Supporting Information for

**Ruthenium-Catalyzed Direct N-Formylation of Lactams with Paraformaldehyde**

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**General Information**

Unless otherwise noted, all reactions were carried out in oven-dried glassware under an inert atmosphere of nitrogen gas. All lactams, paraformaldehyde, and Shvo’s catalyst were obtained from commercial suppliers and used as received without further purification. Analytical TLC was performed on a Merck 60 F254 silica gel (0.25 mm thickness). Column chromatography was performed on Merck 60 silica gel (230-400 mesh). NMR spectra were recorded on a Bruker 500MHz or Varian 400MHz spectrometer. Tetramethysilane was used as reference, and the chemical shifts were reported in ppm and the coupling constants in Hz. GC yields were obtained on an Agilent 7890A instrument equipped with an HP-5 column using mesitylene as an internal standard. High Resolution Mass Spectrometry (HR-MS) was performed by Seoul National University National Center for Inter-University Research Facilities (NCIRF) and Organic Chemistry Research Center (OCRC) of Sogang University.

**General Procedure for N-Formylation of Amides with Paraformaldehyde:** Lactam (1.25 mmol), paraformaldehyde (6.25 mmol, 5.0 equiv), Shvo’s catalyst (6.78 mg, 0.5 mol%), and toluene (2.0 mL) were placed in an oven dried sealed reactor inside a glove box under a nitrogen atmosphere. The sealed reactor was taken out and heated to 150 °C in an oil bath. After 1 h, the reaction mixture was cooled to room temperature. All volatiles were removed under vacuum. Unless the crude product was in solution, the desired product could be simply precipitated by washing using hexane and ethyl acetate. In the case that the crude was in solution, purification was performed with silica gel column chromatography using hexane and ethyl acetate (or dichloromethane and methanol solvent mixture) as eluent to afford the desired product. All of the formylation products were identified by spectral comparison with literature data or with analogous literature data.

**N-formylazetidin-2-one (1c):** colorless oil, yield 52%. $^1$H NMR (400 MHz, CDCl$_3$): $\delta = 8.64$ (s, 1H), 3.53 (t, $J = 4.6$ Hz, 2H), 3.03 (t, $J = 4.6$ Hz, 2H). The spectral data were consistent with those reported in the literature.$^1$

**N-formylpyrrolidin-2-one (2c):** Colorless oil, yield 89%. $^1$H NMR (500 MHz, CDCl$_3$): $\delta = 9.00$ (s, 1H), 3.66 (t, $J = 6.8$ Hz, 2H), 2.52 (t, $J = 8.3$ Hz, 2H), 2.07 (quin, $J = 7.8$ Hz, 2H). The spectral data were consistent with those reported in the literature.$^2$

**N-formylpiperidin-2-one (3c):** Colorless oil, yield 62%. $^1$H NMR (500 MHz, CDCl$_3$): $\delta = 9.36$ (s, 1H), 3.50 (t, $J = 2.0$ Hz, 2H), 2.46 (t, $J = 2.0$ Hz, 2H), 1.76 (quin, $J = 3.4$ Hz, 4H). The spectral data were consistent with those reported in the literature.$^2$
N-formylazepan-2-one (4c): Colorless oil, yield 65%. $^1$H NMR (500 MHz, CDCl$_3$): $\delta =$ 9.30 (s, 1H), 3.70 (t, $J =$ 4.8 Hz, 2H), 2.60 (t, $J =$ 5.5 Hz, 2H), 1.70 (m, 4H), 1.60 (quin, $J =$ 4.3 Hz, 2H). The spectral data were consistent with those reported in the literature.$^2$

N-formylazocan-2-one (5c): Colorless oil, yield 35%. $^1$H NMR (400 MHz, CDCl$_3$): $\delta =$ 9.35 (s, 1H), 3.76 (t, $J =$ 5.6 Hz, 2H), 2.58 (t, $J =$ 6.2 Hz, 2H), 1.81 (quin, $J =$ 5.8 Hz, 2H), 1.60 (quin, $J =$ 5.4 Hz, 2H), 1.52 (quin, $J =$ 5.6 Hz, 2H), 1.43 (quin, $J =$ 4.4 Hz, 2H). The spectral data were consistent with those reported in the literature.$^2$

N-formyl-5-methylpyrrolidin-2-one (6c): Colorless oil, yield 34%. $^1$H NMR (400 MHz, CDCl$_3$): $\delta =$ 9.04 (s, 1H), 4.52 (m, 1H), 2.62 (m, 1H), 2.49 (m, 1H), 2.11 (m, 1H), 1.67 (m, 1H), 1.32 (d, $J =$ 6.4 Hz, 3H). The spectral data were consistent with those reported in the literature.$^3$

N-formylisoindolin-1-one (7c): White solid, yield 69%, mp 146 oC. $^1$H NMR (400 MHz, CDCl$_3$): $\delta =$ 9.31 (s, 1H), 7.91 (d, $J =$ 8.0 Hz, 1H), 7.67 (d, $J =$ 7.6 Hz, 1H), 7.54 (t, $J =$ 8.0 Hz, 2H), 4.74 (s, 2H). $^{13}$C NMR (101 MHz, CDCl$_3$): $\delta =$ 168.7, 160.1, 142.1, 134.7, 130.1, 128.9, 125.3, 123.8, 45.5. HR-MS (ESI): $m/z$ [M+Na]$^+$, calcd for C$_9$H$_7$NO$_2$: 184.0374; found: 184.0365.

