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Solvent-free Suzuki and Stille cross-coupling reactions of 4- and 5-halo-1,2,3-triazoles

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General information

All catalytic reactions were carried out under ambient atmosphere. Chemicals and solvents were obtained from commercial sources and used without further purification. Anhydrous CsF was purchased from Acros Organics.

1,4-Disubstituted-4-halo-1,2,3-triazoles (**1a**–**d**),[S1,S2,S3,S4] 1,4-disubstituted-5-halo-1,2,3-triazoles (**3a-c**),[S5] and pinacol arylboronates[S6] were synthesized according to literature procedures.

NMR spectra were obtained on a Bruker Avance 600 (600 MHz ^{1}H, 151 MHz ^{13}C) spectrometer in $CDCl_3$. The chemical shifts are frequency referenced relative to the residual undeuterated solvent peaks. Coupling constants J are given in Hertz as positive values regardless of their real individual signs. The multiplicity of the signals is indicated as ‘‘s”, ‘‘d”, “t”, or ‘‘m” for singlet, doublet, triplet, or multiplet, respectively.

Analytical thin layer chromatography was performed using Merck TLC Silica gel 60 F_{254} plates, visualization under 254 nm UV light or iodine vapor. Merck Silica gel 60 (0.040-0.063 mm) was used for both column and flash chromatography purification.

*1-Benzyl-5-methyl-4-p-tolyl-1H-1,2,3-triazole (**2a**)* [S7]

Following the general procedures, compound **2a** was obtained from 1-benzyl-4-bromo-5-methyl-1*H*-1,2,3-triazole **1a** (method A: 123 mg, 94%; method C: 61 mg, 46%) or 1-benzyl-4-iodo-5-methyl-1*H*-1,2,3-triazole **1b** (method B: 96 mg, 73%). The resulting solid was purified by chromatography (*n*-hexane–EtOAc, 10 : 1) to give 1-benzyl-5-methyl-4-*p*-tolyl-1*H*-1,2,3-triazole **2a** as white solid; m.p. 88–89 °C; R_f = 0.13 (CH_2Cl_2).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.58 (d, *J* = 8.1 Hz, 2H), 7.32 (dt, *J* = 14.9, 6.9 Hz, 3H), 7.24 (d, *J* = 8.0 Hz, 2H), 7.19 (d, *J* = 7.0 Hz, 2H), 5.51 (s, 2H), 2.37 (s, 3H), 2.30 (s, 3H).

^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$) δ 145.0 , 137.4 , 134.9 , 129.4 , 129.0 , 128.9 , 128.8 , 128.3 , 127.2 , 127.0 , 52.0 , 21.3 , 9.2 .

*1-Benzyl-5-methyl-4-o-tolyl-1H-1,2,3-triazole (**2b**)* [S7]

Following general procedure A, compound **2b** was obtained from 1-benzyl-4-bromo-5-methyl-1*H*-1,2,3-triazole **1a** (94 mg, 71%). The resulting solid was purified by chromatography (*n*-hexane–EtOAc, 10 : 1) to give 1-benzyl-5-methyl-4-*o*-tolyl-1*H*-1,2,3-triazole **2b** as white solid; m.p. 131-132 °C; R_f = 0.15 (CH_2Cl_2).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.35 (dd, *J* = 17.3, 7.2 Hz, 3H), 7.29 (dt, *J* = 6.3, 3.3 Hz, 2H), 7.23 (t, *J* = 5.6 Hz, 4H), 5.56 (s, 2H), 2.30 (s, 3H), 2.11 (s, 3H).

^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$) δ 145.7 , 137.6 , 135.0 , 130.5 , 130.4 , 130.3 , 129.1 , 128.4 , 128.4 , 127.2 , 125.7 , 52.2 , 20.2 , 8.6 .

*1-Benzyl-4-(4-fluorophenyl)-5-methyl-1H-1,2,3-triazole (**2c**)* [S7]

Following general procedure A, compound **2c**)was obtained from 1-benzyl-4-bromo-5-methyl-1*H*-1,2,3-triazole **1a** (94 mg, 70%). The resulting solid was purified by chromatography (*n*-hexane–EtOAc, 10 : 1) to give 1-benzyl-4-(4-fluorophenyl)-5-methyl-1*H*-1,2,3-triazole **2c** as white solid; m.p. 93–94 °C; R_f = 0.22 (CH_2Cl_2).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.66 (dt, J = 9.0, 4.7 Hz, 2H), 7.34 (dd, J = 14.6, 7.2 Hz, 3H), 7.21 (d, J = 7.2 Hz, 2H), 7.15 – 7.09 (m, 2H), 5.55 (s, 2H), 2.32 (s, 3H).

