Supporting Information

Practical and Simple Synthesis of Substituted Quinolines by an HCl-DMSO System on a Large Scale: Remarkable Effect of the Chloride Ion

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General. IR spectra were recorded as thin films or as solids in KBr pellets. ^1H and ^{13}C NMR spectra were obtained with TMS as internal standard. Techniques of HMBC or HMQC were employed to assign signals. Column chromatography was performed on silica gel. Yields were determined by ^1H NMR using internal standards.

Materials. DMSO was predried by CaH_2 and distilled. DMF was predried by MS3A and distilled. THF were distilled from sodium with benzophenone. Dichloroethane was predried by P_2O_5 and distilled. HCl (4M in dioxane) and the imine **2a**, **2c**, and **2g** were purchased from Tokyo Kasei Kogyo (TCI). The imines **2b**, **2d**, **2e**, **2f**, **2h**, and **2i** were prepared by the previously described condensation of the aldehydes and amines.¹ HCl (aqueous, 10M), TiCl_4 , InCl_3 , $\text{Yb}(\text{OTf})_3$, pyridinium chloride, CF_3COOH , H_2SO_4 , $\text{CF}_3\text{SO}_3\text{H}$, amines **6a-6d** and carbonyl compounds **1a-f** were commercially available.

Reaction of heptanal (1a) and Benzyldeneaniline (2a) catalyzed by HCl under N_2 atmosphere. (Table 1, entry 1). To a stirred solution of heptanal (0.6 mmol) and benzyldeneaniline **2a** (0.6 mmol) in dry DMSO (2 mL) was added HCl (4M in dioxane) (0.03 mmol) under N_2 atmosphere. The reaction was stirred at 60 °C for 6 h. Aqueous NaHCO_3 (saturated, 10 mL) was added to the reaction mixture. The resulting mixture was extracted with Et_2O , and organic layer was dried over MgSO_4 . The solvent was evaporated under reduced pressure to give the crude products as the mixture of **3aa**, **4**, and **5**.

General Procedure for Quinoline Synthesis Using carbonyl compounds and imines (Table 3). The reaction flask was equipped with a drying tube (CaCl_2) in order to perform the reaction under air atmosphere. To a mixture of carbonyl compounds (0.6 mmol) and imines (0.72 mmol) in dry DMSO (2 mL) was added HCl (4M in dioxane) (0.03-0.3 mmol) and the reactions were performed under the conditions described in the Table 3. The reaction mixture was poured into NaHCO_3 aq. (10 mL) and water (20 mL). The solution was extracted with Et_2O (10 mL x 3). Collected organic layers were dried over MgSO_4 . The procedures of further purification for new compounds are shown in the Product Data section.

Large-Scale Synthesis of Quinoline 3aa Using heptanal (1a) and Benzyldeneaniline (2a) (Scheme 3). The reaction flask (300 mL) was equipped with a CaCl_2 -tube, and air bubbling was effectively performed through it (see below figure). To a mixture of heptanal (50 mmol) and benzyldeneaniline (60 mmol) in dry DMSO (150 mL) was added HCl (4M in dioxane) (0.625 mL, 2.5 mmol) under an air bubbling condition. After stirred for 6 h at 60 °C, the reaction mixture was poured into NaHCO_3 aq. (50 mL) and water (500 mL). The solution was extracted with Et_2O (100 mL x 3). Collected organic layers were dried over MgSO_4 . The solvent was evaporated under reduced pressure, and the residue was purified by flash column chromatography on silica gel. The solvents (500 mL of hexane, 500 mL of hexane/ EtOAc = 99/1, 300 mL of hexane/ EtOAc = 98/2, 300 mL of hexane/ EtOAc = 97/3, and 700 mL of hexane/ EtOAc = 95/5) eluted bnzylaniline **5** and then afforded the product **3aa** (10.0 g, 73%).

Large-Scale Synthesis of Quinoline 3ai Using heptanal (1a) and Benzyldene-2-methoxy-aniline (2i) (Scheme 3). The reaction was performed by the device described above. To a mixture of heptanal (50 mmol) and benzyldene-2-methoxy-aniline (60 mmol) in dry DMSO (150 mL) was added HCl (4M in dioxane) (0.625 mL, 2.5 mmol) under an air bubbling condition. After stirred for 6 h at 60 °C, the reaction mixture was poured into NaHCO₃ aq. (50 mL) and water (500 mL). The solution was extracted with Et₂O (100 mL x 3). Collected organic layers were evaporated under reduced pressure (without a rigorous removal of water), and the obtained solid was washed with cold hexane (100mL x 5) to give the product **3ai** (7.28 g, 48%).

Quinoline synthesis between butanal (1f) and arylamines (6a-d) (Scheme 2). The reaction performed under air atmosphere. To a mixture of arylamine (6a-d) (0.6 mmol) and butanal (1f) (1.5 mmol) in DMSO (2 mL) was added HCl (4M in dioxane) (0.03 mmol). After stirred for 6 h at 60 °C, the reaction mixture was poured into NaHCO₃ aq. (10 mL) and water (20 mL). The solution was extracted with Et₂O (10 mL x 3). Collected organic layers were evaporated under reduced pressure to give the crude product.

Product Data. The spectral data of **3ca**², **3fa**³, **3fb**³, **3fc**³, and **3fd**³ was in an excellent agreement with the reported data. The spectral data of **5** was in an excellent agreement with the sample which was commercially available. Spectral data for the products, **3aa**, **4**, **3ba**, **3ca**, **3da**, **3ab**, **3ac**, **3ad**, **3ae**, **3af**, **3ag**, **3ah**, and **3ai** are shown below. The experiments for the isolation of the products were employed in about fourfold scale.

3-Pentyl-2-phenylquinoline (3aa)

According to the general procedure, this compound was prepared from **1a**, **2a**, and HCl in DMSO to give the product as a white solid after column chromatography [solvent; hexane 100 mL and hexane/ethyl acetate = 95/5 (300 mL) and 90/10 (200mL)] on silica gel: mp: 43-44 °C; bp: 200 °C, 0.0023 mmHg; IR: (neat) 2958, 2924, 2858, 1489, 1454, 1419, 767, 702 cm⁻¹; ¹H

NMR: (400 MHz, CDCl₃) 8.13 (d, J = 8.5 Hz, 1H, 8-H), 8.01 (s, 1H, 4-H), 7.78 (d, J = 8.2 Hz, 1H, 5-H), 7.67-7.61 (m, 1H, 7-H), 7.56-7.39 (m, 6H, 6-H, *o*, *m* and *p*), 2.75 (t, J = 8.0 Hz, 2H, 1'-H₂), 1.57-1.47 (m, 2H, 2'-H₂), 1.27-1.15 (m, 4H, 3'-H₂ and 4'-H₂), 0.80 (t, J = 6.8 Hz, 3H, 5'-H₃); ¹³C NMR: (100 MHz, CDCl₃): 160.63 (s, C-2), 146.25 (s, C-8a), 140.84 (s, *i*), 135.58 (d, C-4), 133.99 (s, C-3), 129.15 (d, C-8), 128.67 (d, C-7), 128.64 (d, *o*), 128.16 (d, *m*), 127.93 (d, *p*), 127.53 (s, 4a), 126.79 (d, C-5), 126.23 (d C-6), 32.70 (t, C-1'), 31.37 (t, C-3'), 30.15 (t, C-2'), 22.20 (t, C-4'), 13.83 (q, C-5'); MS: (EI, 70 eV) m/z 275 (M⁺, 40), 274 (M⁺ - H, 33), 246 (M⁺ - CH₃CH₂, 11), 232 (M⁺ - CH₃CH₂CH₂, 100), 218 (M⁺ - CH₃CH₂CH₂CH₂, 36), 217 (M⁺ - CH₃CH₂CH₂CH₂ - H, 35); HRMS: (EI, 70 eV) calcd for C₂₀H₂₁N 275.1674 (M⁺) found for m/z 275.1668. Anal. Calcd for C₂₀H₂₁N: C, 87.23; H, 7.69; N, 5.09. Found C, 86.96; H, 7.54; N, 4.89.

