SUPPORTING INFORMATION FOR:

Coupling of Fischer carbene complexes with o-alkynylbenzamides

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General Experimental. Nuclear Magnetic Resonance (^1H and ^{13}C) spectra were recorded on a Varian 200 MHz or a 400 MHz spectrometer. Chemical shifts are reported in parts per million (δ) downfield from the reference tetramethylsilane. Coupling constants (J) are reported in hertz (Hz). The following symbols have been used to indicate multiplicities: s (singlet), d (doublet), t (triplet), q (quartet), m (multiplet). A Nicolet 5DXC FT-IR spectrometer was used to record the infrared spectra and band positions are reported in reciprocal centimeters (cm^{-1}). Only key diagnostic bands are reported, C-H stretching frequencies in the region $2800\text{--}3100\text{ cm}^{-1}$ are not reported. Mass spectra (MS) were obtained at the University of California at Riverside. Flash column chromatography was performed using thick walled glass columns and "flash grade" silica. Thin layer chromatography was done using precoated 0.25mm silica gel plates purchased from Whatman. The relative proportion of solvents in mixed chromatography solvents refers to the volume: volume ratio. All commercially available reagents were purchased in reagent grade and used without purification. Diethyl ether, THF and dioxane were distilled from sodium benzophenone ketyl. All reactions were performed in an inert atmosphere created by a slight positive pressure (ca. 0.1 psi) of nitrogen.

General Procedure 1 – Synthesis of o-Alkynyl Benzamides 3: (1) *Preparation of o-iodobenzamides:* To a solution of amine (1.0 eq) and triethylamine (1.0 eq) in THF (3 mL/mmol) was added 2-iodobenzoyl chloride (1.0 eq) in THF (5 mL), and the mixture was stirred for an additional 1 h. Water was added to the mixture and the aqueous layer was extracted with dichloromethane. Combined organic extracts were washed with 10 % HCl, water, saturated aqueous sodium bicarbonate solution, brine, and dried over anhydrous sodium sulfate. Evaporation of solvent gave a nearly pure crude product, which was used directly in next step. (2) *Preparation of o-alkynyl benzamides:* A mixture of o-iodobenzamide (1.0 eq), $(\text{PPh}_3)_2\text{PdCl}_2$ (0.05 eq), PPh_3 (0.025 eq), trimethylsilylacetylene (or 1-hexyne) (1.5 eq), triethylamine (1.5 eq) in THF (5mL/mmol) was stirred for 20 min and copper(I) iodide (0.01 eq) was then added. After being stirred for 16-36 h at room temperature, the solvent was evaporated and the residue was treated with 1:1 hexane/ ethyl acetate. Filtration through Celite and evaporation of solvent gave crude product, which was purified by flash chromatography on silica gel. (3) *Preparation of 2-ethynyl benzamides:* To a solution of 2-trimethylsilanylethynyl benzamides (1 eq) in methanol (5 mL/mmol) was added anhydrous potassium carbonate (2 eq) at $0\text{ }^\circ\text{C}$ and the mixture was stirred for 0.5 h at the same temperature. Excess potassium carbonate was removed by filtration. The mixture was diluted with water (25

mL/ mmol) and extracted with ether. The combined ether extracts were washed with brine and dried over sodium sulfate. Evaporation of solvent and purification by flash chromatography on silica gel gave pure product.

Synthesis of 2-ethynyl-N, N-dimethyl-benzamide (11A). General Procedure 1 was followed except in first step where dimethylamine (40 % aqueous solution) (14 mL, 0.12 mol) solution was added directly to 2-iodobenzoyl chloride (2.93 g, 11.0 mmol) at 0° C and after 10 min a solution of sodium hydroxide (0.44 g, 11.0mmol) in water was added and extracted with dichloromethane. A Sonogashira coupling of this crude product with (PPh₃)₂PdCl₂ (0.38 g, 0.54 mmol), PPh₃ (0.07 g, 0.27 mmol), trimethylsilylacetylene (1.6 g, 16.5 mmol), triethylamine (1.67 g, 16.5 mmol) and copper (I) iodide (0.02 g, 0.11 mmol) gave 1.6g of product (94 % with respect to recovered starting material) after flash chromatography on silica gel using hexane/ ethyl acetate (6:4) as eluent which was desilylated using K₂CO₃ (1.8 g, 13.1 mmol) in methanol. After final purification by flash chromatography on silica gel using hexane/ ethyl acetate (3:7), 1.02 g of 11A (90 %) was obtained. ¹H NMR (CDCl₃): δ 7.51 (dd, 1 H, J = 8.0, 1.8 Hz), 7.45-7.25 (m, 3 H), 3.19 (s, 1 H), 3.16 (s, 3 H), 2.91 (s, 3 H). The spectral data are in agreement with those previously reported for this compound.¹

