A Route to Dicyanomethylene Pyridines and Substituted Benzonitriles Utilizing Malononitrile Dimer as a Precursor

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Abstract: The conditions of the reaction of malononitrile dimer with enamiones and arylidene malononitrile could be adapted to yield either pyridines or benzene derivatives. A new synthesis of pyrido[1,2-a]pyrimidines from the reaction of malononitrile dimer 1 and 2-phenyl-3-piperidin-1-yl-acrylonitrile (11) is described. Compound 1 condensed with DMFDMA to yield an enaminonitrile that reacted with hydrazine hydrate to yield N',4,6-triamino-2H-pyrazolo[3,4-b]pyridine-5-carboxamidine (17).

Keywords: malononitrile dimer; arylmethylenemalononitrile; benzylidenemalononitrile; pyrazolopyridine

1. Introduction

Polyfunctionally substituted nitriles are versatile reagents that have been extensively utilized in the past as precursors to polyfunctionally substituted heteroaromatics [1-4]. Interest in further developing the synthetic potential of these compounds has been revived [5-7]. 2-Aminoprop-1-ene-1,1,3-tricarbonitrile (1) has proved to be an excellent precursor to condensed pyridines, pyridazines, and pyrazoles [8-10]. However, to our knowledge the utility of 1 as a precursor to polyfunctional aromatics has received little attention. Elnagdi et al. have noted the formation of 3 as a side product from the reaction of 2 with 1, while compound 4 was obtained as the main product [11] (Scheme 1). In
connection to results reported earlier [11] we were able to react 1 with 5a,b to afford either pyridines or benzene derivatives after changing the reaction conditions.

Scheme 1. Malononitrile dimer as precursor to heterocycles and substituted benzenes [11].

2. Results and Discussion

Thus reaction of 1 with 2a,b in ethanolic piperidine has afforded 4a,d as a sole product. On the other hand, when the reaction was conducted in acetic acid in the presence of ammonium acetate and refluxing for 4 hrs only 3a was formed via intermediate 5 (Scheme 2) The 1H-NMR of 4a, in addition to phenyl proton signals, showed two doublets at $\delta = 7.16$ ppm and $\delta = 7.86$ ppm with $J = 8$ Hz, typical for pyridine H-5 and H-4, respectively. A D$_2$O exchangeable one proton signal for a NH group appeared at $\delta = 9.42$ ppm.

Scheme 2. Synthesis of pyridine 3a and substituted benzenes 4a,d.
The $^1$H-NMR spectrum of 3a revealed a singlet at $\delta = 8.29$ ppm for H-6 and two D$_2$O exchangeable amino signals at $\delta = 7.08$ ppm and $\delta = 7.77$ ppm, in addition to the phenyl protons (see Experimental). The $^{13}$C-NMR clearly indicated the carbonyl carbon at $\delta = 190.23$ ppm and two CN signals at $\delta = 114.13$ and 113.85 ppm.

In an attempt to generate further examples of the synthesis of substituted benzenes 3, malononitrile dimer 1 was reacted with 2d in acetic acid/ammonium acetate, and a product with molecular formula C$_{13}$H$_8$N$_4$OS (M$^+$ at $m/z = 268$) which we think to be 3d was isolated after reflux for 1/2 hrs; prolonged heating did not change the identity of the compound. The $^1$H-NMR under D$_2$O exchange of the presumed structure 3d; showed, along with three thiienyl protons, two amino group singlets at $\delta = 7.1$ ppm and $\delta = 7.9$ ppm, and a doublet at $\delta = 8.2$ ppm with $J = 8$ Hz, that could not be explained or assigned to any proton in the suggested structure.

Repeating the same reaction using sodium acetate instead of ammonium acetate, and refluxing for 3 hrs, a whole new set of data were obtained. A compound with molecular formula C$_{20}$H$_{12}$N$_4$O$_2$S$_2$ (M$^+$ 404) was obtained. $^1$H-NMR of this compound showed two singlets at $\delta = 7.47$ ppm and $\delta = 8.98$ ppm each for one proton of C-5 and C-2 of the pyridine ring, respectively, in addition to six thiienyl protons and two amino signals. The $^{13}$C-NMR spectrum showed the presence of 19 different carbon atoms with two carbonyl carbons at $\delta = 184.7$ ppm. These data can be interpreted as corresponding to structure 7 that is assumed to result from initial reaction of the active methylene moiety and the amino function in 1 with 2d to yield the intermediate 6 that then cyclizes to 7 (Scheme 3).