3-Pentyl-2-phenylquinoline(4)

This compound was a side-product in the reaction of **1a** with **2a** under N₂ atmosphere, and was not purely isolated. The selected signals in the crude mixture were shown below: ¹H NMR: (400 MHz, CDCl₃) 6.93-6.86 (m, 2H), 6.62-6.56 (m, 1H), 6.29 (d, J = 7.7 Hz, 1H), 6.25 (s, 1H, 4-H), 5.07 (s, 1H, 2-H), 4.12-3.95 (brs, 1H, NH), 1.87 (t, J = 7.6 Hz, 2H, 1'-H₂), 0.85 (t, J = 6.8 Hz, 3H, 5'-H₃); ¹³C NMR: (100 MHz, CDCl₃) 60.65 (C-2), 33.92 (C-1'), 31.44, 26.58, 22.48, 13.99 (C-5'); MS: (EI, 70 eV) 277 (M⁺, 19), 276 (M⁺ - H, 10), 206 (M⁺ - CH₃CH₂CH₂CH₂CH₂, 55), 200 (M⁺ - C₆H₅, 100)

3-Benzyl-2-phenylquinoline(3ba)

According to the general procedure, this compound was prepared from **1b**, **2a**, and HCl in DMSO to give the product as a white solid after column chromatography [solvent; hexane 200 mL and hexane/ethyl acetate = 95/5 (300 mL) and 90/10 (100mL)] on silica gel: mp: 84-88 °C; IR: (neat) 3055, 3028, 1597, 1489, 1446, 1419, 1346, 1315, 1277, 918, 756, 733, 698 cm⁻¹; ¹H NMR: (400 MHz, CDCl₃) 8.14 (d, J = 8.5 Hz, 1H, 8-H), 7.92 (s, 1H, 4-H), 7.75 (d, J = 8.2 Hz, 1H, 5-H), 7.70-7.65 (m, 1H, 7-H), 7.53-7.38 (m, 6H, 6-H, Ar), 7.27-7.15 (m, 3H, Ar), 7.02-6.97 (m, 2H, *o'*), 4.13 (s, 2H, 3-CH₂Ph); ¹³C NMR: (100 MHz, CDCl₃) 160.60 (s, C-2), 146.53 (s, C-8a), 140.52 (s, *i*), 139.83 (s, *i'*), 136.88 (d, C-4), 132.37 (s, C-3), 129.18 (d, C-8), 129.03 (d,

C-7), 128.87 (d, *o'*), 128.74 (d), 128.36 (d), 128.18 (d), 128.08 (d, *p*), 127.39 (s, C-4a), 127.00 (d, C-5), 126.36 (d, C-6), 126.14 (d, *p'*), 38.98 (t, 3-CH₂Ph); MS: (EI, 70 eV) 295 (M⁺, 56), 294 (M⁺ - H, 100), 217 (M⁺ - C₆H₅, 12); HRMS: (EI, 70 eV) calcd for C₂₂H₁₇N 295.1361 (M⁺) found for m/z 295.1357. Anal. Calcd for C₂₀H₂₁N: C, 89.17; H, 5.80; N, 4.67. Found C, 89.46; H, 5.80; N, 4.74.

4-Methoxycarbonyl-2-phenylquinoline(3ea)

According to the general procedure, this compound was prepared from **1d**, **2a**, and HCl in DMSO to give the product as a white solid after column chromatography [solvent; hexane 200 mL and hexane/ethyl acetate = 99/1 (200 mL) and 98/2 (400mL) and 90/10 (100mL)] on silica gel: mp: 49-51 °C; IR: (neat) 1728 (C=O), 1593, 1346, 1250, 1203, 1149, 771, 694 cm⁻¹; ¹H NMR: (400 MHz, CDCl₃) 8.73 (d, *J* = 8.5 Hz, 1H, 5-H), 8.38 (s, 1H, 3-H), 8.23-8.16 (m, 3H, 8-H and *o*), 7.77-7.71 (m, 1H, 7-H), 7.62-7.57 (m, 1H, 6-H), 7.55-7.49 (m, 2H, *m*), 7.49-7.43 (m, 1H, *p*), 4.03 (s, 3H, OMe); ¹³C NMR: (100 MHz, CDCl₃) 166.45 (s, C=O), 156.29 (s, C-2), 148.98 (s, C-8a), 138.45 (s, *i*), 135.13 (s, C-4), 130.08 (d, C-8), 129.63 (d, C-7), 129.50 (d, *p*), 128.69 (d, *m*), 127.55 (d, C-6), 127.21 (d, *o*), 125.20 (d, C-5), 123.75 (s, C-4a), 120.05 (d, C-3), 52.45 (q, OMe); MS: (EI, 70 eV) 263 (M⁺, 68), 205 (M⁺ - COOMe + 1, 100), 204 (M⁺ - COOMe, 58); HRMS: (EI, 70 eV) calcd for C₁₇H₁₃NO₂ 263.0946 (M⁺) found for m/z 263.0948. Anal. Calcd for C₁₇H₁₃NO₂: C, 77.55; H, 4.98; N, 5.32. Found C, 77.27; H, 4.89; N, 5.27.

2-(4-Bromophenyl)-3-pentylquinoline(3ab)

According to the general procedure, this compound was prepared from **1a**, **2b**, and HCl in DMSO to give the product as a white solid after column chromatography [solvent; hexane 100 mL and hexane/ethyl acetate = 98/2 (200 mL) and 97/3 (200mL)] on silica gel: mp: 50-52 °C; IR: (neat) 2954, 2927, 2858, 1597, 1485, 1419, 1072, 1063, 910, 791, 756 cm⁻¹; ¹H NMR: (400 MHz, CDCl₃) 8.10 (d, *J* = 8.5 Hz, 1H, 8-H), 7.99 (s, 1H, 4-H), 7.76 (d, *J* = 8.2 Hz, 1H, 5-H), 7.66-7.58 (m, 3H, 7-H), 7.59 (d, *J* = 8.4 Hz, 2H, *m*), 7.51-7.45 (m, 1H, 6-H), 7.41 (d, *J* = 8.4 Hz, 2H, *o*), 2.71 (t, *J* = 8.0 Hz, 2H, 1'-H₂), 1.57-1.46 (m, 2H, 2'-H₂), 1.28-1.16 (m, 4H, 3'-H₂ and 4'-H₂), 0.82 (t, *J* = 6.8 Hz, 3H, 5'-H₃); ¹³C NMR: (100 MHz, CDCl₃) 159.15 (s, C-2), 146.19 (s, C-8a), 139.68 (s, *i*), 135.70 (d, C-4), 133.58 (s, C-3), 131.22 (d, *m*), 130.36 (d, *o*), 129.03 (d, C-8), 128.76 (d, C-7), 127.48 (s, C-4a), 126.76 (d, C-5), 126.37 (d, C-6), 122.22 (s, *p*), 32.55 (t, C-1'),

31.28 (t, C-3'), 30.08 (t, C-2') 22.15 (t, C-4'), 13.77 (q, C-5'); MS: (EI, 70 eV) 355 ($M^+ + 2$, 42), 354 ($M^+ - H + 2$, 38), 353 (M^+ , 42), 352 ($M^+ - H$, 30), 326 ($M^+ - CH_3CH_2 + 2$, 11), 324 ($M^+ - CH_3CH_2$, 11), 312 ($M^+ - CH_3CH_2CH_2 + 2$, 94), 310 ($M^+ - CH_3CH_2CH_2$, 97), 298 ($M^+ - CH_3CH_2CH_2CH_2 + 2$, 11), 296 ($M^+ - CH_3CH_2CH_2CH_2$, 10), 230 ($M^+ - Br - CH_3CH_2CH_2 - H$, 15), 217 ($M^+ - Br - CH_3CH_2CH_2CH_2$, 100), 216 ($M^+ - Br - CH_3CH_2CH_2CH_2 - H$, 50); HRMS: (EI, 70 eV) calcd for $C_{20}H_{20}BrN$ 353.0779 (M^+) found for m/z 353.0780. Anal. Calcd for $C_{20}H_{20}BrN$: C, 67.80; H, 5.69; N, 3.95. Found C, 67.76; H, 5.45; N, 4.03.