^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$) δ 162.6 (d, *J* = 246.8 Hz), 144.2 , 134.7 , 129.2 , 129.0 (d, J = 8.0 Hz), 128.6 , 127.3 , 115.8 (d, *J* = 21.6 Hz), 52.4 , 9.3 .

*1-Benzyl-5-methyl-4-(naphthalen-1-yl)-1H-1,2,3-triazole (**2d**)* [S7]

Following general procedure A, compound **2d** was obtained from 1-benzyl-4-bromo-5-methyl-1*H*-1,2,3-triazole **1a** (123 mg, 82%). The resulting solid was purified by chromatography (*n*-hexane–EtOAc, 10 : 1) to give 1-benzyl-5-methyl-4-(naphthalen-1-yl)-1*H*-1,2,3-triazole **2d** as white solid; m.p. 94–95 °C; R_f = 0.17 (CH_2Cl_2).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.93 (d, J = 8.4 Hz, 1H), 7.90 (d, J = 8.4 Hz, 2H), 7.54 – 7.46 (m, 4H), 7.40 (t, J = 7.3 Hz, 2H), 7.36 (d, J = 7.3 Hz, 1H), 7.29 (d, J = 7.2 Hz, 2H), 5.63 (s, 2H), 2.14 (s, 3H).

^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$) δ 144.9 , 135.0 , 134.0 , 132.2 , 131.2 , 129.2 , 128.7 , 128.5 , 128.4 , 128.2 , 127.4 , 126.6 , 126.1 , 126.0 , 125.3 , 52.4 , 8.9 .

*1-Benzyl-5-methyl-4-(thiophen-3-yl)-1H-1,2,3-triazole (**2e**)* [S7]

Following general procedure A, compound **2e** was obtained from 1-benzyl-4-bromo-5-methyl-1*H*-1,2,3-triazole (95 mg, 74%). The resulting solid was purified by chromatography (*n*-hexane–EtOAc, 10 : 1) to give 1-benzyl-5-methyl-4-(thiophen-3-yl)-1*H*-1,2,3-triazole **2e** as a white solid; m.p. 88 °C; R_f = 0.17 (CH_2Cl_2).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.52 (s, 2H), 7.40 (s, 1H), 7.37 – 7.30 (m, 3H), 7.19 (d, *J* = 6.5 Hz, 2H), 5.54 (s, 2H), 2.33 (s, 3H).

^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$) δ 141.5 , 134.9 , 132.5 , 129.2 , 128.9 , 128.5 , 127.2 , 126.6 , 126.2 , 121.4 , 52.2 , 9.3 .

*5-Methyl-1-phenyl-4-p-tolyl-1H-1,2,3-triazole (**2f**)* [S7,S8]

Following general procedure A, compound **2f** was obtained from 4-bromo-5-methyl-1-phenyl-1*H*-1,2,3-triazole **1c** (89 mg, 71%). The resulting solid was purified by chromatography (*n*-hexane–EtOAc, 10 : 1) to give 5-methyl-1-phenyl-4-*p*-tolyl-1*H*-1,2,3-triazole **2f** as white solid; m.p. 146 °C (lit. data[S8]: m.p. 142-144 °C); R_f = 0.15 (CH_2Cl_2).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.68 (d, *J* = 6.7 Hz, 2H), 7.58 – 7.50 (m, 5H), 7.29 (d, *J* = 6.8 Hz, 2H), 2.47 (s, 3H), 2.41 (s, 3H).

^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$) δ 145.0 , 137.8 , 136.6 , 129.6 , 129.6 , 129.5 , 128.6 , 127.3 , 125.4 , 21.4 , 10.4 .

