

SUPPORTING INFORMATION

Title: Palladium-Catalyzed Alkynylcarbonylation of Aryl Iodides with the Use of Mo(CO)₆ in the Presence of *t*Bu₃P Ligand

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General Comments.

¹H-NMR spectra were recorded on a JEOL AL400 using tetramethylsilane as an internal standard. Chemical shifts are expressed in δ (ppm) values, and coupling constants are expressed in hertz (Hz). The following abbreviations are used: s= singlet, d= doublet, t= triplet, q= quartet, m= multiplet, br= broad singlet. Mass spectra were recorded on JEOL JMS- DX303 or JEOL JMS-AX500 spectrometer. IR spectra were measured with SensIR ATR FT-IR. Resioiomer of major pyrazole products was determined by ¹H-NOESY and ¹H-COSY 2D spectra recored on a JEOL ECA 600.

Procedures and Characterization

(Table 1, entry 1)

A test tube was charged with 4-iodoacetophenone (**5**) (123 mg, 0.5 mmol), Pd(dppf)Cl₂ (8 mg, 0.01 mmol), and Mo(CO)₆ (209 mg, 0.79 mmol). The test tube was filled with argon. Et₃N (0.1 ml, 0.72 mmol), CH₃CN (1 ml) and phenylacetylene (0.1 ml, 0.92 mmol) were added. The tube was sealed with screw cap and the mixture was stirred at room temperature for 13.5 h. After the reaction, solvent was removed and the residue was analyzed by ¹H-NMR.

(Table 1, entry 2)

A test tube was charged with 4-iodoacetophenone (**5**) (123 mg, 0.5 mmol), Pd(dppf)Cl₂ (8 mg, 0.01 mmol), and Mo(CO)₆ (209 mg, 0.79 mmol). The test tube was filled with argon. Et₃N (0.1 ml, 0.72 mmol), CH₃CN (1 ml) and phenylacetylene (0.1 ml, 0.92 mmol) were added. The tube was sealed with screw cap and the mixture was stirred at 80 °C for 3 h. After the reaction, solvent was removed and the residue was analyzed by ¹H-NMR.

(Table 1, entry 3)

A test tube was charged with 4-iodoacetophenone (**5**) (123 mg, 0.5 mmol), Pd(PPh₃)₂Cl₂ (0.01 mmol), and Mo(CO)₆ (209 mg, 0.79 mmol). The test tube was filled with argon. Et₃N (0.1 ml, 0.72 mmol), CH₃CN (1 ml) and phenylacetylene (0.1 ml, 0.92 mmol) were added. The tube was sealed with screw cap and the mixture was stirred at 80 °C for 3 h. After the reaction, solvent was removed and the residue was analyzed by ¹H-NMR.

(Table 1, entry 4)

A test tube was charged with 4-iodoacetophenone (**5**) (123 mg, 0.5 mmol), Pd(*t*Bu₃P)₂ (5 mg, 0.01 mmol), and Mo(CO)₆ (209 mg, 0.79 mmol). The test tube was filled with argon. Et₃N (0.1 ml, 0.72 mmol), CH₃CN (1 ml) and phenylacetylene (0.1 ml, 0.92 mmol) were added. The tube was sealed with screw cap and the mixture was stirred at room temperature for 12 h. After the reaction, solvent was removed and the residue was purified by SiO₂ column chromatography using hexane-AcOEt (4:1) as an eluent. The compound **6** was obtained (93 mg, 76%).

1-(4-Acetylphenyl)-3-phenyl-2-propynone (**6**)

mp 98 °C

IR (neat) (cm⁻¹): 2970, 2360, 2342, 2198, 1688, 1640, 1208, 752, 681

400MHz ¹H-NMR(CDCl₃/TMS) δ (ppm): 2.67 (3H, s), 7.40-7.47 (2H, m), 7.48-7.53 (1H, m), 7.67-7.72 (2H, m), 8.08 (2H, d, *J*= 8.3 Hz), 8.29 (2H, d, *J*= 8.3 Hz)

MS *m/z*: 248 (M⁺)

(Table 2, entry 1)

A test tube was charged with iodonitrobenzene (128 mg, 0.5 mmol), Pd(*t*-Bu₃P)₂ (5.7 mg, 0.01 mmol), and Mo(CO)₆ (199.6 mg, 0.75 mmol). The test tube was backfilled with argon. And then Et₃N (0.14 ml, 1 mmol), CH₃CN (1 ml), phenylacetylene (0.1 ml, 0.92 mmol) were added. The tube was sealed with screwcap and the mixture was stirred at room temperature for 12 h. After the reaction, solvent was removed under reduced pressure and the residue was purified by chromatography on silica gel using hexane/ethyl acetate (4/1) to give 1-(4-nitrophenyl)-3-phenyl-2-propynone (61.4 mg, 68%).