2-(4-Methoxyphenyl)-3-pentylquinoline(3ac)

According to the general procedure, this compound was prepared from **1a**, **2c**, and HCl in DMSO to give the product as a white solid after column chromatography [solvent; hexane 200 mL and hexane/ethyl acetate = 98/2 (300 mL) and 97/3 (200mL)] on silica gel: mp: 44-45 °C; IR: (neat) 2954, 2931, 1608, 1516, 1246, 1176, 841, 756 cm^{-1} ; 1H NMR: (400 MHz, $CDCl_3$) 8.11 (d, $J = 8.5$ Hz, 1H, 8-H), 7.99 (s, 1H, 4-H), 7.77 (d, $J = 8.2$ Hz, 1H, 5-H), 7.66-7.61 (m, 1H, 7-H), 7.52-7.46 (m, 1H, 6-H), 7.50 (d, $J = 8.7$ Hz, 2H, *o*), 7.03-6.98 7.77 (d, $J = 8.7$ Hz, 2H, *m*), 3.86 (s, 3H, OMe), 2.78 (t, $J = 8.0$ Hz, 2H, 1'-H₂), 1.59-1.49 (m, 2H, 2'-H₂), 1.29-1.18 (m, 4H, 3'-H₂ and 4'-H₂), 0.82 (t, $J = 6.9$ Hz, 3H, 5'-H₃); ^{13}C NMR: (100 MHz, $CDCl_3$) 160.29 (s, C-2), 159.43 (s, *p*), 146.35 (s, C-8a), 135.52 (d, C-4), 134.12 (s, C-3), 134.44 (s, *i*), 130.02 (d, *o*), 129.11 (d, C-8), 128.57 (d, C-7), 127.41 (s, C-4a), 126.77 (d, C-5), 126.06 (d, C-6), 113.61 (d, *m*), 55.26 (OMe), 32.83 (t, C-1'), 31.43 (t, C-3'), 30.16 (t, C-2') 22.26 (t, C-4'), 13.86 (q, C-5'); MS: (EI, 70 eV) 305 (M^+ , 54), 304 ($M^+ - H$, 32), 276 ($M^+ - CH_3CH_2$, 12), 263 ($M^+ - CH_3CH_2CH$, 23), 262 ($M^+ - CH_3CH_2CH_2$, 100), 248 ($M^+ - CH_3CH_2CH_2CH_2$, 16), 204 ($M^+ - CH_3CH_2CH_2CH_2CH - OMe$, 21); HRMS: (EI, 70 eV) calcd for $C_{21}H_{23}NO$ 305.1780 (M^+) found for m/z 305.1775. Anal. Calcd for $C_{21}H_{23}NO$: C, 82.58; H, 7.59; N, 4.59. Found C, 82.44; H, 7.64; N, 4.55.

2-(4-Carboxyphenyl)-3-pentylquinoline(3ad)

The reaction flask was equipped with a drying tube ($CaCl_2$) in order to perform the reaction under air atmosphere. To a mixture of heptanal (2.0 mmol) and 4-carboxybenzylideneaniline (2.4 mmol) in dry DMSO (7 mL) was added HCl (4M in dioxane) (0.1 mmol) under air atmosphere. After stirred for 6 h at 60 °C, the reaction mixture was poured into NaCl aq. (20 mL) and water (30 mL). The solution was extracted with Et_2O (10 mL x 3). Collected organic layers

were dried over MgSO_4 . The solvent was evaporated under reduced pressure, and the residue was purified by flash column chromatography [solvent; hexane 100 mL and hexane/ethyl acetate = 95/5 (400 mL) and 92.5/7.5 (200mL) and 90/10 (200mL) and 85/15 (200mL) and 80/20 (200mL) and 75/25 (200mL)] on silica gel: mp: 149-156 °C; IR: (KBr) 3467 (OH), 1693 (C=O), 1265, 1253, 775, 752 cm^{-1} ; ^1H NMR: (400 MHz, CDCl_3) 10.90-10.20 (brs, COOH, 1H, D₂O exchangeable), 8.24-8.19 (m, 3H, 8-H and *m*), 8.11 (s, 1H, 4-H), 7.84 (d, J = 8.2 Hz, 1H, 5-H), 7.73-7.66 (m, 1H, 7-H), 7.67 (d, J = 8.0 Hz, 2H, *o*), (7.60-7.53 (m, 1H, 6-H), 2.76 (t, J = 7.9 Hz, 2H, 1'-H₂), 1.59-1.48 (m, 2H, 2'-H₂), 1.29-1.17 (m, 4H, 3'-H₂ and 4'-H₂), 0.82 (t, J = 6.4 Hz, 3H, 5'-H₃); ^{13}C NMR: (100 MHz, CDCl_3) 170.72 (s, COOH), 159.45 (s, C-2), 145.80 (s, C-8a), 145.02 (s, *i*), 136.46 (d, C-4), 134.00 (s, C-3), 130.04 (d, *m*), 129.76 (s, *p*), 129.32 (d, C-7), 128.97 (d, *o*), 128.58 (d, C-8), 127.84 (s, C-4a), 126.98 (d, C-5), 126.86 (d, C-6), 32.62 (t, C-1'), 31.41 (t, C-3'), 30.26 (t, C-2') 22.28 (t, C-4'), 13.88 (q, C-5'); MS: (EI, 70 eV) 319 (M^+ , 45), 318 (M^+ - H, 40), 290 (M^+ - CH_3CH_2 + 2, 11), 276 (M^+ - $\text{CH}_3\text{CH}_2\text{CH}_2$, 100), 262 (M^+ - $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2$, 11), 218 (28), 217 (M^+ - $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2$ - COOH, 30), 216 (17); HRMS: (EI, 70 eV) calcd for $\text{C}_{21}\text{H}_{21}\text{NO}_2$ 319.1572 (M^+) found for m/z 319.1565. Anal. Calcd for $\text{C}_{21}\text{H}_{21}\text{NO}_2$: C, 78.97; H, 6.63; N, 4.39. Found C, 78.81; H, 6.43; N, 4.24.

6-Bromo-3-pentyl-2-phenylquinoline(3ae)

According to the general procedure, this compound was prepared from **1a**, **2e**, and HCl in DMSO to give the product as a white solid after column chromatography [solvent; hexane 200 mL and hexane/ethyl acetate = 97/3 (200 mL) and 96/4 (200mL) and 90/10 (100mL)] on silica gel: mp: 41-46 °C; IR: (neat) 2954, 2927, 2862, 1589, 1473, 918, 829, 760, 702 cm^{-1} ; ^1H NMR: (400 MHz, CDCl_3) 7.97 (d, J = 8.9 Hz, 1H, 8-H), 7.93 (d, J = 2.2 Hz, 1H, 5-H), 7.90 (s, 1H, 4-H), 7.69 (dd, J = 8.9 and 2.2 Hz, 1H, 7-H), 7.55-7.40 (m, 5H, Ar), 2.74 (t, J = 7.8 Hz, 2H, 1'-H₂), 1.56-1.45 (m, 2H, 2'-H₂), 1.26-1.14 (m, 4H, 3'-H₂ and 4'-H₂), 0.79 (t, J = 6.9 Hz, 3H, 5'-H₃); ^{13}C NMR: (100 MHz, CDCl_3) 161.01 (s, C-2), 144.80 (s, C-8a), 140.45 (s, *i*), 135.06 (s, C-3), 134.49 (d, C-4), 132.06 (d, C-7), 130.92 (d, C-8), 128.81 (d, C-5), 128.62 (s, C-4a), 128.55 (d, *o*), 128.22 (d, *m*), 128.14 (d, *p*), 120.04 (s, C-6), 32.69 (t, C-1'), 31.32 (t, C-3'), 30.01 (t, C-2') 22.18 (t, C-4'), 13.81 (q, C-5'); MS: (EI, 70 eV) 355 (M^+ + 2, 42), 354 (M^+ - H + 2, 41), 353 (M^+ , 42), 352 (M^+ - H, 31), 326 (M^+ - CH_3CH_2 + 2, 11), 324 (M^+ - CH_3CH_2 , 11), 312 (M^+ - $\text{CH}_3\text{CH}_2\text{CH}_2$ + 2, 97), 310 (M^+ - $\text{CH}_3\text{CH}_2\text{CH}_2$, 100), 298 (M^+ - $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2$ + 2, 21), 296 (M^+ - $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2$, 21), 217 (M^+ - Br - $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2$, 41), 216 (M^+ - Br - $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2$ - H, 37); HRMS: (EI, 70 eV) calcd for $\text{C}_{20}\text{H}_{20}\text{BrN}$ 353.0779 (M^+) found for m/z 353.0783. Anal. Calcd for $\text{C}_{20}\text{H}_{20}\text{BrN}$: C, 67.80; H, 5.69; N, 3.95. Found C, 67.75; H, 5.65; N, 3.93.

