

Electronic Supplementary Information

Pyridine Synthesis by Reactions of Allyl Amines and Alkynes Proceeding through a Cu(OAc)₂ Oxidation and Rh(III)-Catalyzed N- Annulation Sequence

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1. General

Flash column chromatography was performed using E. Merck 230-400 mesh silica gel and column chromatography was monitored by analytical thin-layer chromatography (TLC) carried out on 0.25 Merck silica gel plates (60F-254) using UV light as a visualizing agent, *p*-anisaldehyde, ninhydrin and KMnO₄ solution as staining solutions, and heat as developing agent. Gas chromatographic analyses were performed on Agilent 7890A instrument with FID detector and an Agilent HP-5 capillary column. Mass chromatography analyses were performed on Agilent 5975C instrument and an Agilent HP-5MS column. IR spectra were recorded using a Bruker Vertex 70 FT-IR spectrometer. ¹H NMR and ¹³C NMR were recorded on a Bruker Advance II/DPX 400(400 MHz ¹H, 100 MHz ¹³C) spectrometers with chemical shifts reported relative to residual deuterated solvent peaks. ¹H NMR spectra were referenced to CDCl₃ (for ¹H, δ = 7.26) as internal standard, and are reported as follows: chemical shift multiplicity (br = broad, s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet). ¹³C NMR spectra were referenced to the residual CDCl₃ (for ¹³C, δ = 77.26) as internal standard]. High-resolution Mass spectra were provided by NCIRF Seoul national university.

2. Materials

Most commercially available reagent grade chemicals (**1a**, **1c**, **1e**, **2a**, **2b-2e** and **4**) were purchased from Aldrich Chemical Company, TCI, ACROS and Burdick & Jackson, and used as received without further purification unless otherwise stated. Reagents (**1b**,¹ **1d**,² and **1f**³) and Complexes [Cp*RhCl₂]₂ (**3**)⁴ were prepared according to the literature procedure and stored in a refrigerator under N₂ atmosphere.

3. Experiments

¹ D. N. Kimpe and D. D. Smaele, *Tetrahedron* 1995, **51**, 5465.

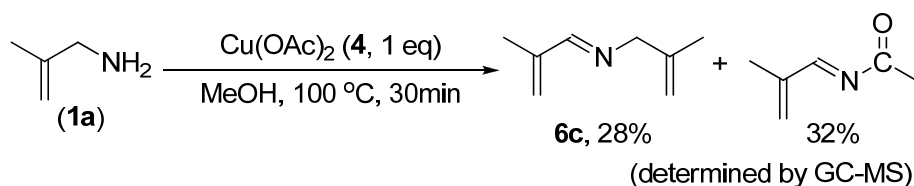
² A. M. Schmidt and P. Eilbracht, *J. Org. Chem.*, 2005, **70**, 5528.

³ A. I. Meyers, J. P. Lawson and D. R. Carver, *J. Org. Chem.*, 1981, **46**, 3119.

⁴ J. W. Kang, K. Moseley and P. M. Maitlis, *J. Am. Chem. Soc.* 1969, **91**, 5970..

- Evidence for dehydrogenation of allylamine by Cu(OAc)₂

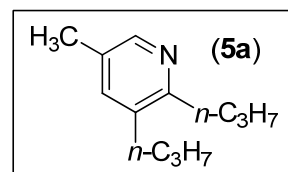
In order to investigate the formation of α,β -unsaturated imine by Cu(II)-promoted oxidation of allylamine, the reaction of 2-methylallylamine (**1a**) with 1 equivalent of Cu(OAc)₂ (**4**) at 100 °C for 30 min was carried out. The reaction resulted in the formation of 2-methyl-N-(2-methylallylidene)prop-2-en-1-amine (**6c**, 28% GC yield), which is identical to the authentic sample, prepared by methacrolein and 2-methylallylamine. This might be formed through Cu(OAc)₂ promoted oxidation of 2-methylallylamine (**1a**) to form **6a** and followed by transamination of **6a** with **1a**.



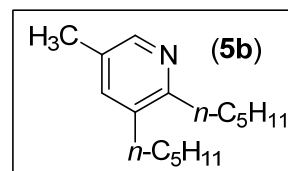
- A typical procedure for synthesis of pyridines from allyl amines and alkynes (Table 2, entry 1)

A 1 ml pressure vial was charged with 2-methylallylamine (**1a**, 14 mg (0.2 mmol)), 4-octyne (**2a**, 26.4 mg, (0.24 mmol)), [Cp**Rh*Cl₂]₂ (**3**, 1.5 mg (0.00625 mmol)), Cu(OAc)₂·H₂O (**4**, 80 mg (0.4 mmol)) and methanol (200 μ l). The reaction mixture was stirred at 100 °C preheated oil-bath for 4 hours. After cooling the vessel to room temperature, the crude mixture was purified by column chromatography (*n*-hexane:ethyl acetate = 2:1) on silica gel to give 5-methyl-2,3-dipropylpyridine (**5a**, 81.6mg, 92 %) as a pale yellow oil.

