH_2), 7.29 (d, *J* = 9.2 Hz, 1 H, ArH), 7.47–7.56 (m, 1 H, ArH), 7.66–7.71 (m, 1 H, ArH), 7.87 (d, *J* = 8.2 Hz, 1 H, ArH), 8.15 (d, *J* = 9.2 Hz, 1 H, ArH), 8.70 (d, *J* = 8.2 Hz, 1 H, ArH).

^{13}C NMR: δ = 21.1, 25.8, 85.6, 111.1, 113.8, 115.1, 123.1, 125.8, 128.7, 129.2, 129.5, 130.2, 141.1, 173.8, 199.6.

MS (EI, 70 eV): *m/z* (%) = 237 (80, M^+), 197 (100), 154 (20), 126 (25).

HRMS (EI): *m/z* calcd for $C_{15}H_{11}NO_2$: 237.07898; found: 237.07929.

Anal. Calcd for $C_{15}H_{11}NO_2$: C, 75.94; H, 4.67; N, 5.90. Found: C, 75.90; H, 4.63; N, 5.96.

Acknowledgment

This work was financially supported by Warsaw University of Technology.

References

(1) Baldwin, J. E. *J. Chem. Soc., Chem. Commun.* **1976**, 734.
(2) Eglington, G.; Whiting, M. C. *J. Chem. Soc.* **1953**, 3052.
(3) Mavrov, M. V.; Kutcherov, V. F. *Izv. Akad. Nauk SSSR, Ser. Khim.* **1964**, 1653.
(4) Mavrov, M. V.; Dierzinskii, A. R.; Kutcherov, V. F. *Izv. Akad. Nauk SSSR, Ser. Khim.* **1965**, 1460.
(5) Kitagawa, O.; Suzuki, T.; Fujiwara, H.; Fujita, M.; Taguchi, T. *Tetrahedron Lett.* **1999**, *40*, 4585.
(6) Mavrov, M. V.; Kutcherov, V. F. *Izv. Akad. Nauk SSSR, Ser. Khim.* **1964**, 1820.
(7) MaGee, D. I.; Leach, J. D.; Setiadji, S. *Tetrahedron* **1999**, *55*, 2847.
(8) Vieser, R.; Eberbach, W. *Tetrahedron Lett.* **1995**, *36*, 4405.
(9) Arcadi, A.; Marinelli, F.; Pini, E.; Rossi, E. *Tetrahedron Lett.* **1996**, *37*, 3387.
(10) Makra, F.; Rohloff, J. C.; Muehldorf, A. V.; Link, J. O. *Tetrahedron Lett.* **1995**, *36*, 6815.
(11) Jackson-Mülly, M.; Zsindely, J.; Schmid, H. *Helv. Chim. Acta* **1976**, *69*, 664.
(12) Arcadi, A.; Cacchi, S.; Fabrizi, G.; Marinelli, F. *Synlett* **1993**, 65.
(13) Arcadi, A.; Cacchi, S.; Fabrizi, G.; Manna, F.; Pace, P. *Synlett* **1998**, 446.
(14) Patra, R.; Maiti, S. B.; Chatterjee, A.; Chakravarty, A. K. *Tetrahedron Lett.* **1991**, *32*, 1363.

(15) Lavoisier-Gallo, T.; Rodriguez, J. *J. Org. Chem.* **1997**, *62*, 3787.
(16) Wang, J.-L.; Ueng, C.-H.; Yeh, M.-C. P. *Tetrahedron Lett.* **1995**, *36*, 2823.
(17) Koradin, C.; Rodriguez, A.; Knochel, P. *Synlett* **2000**, 1452.
(18) Dehmlow, E. W.; Dehmlow, S. S. *Phase Transfer Catalysis*, 3rd ed.; Wiley-VCH: Weinheim, **1993**.
(19) Starks, C. M.; Liotta, M. L.; Halpern, M. *Phase-Transfer Catalysis: Fundamentals, Applications and Industrial Perspectives*; Chapman & Hall: New York / London, **1994**.
(20) Mąkosza, M.; Fedoryński, M. *Catal. Rev.* **2003**, *45*, 321.
(21) Mąkosza, M.; Serafinowa, B.; Bolesławska, B. *Rocz. Chem.* **1968**, *42*, 817.
(22) Mąkosza, M. *Tetrahedron Lett.* **1966**, 5489.
(23) Jończyk, A.; Lipiak, D.; Zdrojewski, T. *Tetrahedron* **1990**, *46*, 102.
(24) Zdrojewski, T.; Jończyk, A. *Synthesis* **1990**, 224.
(25) Zdrojewski, T.; Jończyk, A. *Liebigs Ann. Chem.* **1993**, 375.
(26) Jończyk, A.; Pakulski, Z. *Tetrahedron Lett.* **1996**, *37*, 8909.
(27) Wittig, G.; Blumenthal, H. *Chem. Ber.* **1927**, *60B*, 1085.
(28) Lockhart, I. M.; Tanner, E. M. *J. Chem. Soc.* **1965**, 3610.
(29) Janietz, D.; Rudorf, W.-D. *Tetrahedron* **1989**, *45*, 1661.