Synthesis of o-alkynyl benzamide 11B. General Procedure 1 was followed using 2-iodobenzoyl chloride (0.82 g, 3.1 mmol), N-benzyl but-3-enyl-amine² (0.50 g, 3.1 mmol), trimethylsilylacetylene (0.45 g, 4.6 mmol) and K₂CO₃ (0.76 g, 5.54 mmol). Final purification by flash chromatography on silica gel gave 0.65g of 11B (overall yield 73 %). ¹H NMR (CDCl₃): 1:1 mixture of rotamers δ 7.60-7.10 (m, 9 H), 5.83 (ddt, 1 H of one rotamer, J = 16.4, 10.2, 6.6 Hz), 5.48 (ddt, 1 H of one rotamer, J = 16.4, 10.2, 6.4 Hz), 5.10 (br d, 1 H of one rotamer, J = 16.4 Hz), 5.02 (br d, 1 H of one rotamer, J = 10.2 Hz), 4.91 (br d, 1 H of one rotamer, J = 10.2 Hz), 4.90 (br d, 1 H of one rotamer, J = 16.6 Hz), 4.40 (s, 2 H), 3.55 (very br m, 2 H of one rotamer), 3.27 (s, 1 H of one rotamer), 3.13 (t, 2 H, J = 6.6 Hz), 3.12 (s, 1 H of one rotamer), 2.43 (br q, 2 H of one rotamer, J = 6.6 Hz), 2.17 (br q, 2 H of one rotamer, J = 6.6 Hz); ¹³C NMR (CDCl₃): δ 169.82, 169.70, 139.77, 136.78, 136.33, 135.27, 134.06, 132.66, 128.79, 128.69, 128.35, 128.16, 127.39, 127.17, 127.03, 126.35, 126.18, 118.99, 118.80, 116.96, 116.38, 80.93, 80.77, 77.18, 52.21, 47.07, 46.81, 43.61, 32.24, 31.11; IR (cm⁻¹): 1635; MS: (m/e) 289 (M⁺, 1.5), 288 (M⁺-1, 2), 248 (16), 234 (6), 198 (11), 129 (100), 101 (23), 91 (22); HRMS: Calcd. for C₂₀H₁₉NO is 289.146664, found:289.145301

Synthesis of o-alkynyl benzamide 11C: General Procedure 1 was followed (step1 and step2) using 2-iodobenzoyl chloride (0.48 g, 1.8 mmol), N-benzyl but-3-enyl-amine² (0.29 g, 1.8 mmol), and 1-hexyne (0.22 g, 2.7 mmol). Final purification by flash

¹ Tovar, J.D.; Swager, T.M. *J. Org. Chem.* **1999**, *64*, 6499-6504.

² Padwa, A.; Carter, S.P.; Nimmesgern, H.; Stull, P.D. *J. Am. Chem. Soc.* **1988**, *110*, 2894-2900.

chromatography on silica gel using hexane/ ethyl acetate (4:1) gave 0.53g of **11C** (85 %).

^1H NMR (CDCl_3): 1:1 mixture of rotamers δ 7.55-7.05 (m, 9 H), 5.83 (ddt, 1 H of one rotamer, $J = 16.4, 10.2, 6.4$ Hz), 5.49 (ddt, 1 H of one rotamer, $J = 16.4, 10.2, 6.4$ Hz), 5.10 (br d, 1 H of one rotamer, $J = 10.2$ Hz), 5.07 (br d, 1 H of one rotamer, $J = 16.4$ Hz), 4.91 (br d, 1 H of one rotamer, $J = 16.4$ Hz), 4.90 (br d, 1 H of one rotamer, $J = 10.2$ Hz), 4.40 (br s, 2 H), 3.76 (very br m, 2 H of one rotamer), 3.15 (m, 2 H), 2.44 (t, 2 H, $J = 6.4$ Hz), 2.25 (br q, 2 H of one rotamer, $J = 6.4$ Hz), 2.18 (br q, 2 H of one rotamer, $J = 6.4$ Hz); 1.70-1.30 (m, 4 H), 0.95 (t, 3 H of one rotamer, $J = 7.4$ Hz), 0.92 (t, 3 H of one rotamer, $J = 7.4$ Hz); ^{13}C NMR (CDCl_3): δ 170.39, 170.21, 139.07, 138.97, 137.18, 136.52, 135.25, 134.22, 132.22, 128.34, 128.20, 127.43, 127.34, 127.18, 127.07, 126.30, 126.04, 120.97, 120.73, 116.78, 116.21, 94.05, 77.94, 52.30, 47.13, 46.89, 43.60, 32.32, 31.29, 30.49, 30.42, 21.77, 19.06, 18.97, 13.35; IR (cm^{-1}): 1638; MS: (m/e) 345 (M^+ , 5), 303 (11), 291 (15), 254 (46), 185 (100), 143 (14), 115 (31), 91 (50); HRMS: Calcd. for $\text{C}_{24}\text{H}_{27}\text{NO}$ is 345.209265, found: 345.210107