6-Methoxy-3-pentyl-2-phenylquinoline(3af)

According to the general procedure, this compound was prepared from **1a**, **2f**, and HCl in DMSO to give the product as a white solid after column chromatography [solvent; hexane 300 mL and hexane/ethyl acetate = 99/1 (200 mL) and 98/2 (500mL) and 97/3 (200mL) and 95/5 (600mL)] on silica gel: mp: 31-32 °C; IR: (neat) 2954, 2931, 2862, 1624, 1601, 1489, 1454, 1381, 1346, 1227, 1169, 1030, 910, 829, 764, 702 cm⁻¹; ¹H NMR: (400 MHz, CDCl₃) 8.02 (d, *J* = 9.2 Hz, 1H, 8-H), 7.89 (s, 1H, 4-H), 7.55-7.50 (m, 2H, *o*), 7.48-7.36 (m, 3H, *m* and *p*), 7.32 (dd, *J* = 9.2 and 2.8 Hz, 1H, 7-H), 7.03 (d, *J* = 2.8 Hz, 1H, 5-H), 3.87 (s, 3H, OMe), 2.72 (t, *J* = 7.8 Hz, 2H, 1'-H₂), 1.56-1.45 (m, 2H, 2'-H₂), 1.26-1.14 (m, 4H, 3'-H₂ and 4'-H₂), 0.80 (t, *J* = 6.6 Hz, 3H, 5'-H₃); ¹³C NMR: (100 MHz, CDCl₃) 158.02 (s, C-2), 157.52 (s, C-6), 142.31 (s, C-8a), 140.87 (s, *i*), 134.40 (d, C-4), 134.10 (s, C-3), 130.51 (d, C-8), 128.66 (d, *o*), 128.40 (s, C-4a), 128.04 (d, *m*), 127.67 (d, *p*), 121.33 (d, C-7), 104.14 (d, C-5), 55.26 (OMe), 32.60 (t, C-1'), 31.31 (t, C-3'), 30.11 (t, C-2') 22.14 (t, C-4'), 13.76 (q, C-5'); MS: (EI, 70 eV) 305 (M⁺, 64), 304 (M⁺ - H, 27), 276 (M⁺ - CH₃CH₂, 13), 263 (M⁺ - CH₃CH₂CH, 20), 262 (M⁺ - CH₃CH₂CH₂, 100), 248 (M⁺ - CH₃CH₂CH₂CH₂, 21), 205 (M⁺ - C₅H₉ - OMe, 22), 204 (M⁺ - C₅H₁₀ - OMe, 17); HRMS: (EI, 70 eV) calcd for C₂₁H₂₃NO 305.1780 (M⁺) found for *m/z* 305.1782. Anal. Calcd for C₂₁H₂₃NO: C, 82.58; H, 7.59; N, 4.59. Found C, 82.46; H, 7.58; N, 4.56.

6-Hydroxy-3-pentyl-2-phenylquinoline(3ag)

According to the general procedure, this compound was prepared from **1a**, **2g**, and HCl in DMSO to give the product as a white solid after column chromatography [solvent; hexane 100 mL and hexane/ethyl acetate = 95/5 (200 mL) and hexane/CH₂Cl₂ = 90/10 (200 mL) and hexane/ethyl acetate/CH₂Cl₂ = 9/1/1 (500 mL) and hexane/ethyl acetate/CH₂Cl₂ = 15/2/3 (200 mL)] on silica gel: mp: 190-193 °C; IR: (KBr) 3471 (OH), 2927, 1620, 1458, 1396, 1361, 1238, 825, 698 cm⁻¹; ¹H NMR: (400 MHz, CDCl₃) 9.40-8.90 (brs, 1H, OH, D₂O exchangeable), 7.90 (d, *J* = 8.9 Hz, 1H, 8-H), 7.82 (s, 1H, 4-H), 7.53-7.47 (m, 2H, *o*), 7.44-7.33 (m, 3H, *m* and *p*), 7.10 (dd, *J* = 8.9 and 2.7 Hz, 1H, 7-H), 6.91 (d, *J* = 2.7 Hz, 1H, 5-H), 2.70 (t, *J* = 7.8 Hz, 2H, 1'-H₂), 1.55-1.44 (m, 2H, 2'-H₂), 1.27-1.14 (m, 4H, 3'-H₂ and 4'-H₂), 0.80 (t, *J* = 6.9 Hz, 3H, 5'-H₃); ¹³C NMR: (100 MHz, CDCl₃) 157.10 (s, C-2), 155.69 (s, C-6), 140.52 (s, C-8a), 139.62 (s, *i*), 135.17 (d, C-4), 134.08 (s, C-3), 129.15 (s, C-4a), 128.76 (d, *o*), 128.60 (d, C-8), 128.11 (d, *m*), 128.11 (d, *p*), 122.39 (d, C-7), 108.16 (d, C-5), 32.51 (t, C-1'), 31.32 (t, C-3'), 30.12 (t, C-2') 22.17 (t, C-4'), 13.82 (q, C-5'); MS: (EI, 70 eV) 291 (M⁺, 52), 290 (M⁺ - H, 28), 262 (M⁺ -

CH₃CH₂, 12), 248 (M⁺ - CH₃CH₂CH₂, 100), 234 (M⁺ - CH₃CH₂CH₂CH₂, 33), 233 (M⁺ - CH₃CH₂CH₂CH₂ - H, 22); HRMS: (EI, 70 eV) calcd for C₂₀H₂₁NO 291.1623 (M⁺) found for m/z 291.1627. Anal. Calcd for C₂₀H₂₁NO: C, 82.44; H, 7.26; N, 4.81. Found C, 82.70; H, 7.24; N, 4.95.

2-Furyl-3-pentylquinoline(3ah)

According to the general procedure, this compound was prepared from **1a**, **2h**, and HCl in DMSO to give the product as a white solid after column chromatography [solvent; hexane 300 mL and hexane/ethyl acetate = 99/1 (200 mL) and 98/2 (500mL) and 97/3 (200mL) and 95/5 (600mL)] on silica gel: mp: 44-45 °C; IR: (neat) 2954, 2931, 2870, 1493, 1415, 1277, 1153, 1007, 914, 741 cm⁻¹; ¹H NMR: (400 MHz, CDCl₃) 8.12 (d, *J* = 8.5 Hz, 1H, 8-H), 7.98 (s, 1H, 4-H), 7.75 (d, *J* = 8.2 Hz, 1H, 5-H), 7.68-7.62 (m, 2H, 7-H and 4''-H), 7.52-7.46 (m, 1H, 6-H), 7.10 (dd, *J* = 3.4 and 0.73 Hz, 1H, 2''-H), 6.60 (dd, *J* = 3.4 and 1.7 Hz, 1H, 3''-H), 3.06 (t, *J* = 7.8 Hz, 2H, 1'-H₂), 1.73-1.64 (m, 2H, 2'-H₂), 1.46-1.31 (m, 4H, 3'-H₂ and 4'-H₂), 0.91 (t, *J* = 7.1 Hz, 3H, 5'-H₃); ¹³C NMR: (100 MHz, CDCl₃) 153.55 (s, C-1''), 148.25 (s, C-2), 145.94 (s, C-8a), 142.83 (d, C-4''), 136.00 (d, C-4), 132.65 (s, C-3), 128.60 (d, C-8), 128.35 (d, C-7), 126.80 (s, C-4a), 126.31 (d, C-5), 125.77 (d, C-6), 111.53 (d, C-2''), 111.17 (d, C-3''), 32.94 (t, C-1'), 31.30 (t, C-3'), 29.60 (t, C-2'), 21.99 (t, C-4'), 13.60 (q, C-5'); MS: (EI, 70 eV) 265 (M⁺, 100), 236 (M⁺ - CH₃CH₂, 22), 222 (M⁺ - CH₃CH₂CH₂, 37), 208 (M⁺ - CH₃CH₂CH₂CH₂, 37), 194 (M⁺ - CH₃CH₂CH₂CH₂CH₂, 21), 180 (86); HRMS: (EI, 70 eV) calcd for C₁₈H₁₉NO 265.1467 (M⁺) found for m/z 265.1471. Anal. Calcd for C₁₈H₁₉NO: C, 81.47; H, 7.22; N, 5.28. Found C, 81.37; H, 7.07; N, 5.24.

8-Methoxy-3-pentyl-2-phenylquinoline(3ai)

The reaction flask was equipped with a drying tube (CaCl₂) in order to perform the reaction under air atmosphere. To a mixture of heptanal (0.64 mmol) and benzylidene-2-methoxyaniline (0.78 mmol) in dry DMSO (2 mL) was added HCl (4M in dioxane) (0.03 mmol) under air atmosphere. After stirred for 6 h at 60 °C, the reaction mixture was poured into NaHCO₃ aq. (5 mL) and water (20 mL). The solution was extracted with Et₂O (10 mL x 3). Collected organic layers were dried over MgSO₄ and the solvent was evaporated under reduced pressure. The crude product was washed with hexsane, and the residue was filtrated to give the pure product. Further purification was performed by recrystallization in hexane/Et₂O: mp: 132-134 °C; IR: (KBr) 2947,

