Supporting Information

Palladium(II)-Catalyzed Conjugate Addition of Arylsiloxanes in Water

Rachel Lerebours and Christian Wolf
Department of Chemistry, Georgetown University, Washington DC, 20057
cw27@georgetown.edu

1. Synthetic Procedures	S2-S3
2. NMR Spectra	S4-S16
3. References	S17

1. Synthetic Procedures

General procedure for 1,4-additions. A mixture of the α,β -unsaturated substrate (1.00 mmol), aryltrimethoxysilane (1.30 mmol), $\text{Cu}(\text{ACN})_4\text{PF}_6$ (0.1 mmol) and POPd1 (0.05 mmol) was placed with 0.25 mL of water into a 10 mL glass tube. The reaction mixture was heated to 120°C by microwave irradiation (100 W) for 4 hours and the temperature was monitored using a calibrated infrared temperature control. The mixture was then allowed to cool to room temperature, diluted with 4 mL of water, and extracted with methylene chloride. The combined organic layers were washed with brine, dried over MgSO_4 , and the solvents were removed under vacuum. The residue was purified by flash chromatography on silica gel as described below.

3-Phenylcyclohexanone, 3.¹ Flash chromatography (hexanes:ether 5:1) gave 161.4 mg of a clear oil (0.93 mmol, 90%). $^1\text{H-NMR}$ δ 1.69-1.86 (m, 2H), 2.02-2.14 (m, 2H), 2.29-2.58 (m, 4H), 2.93-2.99 (m, 1H), 7.17-7.31 (m, 5H). $^{13}\text{C-NMR}$ δ 25.5, 32.8, 41.2, 44.7, 48.9, 126.6, 126.7, 128.7, 144.3, 211.5. EI-MS: m/z (%) = 174 (67, M^+), 131 (62, $\text{M}^+ - \text{C}_2\text{H}_3\text{O}$), 104 (100, $\text{M}^+ - \text{C}_2\text{H}_3\text{O}$, $-\text{C}_2\text{H}_3$), 91 (45, C_7H_7), 77 (45, Ph).

3-(4-Tolyl)cyclohexanone, 5.² Flash chromatography (hexanes:ether 5:1) gave 178.8 mg of a clear oil (0.95 mmol, 91%). $^1\text{H-NMR}$ δ 1.70-1.81 (m, 2H), 2.00-2.13 (m, 2H), 2.29 (s, 3H), 2.30-2.55 (m, 4H), 2.89-2.96 (m, 1H), 7.06-7.22 (m, 4H). $^{13}\text{C-NMR}$ δ 20.9, 25.6, 32.9, 41.2, 44.4, 49.1, 126.4, 129.3, 136.2, 141.4, 211.1. EI-MS: m/z (%) = 188 (60, M^+), 173 (10, $\text{M}^+ - \text{Me}$) 131 (100, $\text{M}^+ - \text{Me}$, $-\text{C}_2\text{H}_2\text{O}$), 91 (50, C_7H_7), 77 (30, Ph).

3-(4-Chloromethylphenyl)cyclohexanone, 7.³ Flash chromatography (hexanes:ethyl acetate 10:1 with 1% chloroform) gave 192.1 mg of a clear oil (0.86 mmol, 83%). $^1\text{H-NMR}$ δ 1.78-1.93 (m, 2H), 2.01-2.15 (m, 2H), 2.30-2.74 (m, 4H), 3.15-3.25 (m, 1H), 5.91 (s, 2H), 7.51 (d, $J=7.7$ Hz, 2H), 7.81 (d, $J=7.7$ Hz, 2H). $^{13}\text{C-NMR}$ δ 23.1, 32.1, 39.5, 42.5, 50.1, 50.3, 127.1, 128.5, 142.5, 143.1, 204.4.

3-(4-Aminophenyl)cyclohexanone, 9.⁴ Flash chromatography (hexanes:ethyl acetate 15:1 with 1% chloroform and 1% TEA) gave 151.7 mg of a clear oil (0.80 mmol, 77%). $^1\text{H-NMR}$ δ 1.64-1.92 (m, 2H), 2.13-2.25 (m, 2H), 2.30-2.59 (m, 4H), 2.89-2.99 (m, 1H), 4.6 (bs, 2H), 6.31 (d, $J=7.7$ Hz, 2H), 6.52 (d, $J=7.7$ Hz, 2H). $^{13}\text{C-NMR}$ δ 25.1, 33.2, 41.7, 46.1, 49.7, 117.8, 129.3, 129.4, 145.1, 208.7. EI-MS: m/z (%) = 188 (12, $\text{M}^+ - \text{H}$), 160 (46, $\text{M}^+ - \text{H}$, $-\text{CO}$), 128 (10, $\text{M}^+ - \text{C}_2\text{H}_3\text{O}$, $-\text{NH}_3$), 117 (49, $\text{M}^+ - \text{H}$, $-\text{C}_2\text{H}_3\text{O}$, $-\text{C}_2\text{H}_4$), 105 (100, $\text{M}^+ - \text{C}_2\text{H}_3\text{O}$, $-\text{C}_3\text{H}_5$).