Synthesis of *o*-alkynyl benzamide 11D. General Procedure 1 was followed using 2-iodobenzoyl chloride (1.12 g, 4.2 mmol), N-benzyl pent-4-enylamine³ (0.74 g, 4.2 mmol), trimethylsilylacetylene (0.62 g, 6.3 mmol) and K_2CO_3 (1.07 g, 7.8 mmol). Final purification by flash chromatography on silica gel gave 1.1g of **11D** (overall yield 86 %).

^1H NMR (CDCl_3): 1:1 mixture of rotamers δ 7.65-7.10 (m, 9 H), 5.77 (ddt, 1 H of one rotamer, $J = 17.0, 10.4, 7.0$ Hz), 5.49 (ddt, 1 H of one rotamer, $J = 17.0, 10.4, 7.0$ Hz), 5.04 (br d, 1 H of one rotamer, $J = 17.0$ Hz), 4.97 (br d, 1 H of one rotamer, $J = 10.4$ Hz), 4.91 (br d, 1 H of one rotamer, $J = 17.0$ Hz), 4.83 (br d, 1 H of one rotamer, $J = 10.4$ Hz), 4.41 (br s, 2 H), 3.44 (very br m, 2 H of one rotamer), 3.24 (s, 1 H of one rotamer), 3.09 (s, 1 H of one rotamer), 3.06 (t, 2 H of one rotamer, $J = 7.8$ Hz), 2.14 (br q, 2 H of one rotamer, $J = 7.0$ Hz), 1.83 (m, 2 H), 1.58 (m, 2 H of one rotamer); ^{13}C NMR (CDCl_3): δ 169.65, 169.57, 139.80, 137.54, 136.86, 136.64, 136.36, 132.53, 128.74, 128.62, 128.23, 128.05, 127.27, 127.05, 126.89, 126.12, 126.06, 118.83, 118.77, 114.84, 114.63, 80.74, 51.90, 46.99, 46.79, 43.61, 30.80, 30.14, 26.80, 25.71; IR (cm^{-1}): 1633; MS: (m/e) 303 (M^+ , 6), 302 ($\text{M}^+ - 1$, 15), 274 (4), 248 (17), 234 (42), 212 (20), 158 (21), 129 (100), 101 (79), 91 (77); HRMS: Calcd. for $\text{C}_{21}\text{H}_{20}\text{NO}$ ($\text{M} - \text{H}$)⁺ is 302.154489, found: 302.154167

Synthesis of *o*-alkynyl benzamide 11E. General Procedure 1 was followed (step1 and step2) using 2-iodobenzoyl chloride (0.67 g, 2.5 mmol), N-benzyl-pent-4-enyl-amine³ (0.44 g, 2.5 mmol), 1-hexyne (0.31 g, 3.75 mmol). Final purification by flash chromatography on silica gel using hexane/ ethyl acetate (4:1) gave 0.77g of **11E** (86 %).

^1H NMR (CDCl_3): 1:1 mixture of rotamers δ 7.65-7.10 (m, 9 H), 5.81 (ddt, 1 H of one rotamer, $J = 16.8, 10.2, 6.6$ Hz), 5.52 (ddt, 1 H of one rotamer, $J = 16.8, 10.2, 6.6$ Hz), 5.04 (br d, 1 H of one rotamer, $J = 16.8$ Hz), 4.96 (br d, 1 H of one rotamer, $J = 10.2$ Hz), 4.90 (br d, 1 H of one rotamer, $J = 16.8$ Hz), 4.83 (br d, 1 H of one rotamer, $J = 10.2$ Hz), 4.41 (br s, 2 H), 3.82 (very br m, 2 H of one rotamer), 3.24 (s, 1 H of one rotamer), 3.08 (m, 2 H of one rotamer), 2.42 (t, 2 H, $J = 7.2$ Hz), 2.30 (br q, 1 H of one rotamer, $J = 6.6$

³ Surzur, J.M.; Stella, L. *Tetrahedron Lett.* **1974**, 2191-2194.