5-methyl-2,3-dipropylpyridine (5a) yellow oil, ¹H NMR (400 MHz, CDCl₃) δ 8.16 (d, *J* = 1.6 Hz, 1H), 7.17 (d, *J* = 1.7 Hz, 1H), 2.68 (t, *J* = 7.7 Hz, 2H), 2.51 (t, *J* = 7.7 Hz, 2H), 2.21 (s, 3H), 1.72-1.63 (m, 2H), 1.60-1.51 (m, 2H), 0.97-0.92 (m, 6H); ¹³C NMR (100 MHz, CDCl₃) δ 157.2, 147.1, 137.1, 134.7, 130.1, 36.6, 34.3, 24.0, 23.1, 18.0, 14.3, 14.2; IR spectrum (CDCl₃) 2960, 2931, 2871, 1734, 1565, 1459, 964 cm⁻¹; HR-MS(EI⁺) calcd for C₁₂H₁₉N [M]⁺ 177.1517; found 177.1513.

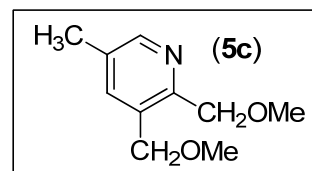


5-methyl-2,3-dipentylpyridine (5b) yellow oil, ¹H NMR (400 MHz, CDCl₃) δ 8.17 (s, 1H), 7.19 (s, 1H), 2.71 (t, *J* = 8.1 Hz, 2H), 2.53 (t, *J* = 8.0

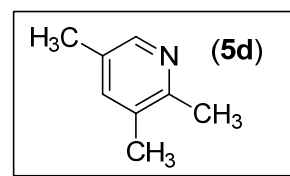


Hz, 2H), 2.23 (s, 3H), 1.68-1.62 (m, 2H), 1.56-1.52 (m, 2H), 1.35-1.33 (m, 8H), 0.91-0.86 (m, 6H); ^{13}C NMR (100 MHz, CDCl_3) δ 157.5, 147.1, 137.5, 134.9, 130.2, 34.7, 32.3, 32.2, 32.0, 30.7, 29.7, 22.8, 22.7, 18.1, 14.2, 14.1; IR spectrum (CDCl_3) 2957, 2928, 2859, 1602, 1564, 1461, 1379, 886, 726, 569 cm^{-1} ; HR-MS(EI+) calcd for $\text{C}_{16}\text{H}_{27}\text{N}$ $[\text{M}]^+$ 233.2143; found 233.2145.

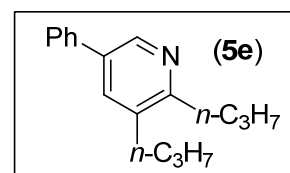
2,3-bis(methoxymethyl)-5-methylpyridine (5c) yellow oil, ^1H NMR (400 MHz, CDCl_3) δ 8.31 (s, 1H), 7.57 (s, 1H), 4.59 (s, 2H), 4.54 (s, 2H), 3.43 (s, 3H), 3.38 (s, 3H), 2.32 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 152.3, 148.5, 136.9, 132.9, 132.6, 74.3, 70.8, 58.8, 58.5, 18.3; IR spectrum (CDCl_3) 2928, 2873, 2823, 1729, 1440, 1378, 1300, 1099, 1086 cm^{-1} ; HR-MS(CI+) calcd for $\text{C}_{10}\text{H}_{16}\text{NO}_2$ $[\text{M}+\text{H}]^+$ 182.1176; found 182.1185.



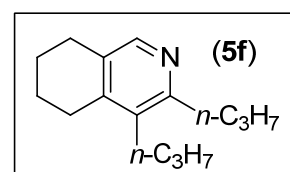
2,3,5-trimethylpyridine (5d) [CAS No. 695-98-7] colorless oil, ^1H NMR (400 MHz, CDCl_3) δ 8.11 (s, 1H), 7.17 (s, 1H), 2.41 (s, 3H), 2.22 (s, 3H), 2.20 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 154.1, 146.8, 138.0, 130.9, 130.5, 22.2, 19.1, 18.0.