1-(4-Nitrophenyl)-3-phenyl-2-propynone (11)

mp 162 °C

IR (neat) (cm⁻¹): 2360, 2342, 2192, 1646, 1517, 1202, 762.2

400MHz ¹H-NMR(CDCl₃/TMS)δ(ppm): 7.43-7.49 (2H, m), 7.50-7.57 (1H, m), 7.69–7.73 (2H, m), 8.37 (4H, s)

MS *m/z*: 251 (M⁺)

(Table 2, entry 2)

A test tube was charged with 4-iodobenzoic acid ethyl ester (139.2 mg, 0.5 mmol), Pd(*t*-Bu₃P)₂ (5.7 mg, 0.01 mmol), and Mo(CO)₆ (198 mg, 0.75 mmol). The test tube was backfilled with argon. And then Et₃N (0.14 ml, 1 mmol), CH₃CN (1 ml), phenylacetylene (0.1 ml, 0.92 mmol) were added. The tube was sealed with screwcap and the mixture was stirred at room temperature for 12 h. After the mixture, solvent was removed. After the reaction, solvent was removed under reduced pressure and the residue was purified by chromatography on silica gel using hexane/ethyl acetate (9/1) to give 4-(3-phenylpropynoyl)benzoic acid ethyl ester (127 mg, 90%).

1-(4-Ethoxycarbonylphenyl)-3-phenyl-2-propynone (12)

mp 65 °C

IR (neat) (cm⁻¹): 2970, 2360, 2342, 2196, 1713, 1646, 1407, 1270, 1102, 754

400MHz ¹H-NMR(CDCl₃/TMS)δ(ppm): 1.42 (3H, t, *J* = 7.1 Hz), 4.41 (2H, q, *J* = 7.1 Hz), 7.40-7.45 (2H, m), 7.47-7.53 (1H, m), 7.67-7.72 (2H, m), 8.17 (2H, d, *J* = 8.3 Hz), 8.26 (2H, d, *J* = 8.3 Hz)

100MHz ¹³C-NMR(CDCl₃/TMS)δ(ppm): 14.2, 61.4, 86.7, 94.0, 119.6, 128.6, 129.2, 129.6, 130.9, 133.0, 134.8, 140.0, 165.3, 176.9

MS *m/z*: 278 (M⁺)

HRMS *m/z* Calcd for C₁₈H₁₄O₃: 278.0943. Found: 278.0927

(Table 2, entry 3)

A test tube was charged with 4-iodoanisole (114 mg, 0.5 mmol), Pd(*t*-Bu₃P)₂ (5.9 mg, 0.01 mmol), and Mo(CO)₆ (197.8 mg, 0.75 mmol). The test tube was backfilled with argon. And then Et₃N (0.14 ml, 1 mmol), CH₃CN (1 ml), phenylacetylene (0.1 ml, 0.92 mmol) were added. The tube was sealed with screwcap and the mixture was stirred at room temperature for 48 h. After the reaction, solvent was removed under reduced pressure and the residue was purified by chromatography on silica gel using hexane/ethyl acetate (7/3) to give 1-(4-methoxyphenyl)-3-phenyl-2-propynone (97.5 mg, 85%).

1-(4-Methoxyphenyl)-3-phenyl-2-propynone (13)

mp 96 °C

IR (neat): 2970, 2360, 2342, 2198, 1629, 1260, 995, 795

400MHz ¹H-NMR(CDCl₃/TMS)δ(ppm): 3.88 (3H, s), 6.97 (2H, d, *J* = 8.3 Hz), 7.38-7.49 (3H, m), 7.63-7.68 (2H, m), 8.19 (2H, d, *J* = 8.3 Hz)MS *m/z*: 236 (M⁺)**(Table 2, entry 4)**

A test tube was charged with 4-iodoacetophenone (**5**) (123 mg, 0.5 mmol), Pd(*t*Bu₃P)₂ (5 mg, 0.01 mmol), and Mo(CO)₆ (209 mg, 0.79 mmol). The test tube was filled with argon. Et₃N (0.1 ml, 0.72 mmol), CH₃CN (1 ml) and trimethylsilylacetylene (0.15 ml, 1 mmol) were added. The tube was sealed with screw cap and the mixture was stirred at room temperature for 12 h. After the reaction, solvent was removed and the residue was purified by SiO₂ column chromatography using hexane-AcOEt (4:1) as an eluent. The compound **6** was obtained (96 mg, 79%).