*5-Methyl-1-phenyl-4-o-tolyl-1H-1,2,3-triazole (**2g**)* [S7]

Following general procedure A, compound **2g** was obtained from 4-bromo-5-methyl-1-phenyl-1*H*-1,2,3-triazole **2c** (97 mg, 78%). The resulting solid was purified by chromatography (*n*-hexane–EtOAc, 10 : 1) to give 5-methyl-1-phenyl-4-*o*-tolyl-1*H*-1,2,3-triazole **2g** as white solid; m.p. 116 °C; R_f = 0.18 (CH_2Cl_2).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.59 – 7.52 (m, 5H), 7.35 – 7.25 (m, 4H), 2.39 (s, 3H), 2.29 (s, 3H).

^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$) δ 145.6 , 137.8 , 136.7 , 130.7 , 130.6 , 130.4 , 130.4 , 129.6 , 129.4 , 128.6 , 125.8 , 125.0 , 20.4 , 9.8 .

*4-(4-Fluorophenyl)-5-methyl-1-phenyl-1H-1,2,3-triazole (**2h**)* [S4,S7]

Following general procedure A, compound **2h** was obtained from 4-bromo-5-methyl-1-phenyl-1*H*-1,2,3-triazole **1c** (76 mg, 60%). The resulting solid was purified by chromatography (*n*-hexane–EtOAc, 10 : 1) to give 4-(4-fluorophenyl)-5-methyl-1-phenyl-1*H*-1,2,3-triazole **2h** as white solid; m.p. 171 °C (lit. data[S4]: m.p. 160-162 °C); R_f = 0.21 (CH_2Cl_2).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.79 – 7.70 (m, 2H), 7.59 – 7.47 (m, 5H), 7.16 (t, *J* = 7.7 Hz, 2H), 2.46 (s, 3H).

^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$) δ 162.6 (d, *J* = 247.2 Hz), 144.1 , 136.4 , 129.7 , 129.1 (d, J = 8.0 Hz), 127.6 (d, *J* = 2.7 Hz), 125.3 , 115.9 (d, *J* = 21.7 Hz), 10.3 .

*5-Methyl-4-(naphthalen-1-yl)-1-phenyl-1H-1,2,3-triazole (**2i**)* [S7]

Following general procedure A, compound **2i** was obtained from 4-bromo-5-methyl-1-phenyl-1*H*-1,2,3-triazole **1c** (117 mg, 82%). The resulting solid was purified by chromatography (*n*-hexane–EtOAc, 10 : 1) to give 5-methyl-4-(naphthalen-1-yl)-1-phenyl-1*H*-1,2,3-triazole **2i** as white solid; m.p. 166 °C; R_f = 0.16 (CH_2Cl_2).

^{1}H NMR (600 MHz, $CDCl_3$) δ 8.11 – 7.99 (m, 1H), 7.94 (s, 2H), 7.67 – 7.49 (m, 9H), 2.32 (s, 3H).

^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$) δ 144.7 , 136.7 , 134.0 , 132.2 , 131.7 , 129.7 , 129.6 , 129.1 , 128.5 , 128.4 , 128.3 , 126.6 , 126.2 , 126.0 , 125.4 , 125.2 , 10.1 .

*5-Methyl-1-phenyl-4-(thiophen-3-yl)-1H-1,2,3-triazole (**2j**)* [S7]

Following general procedure A, compound **2j** was obtained from 4-bromo-5-methyl-1-phenyl-1*H*-1,2,3-triazole **1c** (78 mg, 65%). The resulting solid was purified by chromatography (*n*-hexane–EtOAc, 10 : 1) to give 5-methyl-1-phenyl-4-(thiophen-3-yl)-1*H*-1,2,3-triazole **2j** as white solid; m.p. 134 °C; R_f = 0.14 (CH_2Cl_2).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.61 (s, 2H), 7.59 – 7.49 (m, 5H), 7.44 (s, 1H), 2.49 (s, 3H).

^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$) δ 141.4 , 136.4 , 132.3 , 129.7 , 129.4 , 126.7 , 126.2 , 125.4 , 121.6 , 10.2 .

*1-Phenyl-5-propyl-4-p-tolyl-1H-1,2,3-triazole (**2k**)* [S7]

Following the general procedures, compound **2k** was obtained from 4-chloro-1-phenyl-5-propyl-1*H*-1,2,3-triazole **1d** (method A: 51 mg, 37%; method C: 35 mg, 25%). The resulting solid was purified by chromatography (*n*-hexane–EtOAc, 10 : 1) to give 1-phenyl-5-propyl-4-*p*-tolyl-1*H*-1,2,3-triazole **2k** as white solid; m.p. 100 °C; R_f = 0.13 (CH_2Cl_2).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.66 (d, *J* = 6.7 Hz, 2H), 7.56 (d, *J* = 6.5 Hz, 3H), 7.48 (d, *J* = 6.5 Hz, 2H), 7.28 (d, *J* = 6.9 Hz, 2H), 2.91 – 2.77 (m, 2H), 2.41 (s, 3H), 1.52 – 1.35 (m, 2H), 0.78 (t, *J* = 6.7 Hz, 3H).