**Scheme 3.** Synthesis of 4,7-diamino-3,6-di(thiophene-2-carbonyl)quinoline-8-carbonitrile (7).
Like the recently reported formation of 9 from reaction of 1 and 8a,b in ethanolic chitosan, compound 1 reacted with 8a,b to yield dihydropyridine 9a,b. However in refluxing acetic acid in the presence of ammonium acetate, the benzene derivative 10 was obtained as indicated by the spectral data (Scheme 4).

**Scheme 4.** Synthesis of 6-amino-2-dicyanomethylene-4-aryl-2,3-dihydropyridine-3,5-dicarbonitriles 9a,b and 3,5-diaminobiphenyl-2,4,6-tricarbonitrile (10).

The reaction of 1 with 11, which was recently obtained by reacting benzyl cyanide with triethyl orthoformate and piperidine [12], afforded 14 via intermediates 12 and 13. Attempts to isolate 13 have failed (cf. Scheme 5). The reaction of 1 with DMFDMA afforded 16 which may exist in E or Z forms. Isomeric structure 15 was ruled out based on ¹H NMR that revealed the D₂O exchangeable amino signal at δ = 7.19 ppm. In addition, the ¹³C NMR did not reveal any signals for the sp³ carbons other than those of the dimethylamino moiety. Reacting 16 with hydrazine hydrate afforded 4,6-diamino-2H-pyrazolo[3,4-b]pyridine-5-carboxamide hydrazone 17 (cf. scheme 6).
Scheme 5. Synthesis of 2-(4-amino-7-cyano-3,9-diphenyl-pyrido[1,2-a]pyrimidin-6-ylidene)-malononitrile (14).

Scheme 6. Synthesis of 4,6-diamino-2H-pyrazolo[3,4-b]pyridine-5-carboxamide hydrazone (17).
3. Experimental

3.1. General

All melting points are uncorrected and were determined on a Sanyo (Gallenkamp) instrument. Infrared spectra were recorded from KBr discs on a Perkin-Elmer 2000 FT–IR system. ¹H-NMR and ¹³C-NMR spectra were determined on a Bruker DPX spectrometer operating at 400 MHz for ¹H-NMR and 100 MHz for ¹³C-NMR using DMSO-d₆ as solvent and TMS as internal standard; chemical shifts are reported in  δ (ppm). Mass spectra were measured on VG Autospec Q MS 30 and MS 9 (AEI) spectrometers, with EI at 70 eV. Elemental analyses were measured by means of LEOCHNS-932 Elemental Analyzer. General purpose silica gel on polyester 20 x 20 cm TLC plates with UV indicator were used in TLC experiments to monitor completion of reactions, in which ethyl acetate-petroleum ether (1:1) was used as eluent.

3.2. 2,4-Diamino-5-benzoyl-isophthalonitrile (3a)

A mixture of 2-aminoprop-1-ene-1,1,3-tricarbonitrile (1, 1.32 g, 0.01 mol) and enaminone 2a (0.01 mol) in AcOH (10 cm) and 0.2 gm of NH₄OAc, was kept at reflux temperature for 4 hrs. The mixture was cooled and then poured onto ice-water. The solid, so formed, was collected by filtration and recrystallized from EtOH to give yellow crystals; Yield 83%; m.p. 298–299 °C; Anal. Calcd. for C₁₅H₁₀N₄O (262.27): C, 68.69; H, 3.84; N, 21.36%. Found: C, 68.53; H, 3.92; N, 21.34%; IR (KBr, cm⁻¹): 3,443, 3,352 (NH₂), 3,322, 3,209 (NH₂), 2,210, 2,206 (2CN); ¹H-NMR:  δ, ppm = 7.08 (br s, 2H, NH₂, D₂O exchangeable) 7.50–7.57 (3H, m, H-3',4',5'), 7.77 (2H, br. s, NH₂, D₂O exchangeable), 8.22 (2H, dd, J = 8.0, 4J = 1.6, H-2',6'), 8.29 (1H, s, H-6); ¹³C-NMR:  δ, ppm = 190.23, 159.85, 159.62, 157.90, 154.44, 154.12, 143.65, 136.01, 130.21 (2C), 127.32 (2C), 115.89, 114.13, 113.85; MS: m/z (%) 262 (M⁺, 100), 234 (15), 217 (5), 192 (5), 164 (25), 131 (10).