2924, 2854, 1558, 1462, 1346, 1265, 1157, 1099, 1011, 906, 760, 698 cm^{-1} ; ^1H NMR: (400 MHz, CDCl_3) 8.00 (s, 1H, 4-H), 7.58-7.54 (m, 2H, *o*), 7.47-7.35 (m, 5H, 5-H, 6-H, *m* and *p*), 7.00 (d, $J = 7.7$ Hz, 1H, 7-H), 4.05 (s, 3H, OMe), 2.76 (t, $J = 8.0$ Hz, 2H, 1'-H₂), 1.57-1.47 (m, 2H, 2'-H₂), 1.28-1.15 (m, 4H, 3'-H₂ and 4'-H₂), 0.80 (t, $J = 6.8$ Hz, 3H, 5'-H₃); ^{13}C NMR: (100 MHz, CDCl_3) 159.29 (s, C-2), 155.24 (s, C-8), 140.86 (s, *i*), 138.12 (s, C-8a), 135.48 (d, C-4), 134.44 (s, C-3), 129.00 (d, *o*), 128.59 (s, C-4a), 127.86 (d, *m*), 127.71 (d, C-6), 126.30 (d, *p*), 118.59 (d, C-5), 106.78 (d, C-7), 55.74 (OMe), 32.61 (t, C-1'), 31.25 (t, C-3'), 29.99 (t, C-2') 22.10 (t, C-4'), 13.74 (q, C-5'); MS: (EI, 70 eV) 305 (M^+ , 82), 304 ($\text{M}^+ - \text{H}$, 100), 276 ($\text{M}^+ - \text{CH}_3\text{CH}_2$, 39), 275 ($\text{M}^+ - \text{CH}_3\text{CH}_2 - \text{H}$, 19), 246 (13), 217 (15); HRMS: (EI, 70 eV) calcd for $\text{C}_{21}\text{H}_{23}\text{NO}$ 305.1780 (M^+) found for m/z 305.1771. Anal. Calcd for $\text{C}_{21}\text{H}_{23}\text{NO}$: C, 82.58; H, 7.59; N, 4.59. Found C, 82.35; H, 7.57; N, 4.54.

Reaction of **1a with $\text{CF}_3\text{SO}_3\text{H}$ and Bu_4NCl in DMSO-d_6 (formation of enol **1X**).**

To a solution of heptanal **1a** (0.1 mmol) in DMSO-d_6 (0.75 mL) in NMR tube was added $\text{CF}_3\text{SO}_3\text{H}$ (0.3 mmol), then no signal change for compound **1a** was observed (Chart A,B). After the addition of Bu_4NCl (0.3 mmol), the new signals corresponding to the enol **1X** appeared (Chart C). Correlation between H_a and H_b in **1X** was confirmed by ^1H -homospin decoupling spectrum. (A small amount of the chloroaldehyde **1Y** was formed, and it showed a good agreement with the authentic sample.) Unfortunately, we did not find **1X** in the reaction between **1a** and HCl (3 equiv) in DMSO-d_6 as standard conditions of our work. Further investigation about the effect of chloride ion in our system is underway.

Chart A. Authentic sample 1a (DMSO-d₆)

Chart B. 1a + CF₃SO₃H (3 equiv) (DMSO-d₆)

Chart C. 1a + CF₃SO₃H (3 equiv) + Bu₄NCl (3 equiv) (DMSO-d₆)

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^1H and ^{13}C NMR spectra

X-ray Structure Report for 3ba

Experimental

Data Collection

A colorless prismatic crystal of $C_{22}H_{17}N$ having approximate dimensions of 0.20 x 0.20 x 0.20 mm was mounted on a glass fiber. All measurements were made on a Rigaku AFC5R diffractometer with graphite monochromated Mo- $K\alpha$ radiation and a rotating anode generator.

Cell constants and an orientation matrix for data collection, obtained from a least-squares refinement using the setting angles of 16 carefully centered reflections in the range $20.60 < 2\theta < 22.88^\circ$ corresponded to a primitive monoclinic cell with dimensions:

$$\begin{aligned}a &= 13.878(3) \text{ \AA} \\b &= 5.461(3) \text{ \AA} \quad \beta = 94.71(1)^\circ \\c &= 21.321(2) \text{ \AA} \\V &= 1610.6(8) \text{ \AA}^3\end{aligned}$$

For $Z = 4$ and F.W. = 295.38, the calculated density is 1.22 g/cm^3 . The systematic absences of:

$$\begin{aligned}h0l: & h+l \pm 2n \\0k0: & k \pm 2n\end{aligned}$$

uniquely determine the space group to be:

P2₁/n (#14)

The data were collected at a temperature of $23 \pm 1^\circ\text{C}$ using the ω - 2θ scan technique to a maximum 2θ value of 50.0° . Omega scans of several intense reflections, made prior to data collection, had an average width at half-height of 0.31° with a take-off angle of 6.0° . Scans of $(1.68 + 0.30 \tan \theta)^\circ$ were made at a speed of $16.0^\circ/\text{min}$ (in omega). The weak reflections ($I < 10.0\sigma(I)$) were rescanned (maximum of 5 scans) and the counts were accumulated to ensure good counting statistics. Stationary background counts were recorded on each side of the reflection. The ratio of peak counting time to background counting time was 2:1. The diameter of the incident beam collimator was 1.0 mm, the crystal to detector distance was 258 mm, and the detector aperture was 9.0 x 13.0 mm (horizontal x vertical).

Data Reduction

Of the 2763 reflections which were collected, 2344 were unique ($R_{\text{int}} = 0.102$). The intensities of three representative reflection were measured after every 150 reflections. No decay correction was applied.

The linear absorption coefficient, μ , for Mo-K α radiation is 0.7 cm^{-1} . An empirical absorption correction based on azimuthal scans of several reflections was applied which resulted in transmission factors ranging from 0.96 to 1.00.

Structure Solution and Refinement

The structure was solved by direct methods¹ and expanded using Fourier techniques². The non-hydrogen atoms were refined anisotropically. Hydrogen atoms were refined isotropically. The final cycle of full-matrix least-squares

refinement³ was based on 2344 all reflections ($2\theta < 50.01$) and 276 variable parameters and converged (largest parameter shift was 1.15 times its esd) with unweighted and weighted agreement factors of:

$$R = \Sigma (F_o^2 - F_c^2) / \Sigma F_o^2 = 0.187$$

$$R_w = [(\Sigma w (F_o^2 - F_c^2)^2 / \Sigma w (F_o^2)^2)]^{1/2} = 0.239$$

$$R1 = \Sigma ||F_o| - |F_c|| / \Sigma |F_o| = 0.054 \quad \text{for } I > 2.0\sigma(I) \text{ data}$$

The standard deviation of an observation of unit weight⁴ was 1.54. The weighting scheme was based on counting statistics and included a factor ($p = 0.050$) to downweight the intense reflections. Plots of $\Sigma w (F_o^2 - F_c^2)^2$ versus F_o^2 reflection order in data collection, $\sin \theta/\lambda$ and various classes of indices showed no unusual trends. The maximum and minimum peaks on the final difference Fourier map corresponded to 0.26 and -0.27 e⁻/Å³, respectively.

Neutral atom scattering factors were taken from Cromer and Waber⁵. Anomalous dispersion effects were included in F_{calc} ⁶; the values for $\Delta f'$ and $\Delta f''$ were those of Creagh and McAuley⁷. The values for the mass attenuation coefficients are those of Creagh and Hubbel⁸. All calculations were performed using the *teXsan*⁹ crystallographic software package of Molecular Structure Corporation.

References

- (1) SIR92: Altomare, A., Burla, M.C., Camalli, M., Cascarano, M., Giacovazzo,

C., Guagliardi, A., Polidori, G., (1994). J. Appl. Cryst. 27, 435.

(2) DIRDIF94: Beurskens, P.T., Admiraal, G., Beurskens, G., Bosman, W.P., de Gelder, R., Israel, R. and Smits, J.M.M. (1994). The DIRDIF-94 program system, Technical Report of the Crystallography Laboratory, University of Nijmegen, The Netherlands.

(3) Least-Squares:

Function minimized: $\sum w(F_O^2 - F_C^2)^2$ where

$$w = 1/[\sigma^2(F_O^2)] = [\sigma_C^2(F_O^2) + (p(\text{Max}(F_O^2, 0) + 2F_C^2)/3)^2]^{-1}$$

$\sigma_C(F_O^2)$ = e.s.d. based on counting statistics

p = p-factor

(4) Standard deviation of an observation of unit weight:

$$[\sum w(|F_O| - |F_C|)^2 / (N_O - N_V)]^{1/2}$$

where: N_O = number of observations

N_V = number of variables

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Vol C, (A.J.C. Wilson, ed.), Kluwer Academic Publishers, Boston, Table 4.2.4.3, pages 200-206 (1992).

(9) teXsan: Crystal Structure Analysis Package, Molecular Structure Corporation (1985 & 1999).