5-phenyl-2,3-dipropylpyridine (5e) yellow oil, ^1H NMR (400 MHz, CDCl_3) δ 8.61 (d, $J = 2.2$ Hz, 1H), 7.60 (d, $J = 2.2$ Hz, 1H), 7.58-7.55 (m, 2H), 7.47-7.43 (m, 2H), 7.37 (tt, $J = 6.5$ Hz, 1.2 Hz, 1H), 2.83-2.79 (m, 2H), 2.68-2.64 (m, 2H), 1.83-1.74 (m, 2H), 1.72-1.62 (m, 2H), 1.03 (q, $J = 7.3$ Hz, 6H); ^{13}C NMR (100 MHz, CDCl_3) δ 159.3, 145.2, 138.4, 135.4, 135.3, 134.1, 129.1, 127.8, 127.2, 36.9, 34.5, 24.0, 23.1, 14.5, 14.3; IR spectrum (CDCl_3) 3060, 3028, 2960, 2930, 2870, 1601, 1456, 1392, 762, 697 cm^{-1} ; HR-MS(EI+) calcd for $\text{C}_{17}\text{H}_{21}\text{N}$ $[\text{M}]^+$ 239.1674; found 239.1670.

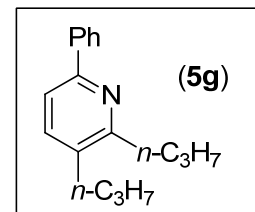


3,4-dipropyl-5,6,7,8-tetrahydroisoquinoline (5f) yellow oil, ^1H NMR (400 MHz, CDCl_3) δ 8.08 (s, 1H), 2.72-2.66 (m, 6H), 2.54-2.50 (m, 2H), 1.80-1.65 (m, 6H), 1.52-1.42 (m, 2H), 1.04-0.97 (m, 6H); ^{13}C NMR (100 MHz, CDCl_3) δ 157.0, 147.4, 144.3, 133.4, 130.3, 37.2, 30.3, 26.9, 26.1, 23.6, 23.3, 23.2, 22.4, 14.9, 14.6; IR spectrum (CDCl_3) 3043, 2930, 2870, 1693, 1581, 1561, 1456,

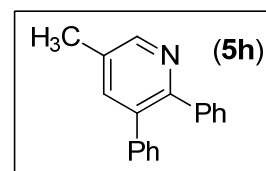


1436, 1407, 1357, 1255, 1196, 1089, 970, 781 cm^{-1} ; HR-MS(EI+) calcd for $\text{C}_{15}\text{H}_{23}\text{N}$ $[\text{M}]^+$ 217.1830; found 217.1833.

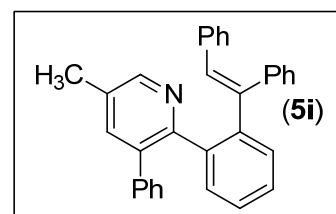
6-phenyl-2,3-dipropylpyridine (5g) yellow oil, ^1H NMR (400 MHz, CDCl_3) δ 8.00 (d, $J = 7.2$ Hz, 2H), 7.49-7.42 (m, 4H), 7.36 (t, $J = 7.3$ Hz, 1H), 2.84 (t, $J = 7.6$ Hz, 2H), 2.63 (t, $J = 7.6$ Hz, 2H), 1.91-1.81 (m, 2H), 1.69-1.60 (m, 2H), 1.06-0.99 (m, 6H); ^{13}C NMR (100 MHz, CDCl_3) δ 160.0, 154.3, 140.1, 137.5, 133.9, 128.8, 128.5, 126.9, 117.8, 37.1, 34.2, 24.0, 22.8, 14.5, 14.3; IR spectrum (CDCl_3) 3061, 3034, 2960, 2931, 2870, 1687, 1564, 1456, 1379, 756, 694 cm^{-1} ; HR-MS(EI+) calcd for $\text{C}_{17}\text{H}_{21}\text{N}$ $[\text{M}]^+$ 239.1674; found 239.1675.



5-methyl-2,3-diphenylpyridine (5h) [CAS No. 122801-45-0] white solid, mp = 125-126 $^\circ\text{C}$, ^1H NMR (400 MHz, CDCl_3) 8.52 (s, 1H), 7.54 (s, 1H), 7.34-7.32 (m, 2H), 7.26-7.21 (m, 6H), 7.18-7.16 (m, 2H), 2.42 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 154.7, 149.0, 140.3, 140.2, 139.3, 135.7, 131.8, 130.0, 129.7, 128.4, 128.0, 127.7, 127.3, 18.2.