3.3. General procedure for the synthesis of compounds 4a,d

A mixture of 2-aminoprop-1-ene-1,1,3-tricarbonitrile (1, 1.32 g, 0.01 mol) and enaminone 2a,b (0.01 mol) in EtOH (10 mL) was treated with piperidine (5 drops). The reaction mixture was refluxed for 4 h. The mixture was cooled and then poured onto ice-water. The solid, so formed, was collected by filtration and recrystallized from EtOH to give yellow crystals.

2-(3-Cyano-6-phenyl-1H-pyridin-2-ylidene)malononitrile (4a). Yield 80%; m.p. 257–259 °C; Anal. Calcd. for C₁₅H₁₀N₄ (244.26): C, 73.76; H, 3.30; N, 22.94%. Found: C, 73.94; H, 3.52; N, 23.04%; IR (KBr, cm⁻¹): 3,097 (NH), 2,210, 2,182 (3CN); ¹H-NMR:  δ, ppm = 7.16 (1H, d, J = 8.0 Hz, H-5), 7.48–7.51 (3H, m, H-3',4',5'), 7.86 (1H, d, J = 8.0 Hz, H-4), 8.01 (2H, m, H-2',6'), 9.42 (1H, br. s, NH, D₂O exchangeable); ¹³C-NMR:  δ, ppm = 180.88, 160.54, 159.45, 155.50, 136.89, 132.09, 128.31 (2C), 127.32 (2C), 114.72, 113.88 (2C), 91.82, 63.25; MS: m/z (%) 243 (M⁺, 100), 217 (25), 152 (15), 105 (100), 77 (10).

2-(3-Cyano-6-thiophen-2-yl-1H-pyridin-2-ylidene)malononitrile (4d). Yield 75%; m.p. 200–202 °C; Anal. Calcd. for C₁₃H₆N₄S (250.28): C, 62.93; H, 2.42; N, 22.39; S, 12.81%. Found: C, 63.06; H, 2.54;
N, 22.54; S, 12.98%; IR (KBr, cm$^{-1}$): 3,189 (NH), 2,230, 2,210 (3CN); $^1$H-NMR: $\delta$, ppm = 7.04 (1H, d, J = 8.0, H-5), 7.14 (1H, t, J = 4.0, thiylan H-4'), 7.66–7.68 (2H, m, H-4, thiylan H-3'), 7.76 (1H, d, J = 4.0, thiylan H-5'), 8.06 (1H, br. s, NH, D$_2$O exchangeable); MS: m/z (%) 250 (M$^+$, 100), 223 (20), 185 (30), 158 (15), 141 (20), 114 (25), 82 (10), 69 (15).

3.4. Synthesis of 4,7-diamino-3,6-di(thiophene-2-carbonyl)quinoline-8-carbonitrile (7).

A mixture of 2-aminoprop-1-ene-1,1,3-tricarbonitrile (1, 1.32 g, 0.01 mol) and enaminone 2d (0.01 mol) in AcOH (10 cm) and 0.2 gm of NH$_4$OAc, was kept at reflux temperature for 3 hrs. The mixture was cooled and then poured onto ice-water. The solid so formed was collected by filtration and recrystallized from EtOH to give yellow crystals; Yield 88%; m.p. 330–332 °C; Anal. Calcd. for C$_{20}$H$_{12}$N$_4$O$_2$S$_2$ (404): C, 59.40; H, 2.97; N, 13.86; O, 7.92; S, 15.84%. Found: C, 59.50; H, 2.78; N, 13.96; O, 7.87; S, 15.89%; $^1$H-NMR: $\delta$, ppm = 7.05 (br. s, 2H, NH$_2$), 7.27 (t, J = 4.0, 1H, thienyl H-4'), 7.31 (t, J = 4.0, 1H, thienyl H-4''), 7.47 (s, 1H, H-5), 7.79 (d, J = 3.2, thienyl H-3'), 7.85 (d, 3H, J = 3.2, thienyl H-3''& NH$_2$), 7.93 (d, 1H, J = 5.2, H-5'), 8.17 (d, 1H, J = 5.2, H-5''), 8.98 (s, 1H, H-2); $^{13}$C-NMR: $\delta$, ppm = 128.9, 154.0 (2C), 184.7 (2 C=O), 77.1, 98.3, 103.9, 115.85, 118.0, 129.2,131.6, 134.0, 135.7, 136.1, 140.6, 143.67, 156.1, 157.1, 160.4, 162.0; MS: m/z (%) 404 (M$^+$, 100), 373 (10), 358 (5), 319 (20), 187 (5), 11 (20).