EXPERIMENTAL DETAILS

A. Crystal Data

Empirical Formula	C ₂₂ H ₁₇ N
Formula Weight	295.38
Crystal Color, Habit	colorless, prismatic
Crystal Dimensions	0.20 X 0.20 X 0.20 mm
Crystal System	monoclinic
Lattice Type	Primitive
No. of Reflections Used for Unit	
Cell Determination (2 θ range)	16 (20.6 - 22.9 $^{\circ}$)
Omega Scan Peak Width at Half-height	0.31 $^{\circ}$
Lattice Parameters	a = 13.878(3) Å b = 5.461(3) Å c = 21.321(2) Å β = 94.71(1) $^{\circ}$ V = 1610.6(8) Å ³
Space Group	P2 ₁ /n (#14)
Z value	4
D _{calc}	1.218 g/cm ³
F ₀₀₀	624.00
μ (MoK α)	0.70 cm ⁻¹

B. Intensity Measurements

Diffractometer	Rigaku AFC5R (rotating anode)
Radiation	MoK α (λ = 0.71069 Å)
	graphite monochromated
Attenuator	Zr foil (factors = 1.00, 3.22, 10.70,
	35.51)
Temperature	23.0 °C
Collimator Size	1.0 mm
Take-off Angle	6.0°
Detector Aperture	9.0 mm horizontal
	13.0 mm vertical
Crystal to Detector Distance	258 mm
Scan Type	ω -2 θ
Scan Rate	16.0°/min (in ω) (up to 5 scans)
Scan Width	(1.68 + 0.30 tan θ)°
2 $\theta_{\max}$	50.0°
No. of Reflections Measured	Total: 2763
	Unique: 2344 (R_{int} = 0.102)
Corrections	Lorentz-polarization
	Absorption
	(trans. factors: 0.9638 - 0.9988)

C. Structure Solution and Refinement

Structure Solution	Direct Methods (SIR92)
Refinement	Full-matrix least-squares

Function Minimized	$\Sigma w (F_o^2 - F_c^2)^2$
Least Squares Weights	$1/\sigma^2(F_o^2)$
p-factor	0.0500
Anomalous Dispersion	All non-hydrogen atoms
No. of Reflections (All, $2\sigma < 50.01^\circ$)	2344
No. Variables	276
Reflection/Parameter Ratio	8.49
Residuals: R; Rw	0.187 ; 0.239
Residuals: R1	0.054
No. of Reflections to calc R1	763
Goodness of Fit Indicator	1.54
Max Shift/Error in Final Cycle	1.146
Maximum peak in Final Diff. Map	0.26 e ⁻ / Å ³
Minimum peak in Final Diff. Map	-0.27 e ⁻ / Å ³

Table 1. Atomic coordinates and $B_{\text{iso}}/B_{\text{eq}}$

atom	x	y	z	B_{eq}
N(1)	0.1314 (4)	0.160 (1)	0.5017 (3)	4.3 (2)
C(1)	0.1862 (5)	0.335 (2)	0.5275 (3)	3.9 (2)
C(2)	0.1620 (5)	0.415 (2)	0.5921 (3)	3.8 (2)
C(3)	0.1091 (7)	0.623 (2)	0.5999 (4)	6.3 (3)
C(4)	0.0867 (6)	0.692 (2)	0.6603 (4)	6.2 (3)
C(5)	0.1196 (6)	0.556 (2)	0.7118 (4)	5.4 (3)
C(6)	0.1715 (6)	0.350 (2)	0.7039 (4)	6.0 (3)
C(7)	0.1928 (6)	0.277 (2)	0.6440 (4)	5.2 (2)
C(8)	0.2633 (5)	0.446 (2)	0.4977 (3)	4.5 (2)
C(9)	0.3255 (6)	0.637 (2)	0.5319 (4)	5.2 (3)
C(10)	0.3995 (5)	0.536 (2)	0.5808 (4)	4.5 (2)
C(11)	0.4181 (6)	0.651 (2)	0.6379 (4)	5.9 (3)
C(12)	0.4870 (7)	0.558 (2)	0.6826 (4)	6.7 (3)
C(13)	0.5368 (7)	0.347 (2)	0.6710 (5)	6.5 (3)
C(14)	0.5184 (6)	0.230 (2)	0.6145 (5)	6.4 (3)
C(15)	0.4503 (6)	0.324 (2)	0.5706 (4)	5.5 (3)
C(16)	0.2805 (6)	0.365 (2)	0.4396 (4)	5.2 (3)
C(17)	0.2247 (5)	0.177 (2)	0.4097 (3)	4.6 (2)
C(18)	0.2387 (7)	0.080 (2)	0.3508 (4)	6.8 (3)
C(19)	0.1840 (7)	-0.110 (2)	0.3254 (4)	6.6 (3)
C(20)	0.1098 (7)	-0.211 (2)	0.3589 (5)	6.8 (3)
C(21)	0.0942 (6)	-0.116 (2)	0.4164 (4)	5.5 (3)
C(22)	0.1502 (5)	0.074 (2)	0.4435 (3)	4.2 (2)
H(1)	0.087 (6)	0.72 (2)	0.565 (4)	8.6 (9)
H(2)	0.040 (8)	0.85 (2)	0.668 (5)	15.1 (6)
H(3)	0.097 (4)	0.60 (1)	0.755 (3)	6 (1)
H(4)	0.191 (6)	0.24 (2)	0.744 (4)	11.6 (7)
H(5)	0.238 (5)	0.15 (1)	0.640 (3)	5 (1)

H(6)	0.284(5)	0.76(1)	0.556(3)	6.4(10)
H(7)	0.358(5)	0.73(1)	0.504(3)	6.1(9)
H(8)	0.385(5)	0.80(2)	0.648(3)	6.7(8)
H(9)	0.500(5)	0.63(1)	0.724(3)	6(1)
H(10)	0.583(5)	0.28(2)	0.703(4)	7.7(9)
H(11)	0.555(6)	0.08(2)	0.605(4)	8.3(8)
H(12)	0.444(3)	0.258(9)	0.529(2)	1(1)
H(13)	0.333(5)	0.45(1)	0.420(3)	6.1(10)
H(14)	0.287(5)	0.14(2)	0.327(3)	6.6(9)
H(15)	0.193(5)	-0.18(2)	0.279(3)	7(1)
H(16)	0.072(5)	-0.35(1)	0.341(3)	6.7(9)
H(17)	0.041(4)	-0.16(1)	0.440(3)	5.5(10)

$$B_{eq} = 8/3 \pi^2 (U_{11}(aa^*)^2 + U_{22}(bb^*)^2 + U_{33}(cc^*)^2 + 2U_{12}(aa*bb*)\cos \gamma + 2U_{13}(aa*cc*)\cos \beta + 2U_{23}(bb*cc*)\cos \alpha)$$

Table 2. Anisotropic Displacement Parameters

atom	U ₁₁	U ₂₂	U ₃₃	U ₁₂	U ₁₃	U ₂₃
N(1)	0.049(4)	0.062(5)	0.051(4)	-0.002(4)	-0.003(3)	-0.006(4)
C(1)	0.047(5)	0.056(6)	0.044(4)	0.004(5)	0.002(4)	0.000(5)
C(2)	0.038(4)	0.046(6)	0.060(5)	-0.006(4)	0.004(4)	-0.002(5)
C(3)	0.099(7)	0.074(9)	0.068(7)	0.022(7)	0.012(5)	0.002(6)
C(4)	0.101(7)	0.056(7)	0.081(7)	0.014(6)	0.015(6)	-0.001(6)
C(5)	0.071(6)	0.076(8)	0.059(6)	-0.001(6)	0.006(5)	-0.010(6)
C(6)	0.076(6)	0.100(9)	0.053(6)	0.018(7)	0.015(4)	0.006(6)
C(7)	0.066(6)	0.073(7)	0.060(5)	0.031(5)	0.002(5)	0.005(6)
C(8)	0.048(5)	0.068(7)	0.054(5)	0.000(5)	0.009(4)	0.004(5)
C(9)	0.066(6)	0.058(7)	0.074(6)	-0.016(6)	0.012(5)	0.005(5)
C(10)	0.052(5)	0.049(6)	0.072(6)	-0.015(5)	0.014(4)	-0.005(5)
C(11)	0.080(7)	0.071(7)	0.072(6)	-0.010(6)	0.010(5)	-0.014(6)

C(12)	0.092(7)	0.11(1)	0.052(6)	-0.010(8)	-0.001(5)	-0.006(7)
C(13)	0.069(7)	0.085(9)	0.091(8)	-0.006(7)	0.005(6)	0.012(7)
C(14)	0.055(7)	0.078(9)	0.109(8)	-0.007(6)	0.009(6)	0.003(7)
C(15)	0.064(6)	0.074(8)	0.073(7)	-0.013(6)	0.008(5)	-0.010(6)
C(16)	0.059(6)	0.077(7)	0.064(6)	-0.009(6)	0.016(5)	0.002(6)
C(17)	0.057(6)	0.080(8)	0.039(5)	0.008(5)	0.005(4)	0.012(5)
C(18)	0.072(7)	0.13(1)	0.055(6)	0.007(8)	0.006(5)	-0.003(7)
C(19)	0.081(7)	0.124(10)	0.042(5)	0.024(7)	-0.014(5)	-0.025(7)
C(20)	0.070(7)	0.12(1)	0.068(7)	-0.001(7)	-0.017(5)	-0.021(7)
C(21)	0.063(6)	0.079(8)	0.063(6)	0.003(6)	-0.006(5)	-0.010(6)
C(22)	0.051(5)	0.068(7)	0.038(4)	0.004(5)	-0.006(4)	-0.001(5)