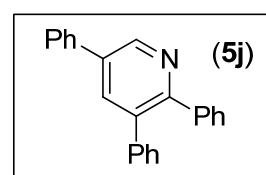


(E)-2-(2-(1,2-diphenylvinyl)phenyl)-5-methyl-3-phenylpyridine (5i) white solid, mp = 105-107 $^\circ\text{C}$, ^1H NMR (400 MHz, CDCl_3) δ 8.16 (s, 1H), 7.48 (d, $J = 7.4$ Hz, 1H), 7.38 (t, $J = 7.4$ Hz, 1H), 7.31-7.23 (m, 5H), 7.05-6.97 (m, 7H), 6.92 (t, $J = 7.4$, 2H), 6.79-6.78 (m, 2H), 6.42 (d, $J = 7.2$, 2H), 5.82 (s, 1H), 2.26 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ



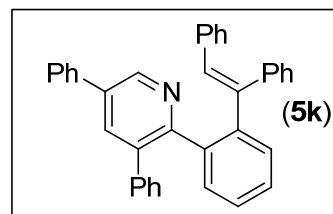
155.2, 148.4, 143.7, 142.0, 140.3, 140.1, 139.9, 138.1, 137.7, 135.9, 131.56, 131.52, 130.7, 130.5, 130.0, 129.7, 129.5, 128.3, 127.9, 127.8, 127.7, 127.0, 126.7, 126.6, 18.21; IR spectrum (CDCl_3) 3078, 3055, 3021, 2974, 2925, 2866, 2739, 1950, 1737, 1598, 1492, 1424, 1117, 759, 696 cm^{-1} ; HR-MS(EI+) calcd for $\text{C}_{32}\text{H}_{25}\text{N}$ $[\text{M}]^+$ 423.1987; found 423.1993

2,3,5-triphenylpyridine (5j) white solid, mp = 121-122 $^\circ\text{C}$, ^1H NMR (400 MHz, CDCl_3) δ 8.92 (d, $J = 1.9$ Hz, 1H), 7.92 (d, $J = 2.2$ Hz, 1H), 7.69-7.66 (m, 2H), 7.52-7.48 (m, 2H), 7.44-7.39 (m, 3H), 7.32-7.28 (m, 3H), 7.26-7.23



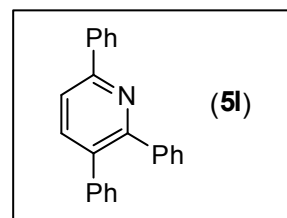
(m, 5H); ^{13}C NMR (100 MHz, CDCl_3) δ 156.1, 146.9, 140.1, 140.0, 137.6, 137.1, 136.1, 135.2, 130.1, 129.8, 129.3, 128.6, 128.4, 128.1, 128.0, 127.5, 127.3; IR spectrum (CDCl_3) 3057, 3027, 2924, 2854, 1452, 1428, 1390, 759, 668 cm^{-1} ; HR-MS(FAB+) calcd for $\text{C}_{23}\text{H}_{17}\text{N}$ $[\text{M}+\text{H}]^+$ 308.1434; found 308.1432.

(E)-2-(2-(1,2-diphenylvinyl)phenyl)-3,5-diphenylpyridine (5k) white solid, mp = 110 °C, ^1H NMR (400 MHz, CDCl_3) δ 8.48 (d, J = 1.7 Hz, 1H), 7.69 (d, J = 1.8 Hz, 1H), 7.55-7.49 (m, 3H), 7.47-7.42 (m, 3H), 7.40-7.28 (m, 5H), 7.15-7.11 (m, 3H), 7.04-7.03 (m, 3H), 6.99 (t, J = 7.3 Hz, 1H), 6.91 (t, J = 7.5 Hz, 2H), 6.81-6.79 (m, 2H), 6.51 (d, J = 7.1

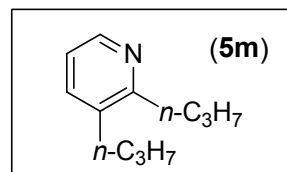


Hz, 2H), 5.83 (s, 1H); ^{13}C NMR (100 MHz, CDCl_3) δ 156.8, 146.3, 144.0, 142.1, 140.3, 139.9, 139.7, 138.0, 137.6, 136.5, 135.9, 135.1, 131.3, 130.74, 130.71, 129.9, 129.7, 129.6, 129.2, 128.4, 128.2, 128.1, 127.9, 127.8, 127.3, 127.2, 126.79, 126.73; IR spectrum (CDCl_3) 3057, 3025, 2952, 2931, 2856, 1598, 1492, 1424, 758, 696 cm^{-1} ; HR-MS(EI+) calcd for $\text{C}_{37}\text{H}_{27}\text{N}$ $[\text{M}]^+$ 485.2143; found 485.2150.