3.5. General procedure for the synthesis of compounds 9a,b

A mixture of 2-aminoprop-1-ene-1,1,3-tricarbonitrile (1, 1.32 g, 0.01 mol) and enaminone 8a,b (0.01 mol) in EtOH (10 mL) as a solvent was treated with piperidine (5 drops). The reaction mixture was refluxed for 4 hr. The mixture was cooled and then poured onto ice-water. The solid so formed was collected by filtration and recrystallized from EtOH to give yellow crystals.

6-Amino-2-dicyanomethylene-4-phenyl-2,3-dihydro-pyridine-3,5-dicarbonitrile (9a). Yield 82%; m.p. 195–197 °C; Anal. Calcd. for C$_{16}$H$_8$N$_6$ (284.28): C, 67.60; H, 2.84; N, 29.56%. Found: C, 67.43; H, 2.61; N, 29.33%; IR (KBr, cm$^{-1}$): 3,467, 3,323 (NH$_2$), 3,222 (NH), 2,314, 2,219 (4CN); $^1$H-NMR: $\delta$, ppm = 7.52–7.61 (7H, m, Ar-H, NH$_2$, D$_2$O exchangeable), 8.19 (1H, br. s, NH, D$_2$O exchangeable); $^{13}$C-NMR: $\delta$, ppm = 160.35, 158.81, 158.71, 133.82, 130.47, 128.76 (2C), 128.67, 128.36 (2C), 116.10, 114.60, 113.5, 95.29, 89.17; MS: m/z (%) 284 (M$^+$, 100), 257 (25), 219 (10), 165 (25), 127 (10), 77 (5).

2-[6-Amino-3-aminoethynyl-5-cyano-4-(4-methoxy-phenyl)-1H-pyridin-2-ylidene]malononitrile (9b). Yield 82%; m.p. 248–250 °C; Anal. Calcd. for C$_{17}$H$_{10}$N$_6$O (314.31): C, 64.96; H, 3.21; N, 26.74%. Found: C, 65.01; H, 3.22; N, 26.44%; IR (KBr, cm$^{-1}$): 3,423, 3,327 (NH$_2$), 3,222 (NH), 2,314, 2,219 (4CN); $^1$H-NMR: $\delta$, ppm = 3.82 (s, 3H, OCH$_3$), 6.86 (br, 2H, NH$_2$, D$_2$O exchangeable), 7.04 (2H, d, J = 8.0, H-3',5'), 7.35 (2H, d, J = 8.0, H-2',6') , 8.22 (1H, br. s, NH, D$_2$O exchangeable); $^{13}$C-NMR: $\delta$, ppm = 162.95, 160.23, 159.47, 158.97, 133.45, 130.19 (2C), 127.80, 121.39, 117.24, 116.92, 113.82 (2C), 85.26, 80.48, 55.31; MS: m/z (%) 284 (M$^+$, 100), 257 (25), 219 (10), 165 (25), 127 (10), 77 (5).
3.6. Synthesis of 3,5-Diaminobiphenyl-2,4,6-tricarbonitrile (10)