3-(3-Furanyl)cyclohexanone, 11.⁵ Flash chromatography (hexanes:ethyl acetate 15:1 with 1% chloroform) gave 143.6 mg of a clear oil (0.87 mmol, 84%). $^1\text{H-NMR}$ δ 1.60-1.95 (m, 2H), 2.01-2.21 (m, 2H), 2.25-2.61 (m, 4H), 3.13-3.21 (m, 1H), 6.61 (d, $J=3.6$ Hz, 1H), 7.26 (dd, $J=3.6$ Hz, $J=0.6$ Hz, 1H), 7.72 (d, $J=0.6$ Hz, 1H). $^{13}\text{C-NMR}$ δ 24.1, 28.2, 39.5, 43.2, 50.1, 109.7, 115.9, 129.2, 140.1, 207.9. EI-MS: m/z (%) = 164 (23, M^+), 96 (100, $\text{M}^+ - \text{C}_4\text{H}_4\text{O}$), 68 (82, $\text{C}_4\text{H}_4\text{O}$).

3-(2-Thienyl)cyclohexanone, 13.⁶ Flash chromatography (hexanes:ethyl acetate 10:1 with 1% chloroform) gave 151.3 mg of a clear oil (0.84 mmol, 81%). $^1\text{H-NMR}$ δ 1.72-2.30 (m, 5H), 2.39-2.60 (m, 3H), 2.92-3.04 (m, 1H), 6.51 (dd, $J=4.8$ Hz, $J=3.7$ Hz, 1H), 7.01 (d, $J=3.7$ Hz, 1H), 7.15 (d, $J=4.8$ Hz, 1H). $^{13}\text{C-NMR}$ δ 23.4, 31.2, 38.3, 39.6, 46.1, 124.2, 124.5, 125.3, 145.1, 202.3. EI-MS: m/z (%) = 180 (8, M^+), 96 (100, $\text{M}^+ - \text{C}_4\text{H}_4\text{S}$).

3-Phenylcyclopentanone, 15.² Flash chromatography (hexanes:ether 5:1) gave 170.0 mg of a clear oil (1.06 mmol, 87%). ¹H-NMR δ 1.89-1.97 (m, 1H), 2.21-2.46 (m, 4H), 2.63 (dd, J = 7.0, 8.0 Hz, 1H), 3.34-3.41 (m, 1H), 7.19-7.32 (m, 5H). ¹³C-NMR δ 31.1, 38.8, 42.5, 45.7, 126.6, 126.7, 128.6, 142.9, 218.5. EI-MS: m/z (%) = 160 (47, M⁺), 104 (100, M⁺-CO, -C₂H₂), 91 (16, C₇H₇), 77 (25, Ph).

3,3-Diphenylpropanal, 17.⁷ Flash Chromatography (hexanes:ethyl acetate 5:1) gave 136.8 mg of a clear oil (0.65 mmol, 86%). ¹H-NMR δ 3.18 (dd, J = 7.8, J = 2.0 Hz, 2H), 4.63 (t, J = 7.8 Hz, 1H), 7.32-7.18 (m, 10H), 9.74 (t, J = 2.0, 1H). ¹³C-NMR δ 45.2, 49.6, 126.9, 127.9, 128.9, 143.4, 201.3. EI-MS: m/z (%) = 210 (50, M⁺), 192 (32, M⁺-CO), 167 (100, M⁺-C₂H₃O), 77 (50, Ph).

tert-Butyl 3-phenylpropanoate, 19.⁸ Flash Chromatography (hexanes:ethyl acetate 3:1) gave 148.3 mg of a clear oil (0.72 mmol, 92%). ¹H-NMR δ 1.44 (s, 9H), 2.56 (t, J = 7.6 Hz, 2H), 2.93 (t, J = 7.6 Hz, 2H), 7.15-7.23 (m, 3H), 7.28-7.32 (m, 2H). ¹³C-NMR δ 28.1, 31.1, 37.1, 80.3, 126.1, 128.3, 128.4, 140.8, 174.2. EI-MS: m/z (%) = 206 (10, M⁺), 149 (100, M⁺-C₄H₉), 77 (55, Ph), 57 (75, C₄H₉).

3,3-Diphenylpropionitrile, 21.⁹ Flash chromatography (hexanes:ethyl acetate 10:1) gave 149.1 mg of a clear oil (0.72 mmol, 93%). ¹H-NMR δ 3.07 (d, J = 6.2 Hz, 2H), 4.42, (t, J = 6.2 Hz, 1H), 7.25-7.45 (m, 10H). ¹³C-NMR δ 33.1, 39.7, 118.7, 128.1, 128.2, 128.8, 140.7. EI-MS: m/z (%) = 207 (5, M⁺), 167 (100, M⁺-C₂H₂N), 77 (35, Ph).