2,3,6-triphenylpyridine (5l) [CAS No. 37786-68-8] white solid, mp = 106-108 °C, ^1H NMR (400 MHz, CDCl_3) δ 8.16 (d, J = 7.2 Hz, 2H), 7.80-7.76 (m, 2H), 7.51-7.41 (m, 5H), 7.30-7.23 (m, 8H); ^{13}C NMR (100 MHz, CDCl_3) δ 156.8, 155.8, 140.6, 140.2, 139.6, 139.2, 134.6, 130.4, 129.7, 129.1, 128.9, 128.5, 128.0, 127.3, 127.2, 118.7.



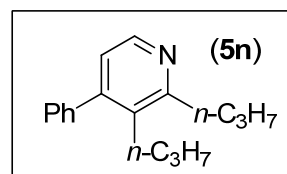
2,3-dipropylpyridine (5m) yellow oil, ^1H NMR (400 MHz, CDCl_3) δ 8.37 (d, J = 2.9 Hz, 1H), 7.40 (d, J = 7.6 Hz, 1H), 7.03 (dd, J = 7.4, 4.8 Hz, 1H), 2.76 (t, J = 7.7 Hz, 2H), 2.58 (t, J = 7.6 Hz, 2H), 1.78-1.68 (m, 2H), 1.65-



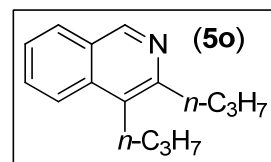
1.56 (m, 2H), 0.99 (q, J = 7.4 Hz, 6H); ^{13}C NMR (100 MHz, CDCl_3) δ 160.3, 146.7, 136.9, 135.5, 121.5, 37.0, 34.4, 24.0, 23.1, 14.4, 14.2; IR spectrum (CDCl_3) 3049, 2961, 2933, 2872, 1715, 1572, 1441, 1378, 1262, 1130, 1089, 789, 612 cm^{-1} ; HR-MS(EI+) calcd for $\text{C}_{11}\text{H}_{17}\text{N}$ $[\text{M}]^+$ 163.1361; found 163.1365.

- Characterization data for 5n and 5o (Scheme 2)

4-phenyl-2,3-dipropylpyridine (5n) yellow oil, ^1H NMR (400 MHz, CDCl_3) δ 8.37 (d, $J = 4.8$ Hz, 1H), 7.43-7.37 (m, 3H), 7.26-7.24 (m, 2H), 6.92 (t, $J = 4.8$ Hz 1H), 2.82 (t, $J = 7.7$ Hz, 2H), 2.53 (t, $J = 8.0$ Hz, 2H), 1.85-1.75 (m, 2H), 1.43-1.34 (m, 2H), 1.04 (t, $J = 7.3$ Hz, 3H), 0.78 (t, $J = 7.2$ Hz, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 161.0, 150.3, 146.1, 140.5, 133.5, 128.7, 128.4, 127.7, 122.8, 37.5, 31.1, 24.4, 23.5, 14.66, 14.63; IR spectrum (CDCl_3) 3055, 3029, 2960, 2930, 2871, 1579, 1546, 1496, 1456, 1404, 838, 762, 702 cm^{-1} ; HR-MS(EI+) calcd for $\text{C}_{17}\text{H}_{21}\text{N}$ $[\text{M}]^+$ 239.1674; found 239.1676.



3,4-Dipropylisoquinoline (5o) [CAS No. 1185276-02-1] yellow oil, ^1H NMR (400 MHz, CDCl_3) δ 9.08 (s, 1H), 7.96 (d, $J = 8.5$ Hz, 1H), 7.90 (d, $J = 8.0$ Hz, 1H), 7.66 (t, $J = 7.5$ Hz, 1H), 7.50 (t, $J = 7.5$ Hz, 1H), 3.01 (t, $J = 7.8$ Hz, 2H), 2.95 (t, $J = 7.5$ Hz, 2H), 1.86-1.77 (m, 2H), 1.73-1.63 (m, 2H), 1.09 (t, $J = 7.2$ Hz, 3H), 1.04 (t, $J = 7.2$ Hz, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 153.0, 150.2, 135.5, 130.1, 128.3, 128.2, 127.3, 125.8, 123.1, 37.4, 30.0, 24.2, 23.8, 14.8, 14.5.



^1H and ^{13}C NMR spectra for new compounds