A mixture of 2-aminoprop-1-ene-1,1,3-tricarbonitrile (1, 1.32 g, 0.01 mol) and benzylidene-malononitrile (8, 0.01 mol) in AcOH (10 cm) and 0.2 gm of NH₄OAc, was kept under reflux temperature for 3 hr. The mixture was cooled and then poured onto ice-water. The solid so formed was collected by filtration and recrystallized from EtOH to give yellow crystals; yield 80%; m.p. 290–292 °C; Anal. Calcd. for C_{15}H_{9}N_{5} (259.27): C, 69.49; H, 3.50; N, 27.01%. Found: C, 69.62; H, 3.34; N, 27.17%; IR (KBr, cm⁻¹): 3,371, 3,305 (NH₂), 3,265, 3,213 (NH₂), 2,218 (3CN);¹H NMR: δ, ppm = 4.51 (br. s, 4H, 2NH₂, D₂O exchangeable), 7.41–7.44 (2H, m, H-3',5'), 7.50–7.53 (3H, m, H-2',4',6');¹³C NMR: δ, ppm = 160.92 (2C), 157.07, 135.08, 129.92, 128.49 (2C), 128.21 (2C), 115.61 (2C), 85.65, 81.06, 75.95, 66.31; MS: m/z (%) 259 (M⁺, 100), 234 (20), 205 (15), 165 (20), 127 (10), 77 (50).

3.7. Synthesis of 2-(4-Amino-7-cyano-3,9-diphenylpyrido[1,2-a]pyrimidin-6-ylidene)-malononitrile (14)

A mixture of 2-aminoprop-1-ene-1,1,3-tricarbonitrile (1, 1.32 g, 0.01 mol) and 2-phenyl-3-piperidin-1-yl-acrylonitrile (11, 0.01 mol) in dioxane (10 mL) was kept under reflux temperature for 3–4 hrs. The mixture was cooled and then poured onto ice-water. The solid so formed was collected by filtration and recrystallized from AcOH to give yellow crystals; yield 85%; m.p. 270–272 °C; Anal. Calcd. for C_{24}H_{14}N_{6} (386.42): C, 64.60; H, 3.65; N, 21.75%. Found: C, 64.48; H, 3.55; N, 21.90%; IR (KBr, cm⁻¹): 3,383, 3,186 (NH₂), 2,237, 2,196 (3CN);¹H-NMR: δ, ppm = 6.82 (2H, br. s, NH₂, D₂O exchangeable), 7.24–7.52 (m, 12H, Ar-H); MS: m/z (%) 386 (M⁺, 10), 379 (40), 337 (70), 319 (100), 278 (95), 259 (35), 251 (30), 210 (20), 179 (20), 155 (10), 140 (25), 115 (15), 140 (25), 115 (10), 77 (15), 59 (20).

3.8. Synthesis of 2-amino-4-(dimethylamino)buta-1,3-diene-1,1,3-tricarbonitrile (16)

A mixture of 2-aminoprop-1-ene-1,1,3-tricarbonitrile (1, 1.32 g, 0.01 mol) and DMFDMA (1.19 g, 0.01 mol) in dioxane (10 mL) was stirred for 3–4 hrs. The mixture then poured onto ice-water. The solid so formed was collected by filtration and recrystallized from AcOH to give yellow crystals; yield 90 % m.p. 189–190 °C. Anal. Calcd. for C_{9}H_{9}N_{5} (187.2): C, 57.74; H, 4.85; N, 37.41%. Found: C, 57.61; H, 4.57; N, 37.19%; IR (KBr, cm⁻¹): 3,344, 3,221 (NH₂), 2,57 (3H, s, CH₃), 7.19 (br. s, 2H, NH₂, D₂O exchangeable), 8.54 (1H, s, olefinic CH); MS: m/z (%) 187 (M⁺, 100), 172 (30), 159 (35), 144 (25), 122 (60), 117 (20), 97 (15), 95 (15), 81 (20), 67 (20), 57 (30).