1-(4-Acetylphenyl)-3-trimethylsilyl-2-propynone

mp 85 °C

IR (neat) (cm⁻¹): 2956, 2360, 1935, 1683, 1642, 1248, 1030, 839, 754400MHz ¹H-NMR(CDCl₃/TMS)δ(ppm): 0.34 (9H,s), 2.66 (3H, s), 8.05 (2H, d, *J* = 8.3 Hz), 8.21 (2H, d, *J* = 8.3 Hz)MS *m/z*: 244 (M⁺)HRMS *m/z* Calcd for C₁₄H₁₆O₂Si: 244.0920. Found: 244.0930**(Table 3, entry 1)**

A test tube was charged with 4-iodonitrobenzene (124.6 mg, 0.5 mmol), Pd₂(dba)₃ (2.6 mg, 0.0025 mmol), PPh₃ (3.0 mg, 0.01 mmol) and DABCO (114.0 mg, 1 mmol). Under carbon monoxide atmosphere THF (5 ml), phenylacetylene (0.1ml, 0.92 mmol) were added. The mixture was stirred at room temperature for 6 h. After the reaction, solvent was removed and the residue was analyzed by ¹H-NMR..

(Table 3, entry 2)

A test tube was charged with 4-iodonitrobenzene (124.6 mg, 0.5 mmol), Pd₂(dba)₃ (2.6 mg, 0.0025 mmol), *t*Bu₃P□HBF₄ (3.0 mg, 0.01 mmol) and DABCO (114.3 mg, 1 mmol). Under carbon monoxide atmosphere THF (5 ml), phenylacetylene (0.1ml, 0.92 mmol) were added. The mixture was stirred at room temperature for 6 h. After the reaction, solvent was removed under reduced pressure and the residue was purified by chromatography on silica gel using hexane/ethyl acetate (4/1) to give 1-(4-nitrophenyl)-3-phenyl-2-propynone (97.5 mg, 76 %)

(Table 3, entry 3)

A test tube was charged with 4-iodonitrobenzene (126.7 mg, 0.5 mmol), Pd(*t*Bu₃P)₂ (2.7 mg, 0.005 mmol), and DABCO (113.5 mg, 1 mmol). Under carbon monoxide atmosphere THF (5 ml), phenylacetylene (0.1ml, 0.92 mmol) were added. The mixture was stirred at room temperature for 6 h. After the reaction, solvent was removed under reduced pressure and the residue was purified by chromatography on silica gel using hexane/ethyl acetate (4/1) to give 1-(4-nitrophenyl)-3-phenyl-2-propynone (81.6 mg, 64 %)

(Table 3, entry 4)

A test tube was charged with 4-iodonitrobenzene (125.0 mg, 0.5 mmol), Pd(*t*Bu₃P)₂ (2.4 mg, 0.005 mmol). Under carbon monoxide atmosphere THF (5 ml), phenylacetylene (0.1 ml, 0.92 mmol) and DBU (0.15 ml, 1 mmol) were added. The mixture was stirred at room temperature for 24 h. After the reaction, solvent was removed under reduced pressure and the residue was analyzed by ¹H-NMR..

(Table 3, entry 5)

A test tube was charged with 4-iodonitrobenzene (125.4 mg, 0.5 mmol), Pd(*t*Bu₃P)₂ (2.8 mg, 0.01 mmol). Under carbon monoxide atmosphere THF (5 ml), phenylacetylene (0.1 ml, 0.92 mmol) and triethylamine (0.1 ml, 0.7 mmol) were added. The mixture was stirred at room temperature for 24 h. After the reaction, solvent was removed under reduced pressure and the residue was analyzed by ¹H-NMR..

4-Phenylethynylnitrobenzene (15)

mp 115 °C

IR (neat) (cm⁻¹): 3566, 1592, 1509, 1347, 1106, 857, 764, 689.

400 MHz ¹H-NMR(CDCl₃/TMS)δ(ppm): 7.35-7.45 (3H, m), 7.53-7.58 (2H, m), 7.65 (2H, d, *J* = 9.0 Hz), 8.21 (2H, d, *J* = 9.0 Hz).