The general temperature factor expression:

$$\exp(-2\pi^2(a^2U_{11}h^2 + b^2U_{22}k^2 + c^2U_{33}l^2 + 2a*b*U_{12}hk + 2a*c*U_{13}hl + 2b*c*U_{23}kl))$$

Table 3. Bond Lengths (Å)

atom	atom	distance	atom	atom	distance
N(1)	C(1)	1.314(9)	N(1)	C(22)	1.371(8)
C(1)	C(2)	1.510(9)	C(1)	C(8)	1.424(9)
C(2)	C(3)	1.37(1)	C(2)	C(7)	1.377(9)
C(3)	C(4)	1.40(1)	C(3)	H(1)	0.94(8)
C(4)	C(5)	1.37(1)	C(4)	H(2)	1.1(1)
C(5)	C(6)	1.35(1)	C(5)	H(3)	1.03(6)
C(6)	C(7)	1.39(1)	C(6)	H(4)	1.05(9)
C(7)	H(5)	0.95(7)	C(8)	C(9)	1.50(1)
C(8)	C(16)	1.357(10)	C(9)	C(10)	1.51(1)
C(9)	H(6)	1.05(7)	C(9)	H(7)	0.93(7)
C(10)	C(11)	1.38(1)	C(10)	C(15)	1.38(1)

C(11)	C(12)	1.39(1)	C(11)	H(8)	0.98(8)
C(12)	C(13)	1.38(1)	C(12)	H(9)	0.98(7)
C(13)	C(14)	1.37(1)	C(13)	H(10)	0.98(8)
C(14)	C(15)	1.37(1)	C(14)	H(11)	0.98(8)
C(15)	H(12)	0.95(4)	C(16)	C(17)	1.41(1)
C(16)	H(13)	0.98(7)	C(17)	C(18)	1.39(1)
C(17)	C(22)	1.423(9)	C(18)	C(19)	1.37(1)
C(18)	H(14)	0.94(7)	C(19)	C(20)	1.41(1)
C(19)	H(15)	1.09(7)	C(20)	C(21)	1.36(1)
C(20)	H(16)	0.99(8)	C(21)	C(22)	1.40(1)
C(21)	H(17)	0.97(6)			

Table 4. Bond Angles($^{\circ}$)

atom	atom	atom	angle	atom	atom	atom	angle
C(1)	N(1)	C(22)	118.7(6)	N(1)	C(1)	C(2)	115.4(6)
N(1)	C(1)	C(8)	123.6(7)	C(2)	C(1)	C(8)	121.0(7)
C(1)	C(2)	C(3)	120.8(7)	C(1)	C(2)	C(7)	119.8(8)
C(3)	C(2)	C(7)	119.4(7)	C(2)	C(3)	C(4)	119.7(8)
C(2)	C(3)	H(1)	120(5)	C(4)	C(3)	H(1)	119(5)
C(3)	C(4)	C(5)	120.4(9)	C(3)	C(4)	H(2)	122(5)
C(5)	C(4)	H(2)	117(5)	C(4)	C(5)	C(6)	119.7(9)
C(4)	C(5)	H(3)	119(3)	C(6)	C(5)	H(3)	120(4)
C(5)	C(6)	C(7)	120.5(9)	C(5)	C(6)	H(4)	117(5)
C(7)	C(6)	H(4)	121(5)	C(2)	C(7)	C(6)	120.3(8)
C(2)	C(7)	H(5)	119(4)	C(6)	C(7)	H(5)	119(3)
C(1)	C(8)	C(9)	120.1(7)	C(1)	C(8)	C(16)	117.6(8)
C(9)	C(8)	C(16)	122.2(8)	C(8)	C(9)	C(10)	114.3(8)
C(8)	C(9)	H(6)	111(4)	C(8)	C(9)	H(7)	110(4)
C(10)	C(9)	H(6)	105(3)	C(10)	C(9)	H(7)	107(4)

H(6)	C(9)	H(7)	107(6)	C(9)	C(10)	C(11)	120.7(9)
C(9)	C(10)	C(15)	121.8(8)	C(11)	C(10)	C(15)	117.5(9)
C(10)	C(11)	C(12)	120.5(10)	C(10)	C(11)	H(8)	121(4)
C(12)	C(11)	H(8)	117(4)	C(11)	C(12)	C(13)	120.7(10)
C(11)	C(12)	H(9)	122(4)	C(13)	C(12)	H(9)	116(4)
C(12)	C(13)	C(14)	119.3(10)	C(12)	C(13)	H(10)	120(4)
C(14)	C(13)	H(10)	119(5)	C(13)	C(14)	C(15)	119(1)
C(13)	C(14)	H(11)	120(4)	C(15)	C(14)	H(11)	119(5)
C(10)	C(15)	C(14)	122.4(10)	C(10)	C(15)	H(12)	117(3)
C(14)	C(15)	H(12)	119(3)	C(8)	C(16)	C(17)	121.4(8)
C(8)	C(16)	H(13)	115(4)	C(17)	C(16)	H(13)	123(4)
C(16)	C(17)	C(18)	125.0(9)	C(16)	C(17)	C(22)	117.0(7)
C(18)	C(17)	C(22)	118.0(9)	C(17)	C(18)	C(19)	122.0(9)
C(17)	C(18)	H(14)	120(4)	C(19)	C(18)	H(14)	117(4)
C(18)	C(19)	C(20)	119.9(9)	C(18)	C(19)	H(15)	122(4)
C(20)	C(19)	H(15)	117(3)	C(19)	C(20)	C(21)	118.9(10)
C(19)	C(20)	H(16)	119(4)	C(21)	C(20)	H(16)	121(4)
C(20)	C(21)	C(22)	122.0(9)	C(20)	C(21)	H(17)	123(4)
C(22)	C(21)	H(17)	114(4)	N(1)	C(22)	C(17)	121.7(8)
N(1)	C(22)	C(21)	119.2(8)	C(17)	C(22)	C(21)	119.1(8)

Table 5. Torsion Angles($^{\circ}$)

atom	atom	atom	atom	angle	atom	atom	atom	atom	angle
N(1)	C(1)	C(2)	C(3)	-100.1(9)	N(1)	C(1)	C(2)	C(7)	79.4(8)
N(1)	C(1)	C(8)	C(9)	-177.1(7)	N(1)	C(1)	C(8)	C(16)	0(1)
N(1)	C(22)	C(17)	C(16)	2(1)	N(1)	C(22)	C(17)	C(18)	-179.7(7)
N(1)	C(22)	C(21)	C(20)	-179.5(8)	C(1)	N(1)	C(22)	C(17)	-2.5(10)
C(1)	N(1)	C(22)	C(21)	178.3(7)	C(1)	C(2)	C(3)	C(4)	179.3(8)
C(1)	C(2)	C(7)	C(6)	179.6(7)	C(1)	C(8)	C(9)	C(10)	77.1(10)

C(1)	C(8)	C(16)	C(17)	0(1)	C(2)	C(1)	N(1)	C(22)	-178.8(7)
C(2)	C(1)	C(8)	C(9)	3(1)	C(2)	C(1)	C(8)	C(16)	-179.8(8)
C(2)	C(3)	C(4)	C(5)	1(1)	C(2)	C(7)	C(6)	C(5)	0(1)
C(3)	C(2)	C(1)	C(8)	79.7(9)	C(3)	C(2)	C(7)	C(6)	0(1)
C(3)	C(4)	C(5)	C(6)	-1(1)	C(4)	C(3)	C(2)	C(7)	0(1)
C(4)	C(5)	C(6)	C(7)	0(1)	C(7)	C(2)	C(1)	C(8)	-100.8(9)
C(8)	C(1)	N(1)	C(22)	1(1)	C(8)	C(9)	C(10)	C(11)	-139.5(8)
C(8)	C(9)	C(10)	C(15)	39(1)	C(8)	C(16)	C(17)	C(18)	-178.7(8)
C(8)	C(16)	C(17)	C(22)	0(1)	C(9)	C(8)	C(16)	C(17)	176.6(8)
C(9)	C(10)	C(11)	C(12)	-179.5(8)	C(9)	C(10)	C(15)	C(14)	179.6(8)
C(10)	C(9)	C(8)	C(16)	-99.8(9)	C(10)	C(11)	C(12)	C(13)	0(1)
C(10)	C(15)	C(14)	C(13)	0(1)	C(11)	C(10)	C(15)	C(14)	0(1)
C(11)	C(12)	C(13)	C(14)	0(1)	C(12)	C(11)	C(10)	C(15)	0(1)
C(12)	C(13)	C(14)	C(15)	0(1)	C(16)	C(17)	C(18)	C(19)	177.5(9)
C(16)	C(17)	C(22)	C(21)	-178.7(7)	C(17)	C(18)	C(19)	C(20)	0(1)
C(17)	C(22)	C(21)	C(20)	1(1)	C(18)	C(17)	C(22)	C(21)	0(1)
C(18)	C(19)	C(20)	C(21)	0(1)	C(19)	C(18)	C(17)	C(22)	0(1)
C(19)	C(20)	C(21)	C(22)	0(1)					