3.9. Synthesis of 4,6-diamino-2H-pyrazolo[3,4-b]pyridine-5-carboxamide hydrazone (17)

A mixture of 13 (1.87 g, 0.01 mol) and hydrazine monohydrate (1.00 g, 0.02 mol) in EtOH (20 mL) was refluxed for 3–4. The mixture then poured onto ice-water. The solid so formed was collected by filtration and recrystallized from EtOH to give a faint yellow product; yield 87 %; m.p. 210–212 °C; Anal. Calcd. for C_{7}H_{10}N_{8} (206.21): C, 40.77; H, 4.89; N, 54.34%. Found: C, 40.58; H, 4.65; N, 54.05%; IR (KBr, cm⁻¹): complicated signals from 3,402 to 3,156 for (NH) and (4NH₂);¹H-NMR: δ, ppm = 5.34 (2H, br. s, NH₂, D₂O exchangeable), 5.97 (2H, br. s, NH₂, D₂O exchangeable), 7.10 (2H, br. s, NH₂, D₂O exchangeable), 7.29 (2H, br. s, NH₂, D₂O exchangeable), 8.00 (1H, s, H-3), 8.82 (1H,
br. s, NH, D\textsubscript{2}O exchangeable); MS: \textit{m/z} (%) 106 (M\textsuperscript{+}, 100), 190 (95), 174 (100), 159 (75), 145 (40), 109 (35), 92 (40), 77 (60), 67 (100).

4. Conclusions

We could successfully utilize 1 as precursor to a variety of polyfunctionally substituted aminoaromatics that seem of value as potential precursors to dyes and pharmaceuticals.

References

1. Fahmy, S.M.; Abed, N.M.; Mohareb, R.M.; Elnagdi, M.H. Activated nitriles in heterocyclic synthesis: Novel synthesis of pyridazines, pyridines, and isoxazoles. \textit{Synthesis} 1982, 6, 490-493.
2. Elmoghayar, M.R.H.; Ibraheim, M.K.A.; Elghandour, A.H.H.; Elnagdi, M.H. A novel synthesis of thiazolo[3,2-a] pyridine derivatives. \textit{Synthesis} 1981, 8, 635-637.
3. Elnagdi, M.H. Reaction with \textit{α}-cyanoethylhydrazine. I. Route for the preparation of pyrazolo[1,5-a] pyrimidines and pyrrolo[1,2-b] pyrazoles. \textit{Tetrahedron} 1974, 30, 2791-2796.
4. Erian, A.W. The chemistry of \textit{β}-enaminonitriles as versatile reagents in heterocyclic synthesis. \textit{Chem. Rev.} 1993, 93, 1991-2005.
5. Al-Matar, H.M.; Khalil, K.D.; Meier, H.; Kolshorn, H.; Elnagdi, M.H. Chitosan as heterogeneous catalyst in Michael additions: The reaction of cinnamonic acids with active methylene moieties and phenols. \textit{ARKIVOC} 2008, 16, 288-301.
6. Al-Awadi, N.A.; Abdelkhalik, M.M.; Abdelhamid, I.A.; Elnagdi, M.H. Pyrolytic methods in organic synthesis: Novel routes for the synthesis of 3-oxoalkanenitriles, 2-acyl anilines, and 2-aryloxy anilines. \textit{Synlett} 2007, 19, 2979-2982.
7. Saleh, M.A.; Moustafa, S.M.; Elnagdi, M.H. Green Synthetic approaches: Solventless synthesis of polyfunctionally substituted aromatics as potential versatile building blocks in organic synthesis utilizing enamines and enaminonitriles as precursors. \textit{Green Chem. Lett. Rev.} 2010, in print.
8. Taylor E.C., McKillop, A. \textit{The Chemistry of Cyclic Enaminonitriles and o-Amino-nitriles}; Interscience; New York, NY, USA, 1970; p. 415.
9. Freeman, F. Chemistry of malononitrile. \textit{Chem. Rev.} 1969, 69, 591.
10. Fatiadi, A.J. New applications of malononitrile in organic chemistry-part I. \textit{Synthesis} 1978, 165.
11. Hassani, A.A.; Abu Zeid, A.; Ghozlan, S.A.; Elnagdi, M.H. Enaminones as Building Blocks in Organic Synthesis: A Novel Route to Polyfunctionally Substituted Benzonitriles, Pyridines, Erythrazole and Diazepines. \textit{J. Heterocycl. Chem.} 2003, 40, 225-228.
12. Helmy, N.M. Synthesis of Polyfunctional Heterocycles Using Microwave As Environmentally Friendly Technique. PhD Thesis, Cairo University, Cairo, Egypt, 2006.

Sample Availability: Samples of the compounds 3a, 4a-d, 7, 9a-b, 10, 14 and 17 are available from the authors.

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