N-formyl-5-methylisoindolin-1-one (8c): White solid, yield 99%, mp 110 oC. $^1$H NMR (400 MHz, CDCl$_3$): $\delta =$ 9.21 (s, 1H), 7.75 (d, $J =$ 7.6 Hz, 1H), 7.26 (d, $J =$ 8.4 Hz, 2H), 4.61 (s, 2H), 2.43 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$): $\delta =$ 168.6, 160.1, 146.1, 142.5, 130.0, 127.4, 125.0, 124.1, 45.3, 22.1. HR-MS (ESI): $m/z$ [M+Na]$^+$ calcd for C$_{10}$H$_9$NO$_2$: 198.0531; found: 198.0524.

N-formyl-5-hydroxyisoindolin-1-one (9c): Ivory solid, yield 81%, mp 298 oC. $^1$H NMR (500 MHz, DMSO): $\delta =$ 10.18 (s, 1H), 7.54 (d, $J =$ 5.5 Hz, 1H), 6.91 (s, 1H), 6.88 (d, 1H), 5.21 (s, 1H), 4.38 (s, 2H). $^{13}$C NMR (101 MHz, DMSO): $\delta =$ 180.34, 173.2, 166.2, 148.7, 129.7, 127.5, 120.8, 114.0, 53.9. HR-MS (CI): $m/z$ [M+H]$^+$ calcd for C$_9$H$_7$NO$_3$: 178.0504; found: 178.0505.

N-formyl-5-fluoroisoindolin-1-one (10c): White solid, yield 97%, mp 143 oC. $^1$H NMR (400 MHz, CDCl$_3$): $\delta =$ 9.27 (s, 1H), 7.94 (d, $J =$ 5.2 Hz, 1H), 7.21 (d, $J =$ 7.6 Hz, 2H), 4.73 (s, 2H). $^{13}$C NMR (101 MHz, CDCl$_3$): $\delta =$ 166.89 (d, $J =$ 257.8 Hz), 167.5, 159.9, 144.8 (d, $J =$ 11.4 Hz), 127.8 (d, $J =$ 15.2 Hz), 126.3, 177.3 (d, $J =$ 30.4 Hz), 111.3, (d, $J =$ 26.6 Hz), 45.4 (d, $J =$ 2.8 Hz). HR-MS (CI): $m/z$ [M+H]$^+$ calcd for C$_9$H$_6$FNO$_2$: 184.0461; found: 180.0461.

N-formyl-5-chloroisoindolin-1-one (11c): White solid, yield 68%, mp 168 oC. $^1$H NMR (500 MHz, CDCl$_3$): $\delta =$ 9.31 (s, 1H), 7.91 (d, $J =$ 8.0 Hz, 1H), 7.57 (s, 1H), 7.54 (d, $J =$ 8.0 Hz, 1H), 4.76 (s, 2H). $^{13}$C NMR (101 MHz, CDCl$_3$): $\delta =$ 167.5, 160.0, 143.5, 141.3, 129.7, 128.6, 126.5, 124.3, 45.2. HR-MS (ESI): $m/z$ [M+Na]$^+$ calcd for C$_9$H$_8$ClNO$_2$: 217.9985; found: 217.9981.
N-formyl-5-bromoisoindolin-1-one (12c): Yellow solid, yield 44%, mp 173 °C. \(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta = 9.30\) (s, 1H), 7.82 (d, \(J = 7.6\) Hz, 1H), 7.79 (s, 1H), 7.68 (d, \(J = 8.0\) Hz, 1H), 4.73 (s, 2H). \(^1^3\)C NMR (101 MHz, CDCl\(_3\)): \(\delta = 168.1, 160.6, 145.6, 132.4, 129.6, 128.9, 128.2, 126.7, 45.8\). HR-MS (ESI): \(m/z\) [M+Na]\(^+\) calcd for C\(_9\)H\(_6\)BrNO\(_2\): 261.9480; found: 261.9471.

N-formyl-3,4-dihydroisoquinolin-1(2H)-one (13c): Ivory solid, yield 51%, mp 76 °C. \(^1\)H NMR (500 MHz, CDCl\(_3\)): \(\delta = 9.63\) (s, 1H), 8.15 (d, \(J = 2.0\) Hz, 1H), 7.57 (t, \(J = 1.5\) Hz, 1H), 7.43 (t, \(J = 6.5\) Hz, 1H), 7.30 (d, \(J = 6.5\) Hz, 1H), 7.01 (t, \(J = 6.3\) Hz, 2H), 3.05 (t, \(J = 6.3\) Hz, 2H). \(^1^3\)C NMR (101 MHz, CDCl\(_3\)): \(\delta = 165.6, 162.4, 139.9, 134.1, 129.3, 127.8, 127.7, 127.6, 38.7, 27.4\). HR-MS (ESI): \(m/z\) [M+Na]\(^+\) calcd for C\(_{10}\)H\(_9\)NO\(_2\): 198.0531; found: 198.0523.

References


NMR Spectra

1c

2c
$^{19}$F NMR (10c) (CDCl$_3$)