^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$) δ 144.7 , 137.8 , 136.8 , 134.2 , 129.8 , 129.6 , 129.6 , 128.8 , 127.4 , 126.0 , 25.4 , 21.9 , 21.4 , 13.9 .

*1-Benzyl-4-phenyl-5-p-tolyl-1H-1,2,3-triazole (**4a**)* [S7,S9]

Following the general procedures, compound **4a** was obtained from 1-benzyl-5-chloro-4-phenyl-1*H*-1,2,3-triazole **3a** (method A: 85 mg, 52%; method C: 106 mg, 65%), 1-benzyl-5-bromo-4-phenyl-1*H*-1,2,3-triazole **3b** (method A: 60 mg, 37%; method C: 57 mg, 35%), or 1-benzyl-5-iodo-4-phenyl-1*H*-1,2,3-triazole **3c** (method B: 156 mg, 96%; method C: 101 mg,

62%). The resulting solid was purified by chromatography (*n*-hexane–EtOAc, 10 : 1) to give 1-benzyl-4-phenyl-5-*p*-tolyl-1H-1,2,3-triazole **4a** as white solid; m.p. 133 °C; R_f = 0.18 (CH_2Cl_2).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.58 (d, *J* = 6.8 Hz, 2H), 7.30 – 7.19 (m, 8H), 7.10 – 6.99 (m, 4H), 5.40 (s, 2H), 2.44 (s, 3H).

^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$) δ 144.5 , 139.9 , 135.6 , 134.1 , 131.1 , 130.1 , 130.0 , 128.8 , 128.5 , 128.2 , 127.8 , 127.6 , 126.8 , 124.8 , 52.0 , 21.6 .

*1-Benzyl-5-(4-fluorophenyl)-4-phenyl-1H-1,2,3-triazole (**4b**)* [S10,S11]

Following general procedure B, compound **4b** was obtained from 1-benzyl-5-iodo-4-phenyl-1*H*-1,2,3-triazole **3c** (method B: 156 mg, 95%). Resulting solid was purified by chromatography (*n*-hexane–EtOAc, 10 : 1) to give 1-benzyl-5-(4-fluorophenyl)-4-phenyl-1*H*-1,2,3-triazole **4b** as a white solid; m.p. 111 °C; R_f = 0.14 (CH_2Cl_2).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.57 – 7.50 (m, 2H), 7.27 (d, *J* = 6.7 Hz, 6H), 7.12 (d, *J* = 6.6 Hz, 4H), 7.03 (s, 2H), 5.42 (s, 2H).

^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$) δ 163.5 (d, *J* = 250.9 Hz), 144.8 , 135.2 , 133.0 , 132.2 (d, *J* = 8.4 Hz), 130.6 , 128.9 , 128.7 , 128.4 , 128.0 , 127.5 , 126.8 , 116.6 (d, *J* = 21.7 Hz), 52.3.

*1-Benzyl-5-(naphthalen-1-yl)-4-phenyl-1H-1,2,3-triazole (**4c**)* [S7,S12]

Following general procedure B, compound **4c** was obtained from 1-benzyl-5-iodo-4-phenyl-1*H*-1,2,3-triazole **3c** (90 mg, 50%). The resulting solid was purified by chromatography (*n*-hexane–EtOAc, 10 : 1) to give 1-benzyl-5-(naphthalen-1-yl)-4-phenyl-1*H*-1,2,3-triazole **4c** as a white solid; m.p. 143 °C; R_f = 0.20 (CH_2Cl_2).

^{1}H NMR (600 MHz, $CDCl_3$) δ 8.01 (d, *J* = 8.1 Hz, 1H), 7.94 (d, *J* = 7.9 Hz, 1H), 7.56 – 7.42 (m, 4H), 7.30 (t, *J* = 7.1 Hz, 1H), 7.21 (t, *J* = 8.3 Hz, 2H), 7.18 – 7.11 (m, 4H), 7.08 (t, *J* = 6.6 Hz, 2H), 6.81 (d, *J* = 7.0 Hz, 2H), 5.39 (d, *J* = 15.0 Hz, 1H), 5.10 (d, *J* = 14.8 Hz, 1H).