Table 6. Non-bonded Contacts out to 3.60 Å

atom	atom	distance	atom	atom	distance
N(1)	H(17) ¹⁾	2.78(6)	N(1)	H(1) ²⁾	2.86(9)
N(1)	H(6) ²⁾	3.20(7)	N(1)	H(1) ³⁾	3.30(8)
C(1)	H(17) ¹⁾	3.41(7)	C(1)	H(6) ²⁾	3.46(8)
C(2)	H(17) ¹⁾	3.16(7)	C(3)	H(16) ¹⁾	3.26(7)
C(3)	H(17) ¹⁾	3.32(7)	C(3)	H(5) ⁴⁾	3.45(7)
C(4)	H(16) ¹⁾	2.88(8)	C(4)	H(5) ⁴⁾	3.31(7)

C(4)	C(7) ⁴⁾	3.55(1)	C(4)	H(4) ⁵⁾	3.57(8)
C(5)	H(4) ⁵⁾	2.91(8)	C(5)	H(16) ¹⁾	3.01(7)
C(5)	H(9) ⁶⁾	3.22(7)	C(5)	H(8) ⁶⁾	3.30(7)
C(6)	H(4) ⁵⁾	3.02(9)	C(6)	H(9) ⁶⁾	3.17(7)
C(6)	H(8) ⁶⁾	3.32(7)	C(6)	H(2) ²⁾	3.3(1)
C(6)	H(16) ¹⁾	3.43(7)	C(6)	H(3) ⁶⁾	3.53(6)
C(7)	H(2) ²⁾	3.2(1)	C(9)	H(12) ⁷⁾	3.59(5)
C(10)	H(12) ⁷⁾	3.51(5)	C(11)	H(4) ⁵⁾	3.09(9)
C(11)	H(11) ⁴⁾	3.14(9)	C(11)	H(3) ⁵⁾	3.36(7)
C(11)	C(14) ⁴⁾	3.51(1)	C(12)	H(3) ⁶⁾	3.11(7)
C(12)	H(4) ⁵⁾	3.20(9)	C(12)	H(2) ⁶⁾	3.4(1)
C(12)	H(15) ⁸⁾	3.44(7)	C(12)	H(13) ⁷⁾	3.46(7)
C(12)	H(3) ⁵⁾	3.48(7)	C(12)	H(11) ⁴⁾	3.48(9)
C(12)	H(14) ⁷⁾	3.55(7)	C(13)	H(3) ⁶⁾	2.87(7)
C(13)	H(13) ⁷⁾	2.98(7)	C(13)	H(15) ⁸⁾	3.54(7)
C(14)	H(13) ⁷⁾	2.86(8)	C(14)	H(8) ²⁾	3.10(8)
C(14)	H(7) ⁷⁾	3.17(7)	C(14)	H(3) ⁶⁾	3.39(7)
C(14)	H(14) ⁹⁾	3.54(7)	C(15)	H(7) ⁷⁾	3.22(7)
C(15)	H(13) ⁷⁾	3.25(7)	C(15)	H(8) ²⁾	3.45(8)
C(15)	H(12) ⁷⁾	3.52(5)	C(16)	H(11) ⁹⁾	3.53(9)
C(17)	H(11) ⁹⁾	3.41(8)	C(17)	H(7) ²⁾	3.58(7)
C(17)	H(16) ⁴⁾	3.58(7)	C(18)	H(11) ⁹⁾	3.08(8)
C(18)	H(15) ¹⁰⁾	3.26(8)	C(18)	H(10) ⁹⁾	3.43(8)
C(19)	H(9) ¹¹⁾	3.20(7)	C(19)	H(10) ¹¹⁾	3.39(8)
C(19)	H(2) ³⁾	3.4(1)	C(19)	H(10) ⁹⁾	3.47(7)
C(19)	H(14) ¹²⁾	3.57(7)	C(20)	H(2) ³⁾	2.9(1)
C(20)	H(9) ¹¹⁾	3.16(7)	C(21)	H(2) ³⁾	2.9(1)
C(21)	H(1) ²⁾	3.30(8)	C(21)	H(1) ³⁾	3.37(9)
C(22)	H(6) ²⁾	3.38(7)	C(22)	H(1) ²⁾	3.41(9)
C(22)	H(2) ³⁾	3.4(1)	C(22)	H(1) ³⁾	3.47(8)
C(22)	H(7) ²⁾	3.59(7)	H(1)	H(17) ⁴⁾	2.8(1)
H(1)	H(17) ³⁾	3.0(1)	H(1)	H(5) ⁴⁾	3.5(1)

H(1)	H(17) ¹⁾	3.5(1)	H(2)	H(9) ⁵⁾	2.9(1)
H(2)	H(17) ³⁾	3.0(1)	H(2)	H(16) ¹⁾	3.1(1)
H(2)	H(16) ³⁾	3.1(1)	H(2)	H(5) ⁴⁾	3.3(1)
H(2)	H(4) ⁴⁾	3.3(1)	H(2)	H(10) ⁵⁾	3.4(1)
H(3)	H(8) ⁶⁾	2.6(1)	H(3)	H(10) ⁵⁾	2.88(10)
H(3)	H(9) ⁶⁾	2.9(1)	H(3)	H(4) ⁵⁾	3.0(1)
H(3)	H(5) ⁵⁾	3.07(9)	H(3)	H(9) ⁵⁾	3.2(1)
H(3)	H(16) ¹⁾	3.28(9)	H(4)	H(8) ⁶⁾	2.6(1)
H(4)	H(9) ⁶⁾	2.9(1)	H(4)	H(4) ⁵⁾	3.18(8)
H(4)	H(4) ⁶⁾	3.18(8)	H(4)	H(5) ⁵⁾	3.4(1)
H(5)	H(8) ²⁾	2.8(1)	H(5)	H(6) ²⁾	2.9(1)
H(6)	H(12) ⁴⁾	3.59(9)	H(7)	H(11) ⁷⁾	2.9(1)
H(7)	H(12) ⁷⁾	2.89(8)	H(7)	H(12) ⁴⁾	3.16(9)
H(8)	H(11) ⁴⁾	3.0(1)	H(9)	H(15) ⁸⁾	2.83(10)
H(9)	H(16) ⁸⁾	2.9(1)	H(9)	H(14) ⁷⁾	3.45(10)
H(10)	H(14) ⁹⁾	3.0(1)	H(10)	H(15) ⁸⁾	3.1(1)
H(10)	H(15) ⁹⁾	3.15(10)	H(10)	H(13) ⁷⁾	3.3(1)
H(11)	H(14) ⁹⁾	2.8(1)	H(11)	H(13) ⁷⁾	3.1(1)
H(11)	H(13) ⁹⁾	3.4(1)	H(11)	H(12) ⁹⁾	3.41(10)
H(12)	H(12) ⁷⁾	3.35(10)	H(12)	H(12) ⁹⁾	3.49(10)
H(12)	H(13) ⁷⁾	3.57(8)	H(14)	H(15) ¹⁰⁾	2.5(1)
H(15)	H(15) ¹⁰⁾	3.43(8)	H(15)	H(15) ¹²⁾	3.43(8)
H(17)	H(17) ¹⁾	3.4(1)			

Symmetry operations

(1)	-X, -Y, -Z+1	(2)	X, Y-1, Z
(3)	-X, -Y+1, -Z+1	(4)	X, Y+1, Z

$$(5) \quad -X+1/2, Y+1/2, -Z+3/2$$

$$(7) \quad -X+1, -Y+1, -Z+1$$

$$(9) \quad -X+1, -Y, -Z+1$$

$$(11) \quad X-1/2, -Y+1/2, Z-1/2$$

$$(6) \quad -X+1/2, Y-1/2, -Z+3/2$$

$$(8) \quad X+1/2, -Y+1/2, Z+1/2$$

$$(10) \quad -X+1/2, Y+1/2, -Z+1/2$$

$$(12) \quad -X+1/2, Y-1/2, -Z+1/2$$