MS *m/z*: 223 (M⁺)

1-Methyl-3-(4-nitro-phenyl)-5-phenyl-1H-pyrazole (16)

To a 25×150 mm screw cap test tube equipped with a magnetic stirring bar under air atmosphere were added with 1-iodo-4-nitrobenzene (125.1 mg, 0.50 mmol), Pd(OAc)₂ (2.7 mg, 0.01 mmol), *t*Bu₃PHBF₄ (6.2 mg, 0.02 mmol), and Mo(CO)₆ (197.6 mg, 0.75 mmol). Under argon atmosphere CH₃CN (1 ml), saturated LiCl water solution (1 ml), methylhydrazine (50 μl, 0.94 mmol), phenylacetylene (100 μl, 0.91 mmol), and Et₃N (100 μl, 0.72 mmol) were added via syringe capped rapidly and stirred at room temperature. After 14 h, the mixture were diluted with ethyl acetate and dried over anhydrous MgSO₄. The solution was filtered, concentrated, and the residue was purified by chromatography on silica gel using toluene/ethyl acetate (20/1) to give **16** (80.8 mg, 58%).

Pale yellow solid; mp 142 °C (lit. 141-142 °C)¹

IR (neat) (cm⁻¹): 1600, 1513, 1339, 1314, 1007, 957.0, 852.9

¹H-NMR (400 MHz, CDCl₃) δ 3.95 (3H, s), 6.69 (1H, s), 7.42-7.53 (5H, m), 7.97 (2H, d, *J* = 8.8 Hz), 8.25 (2H, d, *J* = 8.8 Hz)

¹³C-NMR (100 MHz, CDCl₃) δ 37.9, 104.1, 124.0, 125.7, 128.6, 128.7, 128.8, 129.9, 139.7, 145.6, 146.9, 148.0

MS *m/z*: 279 (M⁺)

HRMS *m/z* Calcd. for C₁₆H₁₃N₃O₂: 279.1008, Found: 279.0984.

4-(1-Methyl-5-phenyl-1H-pyrazol-3-yl)-benzoic acid methyl ester (17)

To a 25×150 mm screw cap test tube equipped with a magnetic stirring bar under air atmosphere were added with methyl 4-iodobenzoate (130.5 mg, 0.50 mmol), Pd(OAc)₂ (2.4 mg, 0.01 mmol), *t*Bu₃PHBF₄ (7.4 mg, 0.02 mmol), and Mo(CO)₆ (201.1 mg, 0.77 mmol). Under argon atmosphere CH₃CN (1 ml), saturated LiCl water solution (1 ml), methylhydrazine (50 μl, 0.94 mmol), phenylacetylene (100 μl, 0.91 mmol), and Et₃N (100 μl, 0.72 mmol) were added via syringe capped rapidly and stirred at room temperature. After 13.5 h, the mixture was diluted with ethyl acetate and dried over anhydrous MgSO₄. The solution was filtered, concentrated, and the residue was purified by chromatography on silica gel using toluene/ethyl acetate (9/1) to give **17** (137.2 mg, 94%).

White solid; mp 124-126 °C

IR (neat) (cm⁻¹): 2946, 1715, 1609, 1436, 1272, 1108, 957.0, 775.7.

¹H-NMR (400 MHz, CDCl₃) δ 3.91 (3H, s), 3.92 (3H, s), 6.65 (1H, s), 7.39-7.51 (m, 5H), 7.90 (2H, d, *J* = 8.2 Hz), 8.07 (2H, d, *J* = 8.2 Hz).

¹³C-NMR (100 MHz, CDCl₃) δ 37.6, 51.9, 103.7, 125.1, 128.6, 128.7, 128.9, 130.0, 130.3, 137.8, 145.3, 149.2, 166.9.

MS *m/z*: 292 (M⁺)

HRMS *m/z* Calcd. for C₁₈H₁₆N₂O₂: 292.1212, Found: 292.1208.

4-(5-Butyl-1-methyl-1H-pyrazol-3-yl)-benzoic acid methyl ester (18)

To a 25×150 mm screw cap test tube equipped with a magnetic stirring bar under air atmosphere were added with methyl 4-iodobenzoate (130.3 mg, 0.50 mmol), Pd(OAc)₂ (2.3 mg, 0.01 mmol), *t*Bu₃PHBF₄ (7.2 mg, 0.02 mmol), Mo(CO)₆ (197.7 mg, 0.76 mmol). Under argon atmosphere CH₃CN (1 ml), saturated LiCl water solution (1 ml), methylhydrazine (50 μl, 0.94 mmol), 1-hexyne (100 μl, 0.87 mmol), and Et₃N (100 μl, 0.72 mmol) were added via syringe capped rapidly and stirred at room temperature. After 13.5 h, the mixture was diluted with ethyl acetate and dried over anhydrous MgSO₄. The solution was filtered, concentrated, and the residue was purified by chromatography on silica gel using toluene/ethyl acetate (9/1) to give **18** (101.7 mg, 75%).