^{13}C{^{1}H} NMR (151 MHz, $CDCl_3$) δ 145.6 , 134.9 , 133.7 , 132.0 , 130.9 , 130.6 , 129.3 , 128.6 , 128.5 , 128.5 , 128.2 , 127.9 , 127.8 , 127.5 , 126.8 , 126.3 , 125.5 , 125.3 , 124.7 , 52.6 .

*1-Benzyl-4-phenyl-5-(thiophen-3-yl)-1H-1,2,3-triazole (**4d**)*

Following general procedure B, compound **4d** was obtained from 1-benzyl-5-iodo-4-phenyl-1*H*-1,2,3-triazole **3c** (97 mg, 68%). The resulting solid was purified by chromatography (*n*-hexane–EtOAc, 10 : 1) to give 1-benzyl-4-phenyl-5-(thiophen-3-yl)-1*H*-1,2,3-triazole **4d** as a white solid; m.p. 119 °C; R_f = 0.12 (CH_2Cl_2).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.60 (d, J = 7.1 Hz, 2H), 7.43 (dd, J = 4.8, 3.0 Hz, 1H), 7.32–7.25 (m, 6H), 7.17 (d, J = 2.1 Hz, 1H), 7.11–7.04 (m, 2H), 6.87 (d, J = 4.9 Hz, 1H), 5.45 (s, 2H).

$^{13}C\{^{1}H\}$ NMR (151 MHz, $CDCl_3$) δ 145.1, 135.6, 130.9, 129.4, 129.0, 128.6, 128.4, 128.3, 128.0, 127.4, 127.3, 127.2, 127.1, 126.9, 52.3.

EA calcd. for $C_{19}H_{15}N_3S$: C, 71.90; H, 4.76; N, 13.24. Found: C, 71.85; H, 4.74; N, 13.51.

HRMS: calcd for $C_{19}H_{16}N_3S$ $[M + H]^+$: 318.1065, found: 318.1063.

References

S1. R. Hüttel and A. Gebhardt, *Justus Liebigs Ann. Chem.*, 1947, **558**, 34.

S2. G. S. Akimova, V. N. Chistokletov and A. A. Petrov, *Zh. Org. Khim.*, 1967, **3**, 2241 (in Russian).

S3. A. Krasiński, V. V. Fokin and K. B. Sharpless, *Org. Lett.*, 2004, **6**, 1237.

S4. Z. K. Chen, Q. Q. Yan, Z. X. Liu, Y. M. Xu and Y. H. Zhang, *Angew. Chem. Int. Ed.*, 2013, **52**, 13324.

S5. P. S. Gribanov, M. A. Topchiy, I. V. Karsakova, G. A. Chesnokov, A. Y. Smirnov, L. I. Minaeva, A. F. Asachenko and M. S. Nechaev, *Eur. J. Org. Chem.*, 2017, 5225.

S6. P. B. Dzhevakov, M. A. Topchiy, D. A. Zharkova, O. S. Morozov, A. F. Asachenko and M. S. Nechaev, *Adv. Synth. Catal.*, 2016, **358**, 977.

S7. P. S. Gribanov, G. A. Chesnokov, M. A. Topchiy, A. F. Asachenko and M. S. Nechaev, *Org. Biomol. Chem.*, 2017, **15**, 9575.

S8. A. B. Shashank, S. Karthik, R. Madhavachary and D. B. Ramachary, *Chem. Eur. J.*, 2014, **20**, 16877.

S9. F. Wei, H. Li, C. Song, Y. Ma, L. Zhou, C.-H. Tung and Z. Xu, *Org. Lett.*, 2015, **17**, 2860.

S10. L. Ackermann, H. K. Potukuchi, D. Landsberg and R. Vicente, *Org. Lett.*, 2008, **10**, 3081.

S11. S. Keshipour and A. Shaabani, *Appl. Organomet. Chem.*, 2014, **28**, 116.

S12. B. Liégault, D. Lapointe, L. Caron, A. Vlassova and K. Fagnou, *J. Org. Chem.*, 2009, **74**, 1826.