2-Methyl-3-phenylpropionitrile, 23.¹⁰ Flash chromatography (hexanes:ethyl acetate 10:1) gave 201.3 mg of a yellow oil (1.39 mmol, 93%). ¹H-NMR 1.36 (d, J = 6.3 Hz, 3H), 2.80-3.12 (m, 3H), 7.28-7.37 (m, 5H). ¹³C-NMR δ 20.3, 32.3, 40.1, 119.8, 125.1, 128.1, 128.3, 139.8. EI-MS: m/z (%) = 145 (10, M⁺), 91 (C₇H₇).

2,2-Diphenyl-1-nitroethane, 25.¹¹ Flash Chromatography (hexanes:ethyl acetate 2:1) gave 134.1 mg of a clear oil (0.59 mmol, 88%). ¹H-NMR δ 4.91 (t, J = 7.0 Hz, 1H), 4.99 (d, J = 7.0 Hz, 2H), 7.36-7.23 (m, 10H). ¹³C-NMR δ 49.1, 79.4, 127.8, 127.9, 129.2, 139.4. EI-MS: m/z (%) = 227 (3, M⁺), 180 (100, M⁺-H⁺, -NO₂), 167 (20, M⁺-CH₂NO₂), 77 (30, Ph).

2-Phenylnitrocyclohexane, 27.¹² Flash Chromatography (hexanes:methylene chloride 5:1) gave 140.7 mg of a clear oil (0.69 mmol, 87 %). ¹H-NMR δ 1.60-2.55 (m, 8H), 3.05 (dt, J = 12.0, J = 4.3 Hz, 1H), 4.89-4.98 (m, 1H), 7.14-7.42 (m, 5H). ¹³C-NMR δ 20.1, 25.1, 25.2, 30.2, 45.2, 87.2, 127.2, 127.3, 128.5, 140.5. EI-MS: m/z (%) = 205 (10, M⁺), 159 (M⁺-NO₂), 129 (M⁺-H⁺, -Ph), 91 (100, C₇H₇).

2. NMR Spectra

3-Phenylcyclohexanone, 3.

3-(4-Tolyl)cyclohexanone, 5.

3-(4-Chloromethylphenyl)cyclohexanone, 7.

3-(4-Aminophenyl)cyclohexanone, 9.

3-(Furanyl)cyclohexanone, 11.

3-(2-Thienyl)cyclohexanone, 13.

3-Phenylcyclopentanone, 15.

3,3-Diphenylpropanal, 17.

***tert*-Butyl 3-phenylpropanoate, 19.**

3,3-Diphenylpropionitrile, 21.

2-Methyl-3-phenylpropionitrile, 23.

2,2-Diphenyl-1-nitroethane, 25.

2-Phenylnitrocyclohexane, 27.

3. References

- (1) (a) Duursma, A.; Boiteau, J.-G.; Lefort, L.; Boogers, J. A. F.; de Vries, A. H. M.; de Vries, J. G.; Minnaard, A. J.; Feringa, B. L. *J. Org. Chem.* **2004**, *69*, 8045-8052.
- (2) Oi, S.; Moro, M.; Ito, H.; Honma, Y.; Miyano, S.; Inoue, Y. *Tetrahedron* **2002**, *58*, 91-97.
- (3) Kishimoto, S.; Tetsuya, A.; Minamida, I.; Tanaka, K.; Noguchi, S. *Chem. Pharm. Bull.* **1974**, *22*, 2231-2233.
- (4) Jones, P.; Reddy, K.; Knochel, P. *Tetrahedron* **1998**, *54*, 1471-1490.
- (5) Kojima, Y.; Wakita, S.; Kato, N. *Tetrahedron Lett.* **1979**, *19*, 4577-4580.
- (6) Jones, P.; Reddy, K.; Knochel, P. *Tetrahedron* **1998**, *54*, 1471-1490.
- (7) (a) Nishikata, T.; Yamamoto, Y.; Miyaura, N. *Organometallics* **2004**, *23*, 4317-4324.
- (b) Denmark, S. E.; Amishiro, N. *J. Org. Chem.* **2003**, *68*, 6997-7003.
- (8) Kissling, R. M.; Gagne, M. R. *Org. Lett.* **2000**, *2*, 4209-4212.
- (9) Ishakawa, F. *Chem. Pharm. Bull.* **1980**, *28*, 1394-1397.
- (10) Freerksen, R. W.; Selikson, S. J.; Wroble, R. R.; Kyler, K. S.; Watt, D. S. *J. Org. Chem.* **1983**, *48*, 4087-4096.
- (11) Lipschutz, B. H. *Synthesis* **1987**, 325-341.
- (12) Pecunioso, P.; Menicagli, R. *J. Org. Chem.* **1989**, *54*, 2391-2396.