Pale orange solid; mp 81 °C

IR (neat) (cm⁻¹): 2933, 2871, 1711, 1656, 1605, 1432, 1272, 1106, 773.7, 733.2.

¹H-NMR (400 MHz, CDCl₃) δ 0.97 (3H, t, *J* = 7.2 Hz), 1.43 (2H, m), 1.66 (2H, m), 2.60 (2H, t, *J* = 7.5 Hz), 3.83 (3H, s), 3.91 (3H, s), 6.38 (1H, s), 7.83 (2H, d, *J* = 8.5 Hz), 8.04 (2H, d, *J* = 8.5 Hz).

¹³C-NMR (100 MHz, CDCl₃) δ 13.7, 22.3, 25.3, 30.5, 36.2, 51.9, 102.0, 125.0, 128.6, 129.9, 138.1, 144.8, 148.7, 167.0.

MS *m/z*: 272 (M⁺)

HRMS *m/z* Calcd. for C₁₆H₂₀N₂O₂: 272.1525, Found: 272.1502.

3-(4-Methoxy-phenyl)-1-methyl-5-phenyl-1H-pyrazole (19)

To a 25×150 mm screw cap test tube equipped with a magnetic stirring bar under air atmosphere were added with 4-iodoanisole (113.8 mg, 0.49 mmol), Pd(OAc)₂ (2.4 mg, 0.01 mmol), tBu₃PHBF₄ (6.4 mg, 0.02 mmol), Mo(CO)₆ (194.9 mg, 0.75 mmol). Under argon atmosphere CH₃CN (1 ml), saturated LiCl water solution (1 ml), methylhydrazine (50 μl, 0.94 mmol), phenylacetylene (100 μl, 0.91 mmol), and Et₃N(100 μl, 0.72 mmol) were added via syringe capped rapidly and stirred at room temperature. After 26.5 h, the mixture were diluted with ethyl acetate and dried over anhydrous MgSO₄. The solution was filtered, concentrated, and the residue was purified by chromatography on silica gel using toluene/ethyl acetate (10/1) to give **19** (96.0 mg, 75%)

Pale orange solid; mp 89 °C

IR (neat) (cm⁻¹): 2960, 1609, 1542, 1437, 1241, 1179, 111.1, 831.6, 768.0.

¹H-NMR(400 MHz, CDCl₃) δ 3.84 (3H, s), 3.92 (3H, s), 6.54 (1H, s), 6.95 (2H, d, *J* = 8.5 Hz), 7.39-7.49 (5H, m), 7.76 (2H, d, *J* = 8.5 Hz).

MS *m/z*: 264 (M⁺)

1-[4-(1-Methyl-5-phenyl-1H-pyrazol-3-yl)-phenyl]-ethanone (20)

To a 25×150 mm screw cap test tube equipped with a magnetic stirring bar under air atmosphere were added with 4'-iodoacetophenone (123.4 mg, 0.50 mmol), Pd(OAc)₂ (2.0 mg, 0.01 mmol), tBu₃PHBF₄ (7.7 mg, 0.03 mmol), Mo(CO)₆ (199.4 mg, 0.76 mmol). Under argon atmosphere CH₃CN (1 ml), saturated LiCl water solution (1 ml), methylhydrazine (50 μl, 0.94 mmol), phenylacetylene (100 μl, 0.91 mmol), and Et₃N(100 μl, 0.72 mmol) were added via syringe capped rapidly and stirred at room temperature. After 14 h, the mixture were diluted with ethyl acetate and dried over anhydrous MgSO₄. The solution was filtered, concentrated, and the residue was purified by chromatography on silica gel using toluene/ethyl acetate (10/1) to give **20** (114.6 mg, 83%)

Pale orange solid; mp 106 °C

IR (neat) (cm⁻¹): 2925, 1667, 1648, 1607, 1544, 1264, 827.8, 771.8, 704.3.

¹H-NMR (400 MHz, CDCl₃) δ 2.61 (3H, s), 3.93 (3H, s), 6.67 (1H, s), 7.41-7.50 (5H, m), 7.91 (2H, d, *J* = 8.8 Hz), 7.99 (2H, d, *J* = 8.8 Hz).

¹³C-NMR(100MHz, CDCl₃) δ 26.6, 37.7, 103.8, 125.2, 128.59, 128.62, 128.65, 128.75, 130.2, 135.9, 137.8, 145.2, 149.0, 197.5.

MS *m/z*: 276 (M⁺)

HRMS *m/z* Calcd. for C₁₈H₁₆N₂O₁: 276.1263, Found: 276.1238.