Hz), 2.11 (br q, 2 H of one rotamer, $J = 6.6$ Hz), 1.90-1.30 (m, 6 H), 0.95 (t, 3 H of one rotamer, $J = 7.2$ Hz), 0.92 (t, 2 H of one rotamer, $J = 7.2$ Hz); ^{13}C NMR (CDCl_3): δ 170.19, 170.42, 139.06, 139.01, 137.52, 137.23, 136.70, 136.51, 132.08, 132.04, 128.21, 128.11, 128.06, 127.35, 127.23, 126.99, 125.96, 120.80, 120.67, 114.70, 114.56, 93.87, 77.88, 51.87, 46.97, 46.85, 43.50, 30.77, 30.39, 30.30, 30.21, 26.81, 25.93, 21.69, 21.63, 18.94, 18.84, 13.24; IR(cm^{-1}): 1642; MS: (m/e) 360 ($M^+ + 1$, 3), 359 (M^+ , 9), 317 (12), 290 (17), 268 (33), 248 (14), 226 (12), 200 (26), 185 (53), 143 (19), 115 (49), 91 (100); HRMS: Calcd. for $\text{C}_{25}\text{H}_{29}\text{NO}$ is 359.224915, found: 359.225979

Carbene Complex 2E. 1) *Preparation of dipotassium pentacarbonylchromate*: Graphite (3.51 g, 97.5 mmol) was heated at $150^\circ\text{C} - 160^\circ\text{C}$ while being stirred under argon for 2 h. The graphite was cooled to room temperature and potassium (1.42 g, 36.5 mmol) was added as tiny pieces under a positive flow of argon. The mixture was heated to 160°C with stirring for 1 h. THF was added to the bronze colored material formed and the suspension was then cooled to -78°C . Chromium hexacarbonyl (3.63 g, 16.5 mmol) was then added under a positive flow of argon. The reaction mixture was stirred for 30 min at -78°C and placed in an ice bath until a thick slurry formed. This slurry was used directly in the next step. 2) *Preparation of tetramethylammonium salt of the chromium carbene complex*. To the solution of dipotassium pentacarbonylchromate in THF at -78°C obtained from step 1, 3,3-dimethyl-4-pentenoyl chloride⁴ (1.38 g, 9.4 mmol) in THF was added dropwise. The resultant mixture was stirred at -78°C for 15 min, at 0°C for 1.5 h and at room temperature for 1 h. The solvent was removed under reduced pressure. Cold water was added to the residue and filtered through Celite. To the filtrate was added a saturated aqueous solution of tetramethylammonium bromide, leading to immediate precipitation of the ammonium salt. The precipitate was removed by extracting the aqueous layer with dichloromethane. The organic layer was then dried over anhydrous sodium sulfate and the solvent was removed on a rotary evaporator to give a pale yellow solid. 3) *Alkylation of tetramethylammonium acylate salt*. To a solution of ammonium salt in dichloromethane obtained in step 2, methyl triflate (1.8 g, 11.0 mmol) was added at 0°C . The reaction mixture was then stirred at 0°C for 0.5 h and at room temperature for 1 h. The mixture was filtered through Celite, washed with saturated aqueous sodium bicarbonate solution, water, brine and dried over sodium sulfate. The solvent was removed on a rotary evaporator to yield the carbene complex. Purification was done by flash column chromatography using hexane as the eluent. A dark yellow liquid identified as carbene complex 2E (1.55 g, 52% yield) was obtained. ^1H NMR (CDCl_3): δ 5.84(dd, 1H, $J = 17.0, 11.2$ Hz), 4.87(d, 1H, $J = 11.2$ Hz), 4.83(d, 1H, $J = 17.0$ Hz), 4.78(s, 3H), 3.46(s, 2H), 1.07(s, 6H); ^{13}C NMR (CDCl_3): δ 216.43, 211.55, 147.34, 110.11, 73.75, 67.39, 39.54, 27.87 (2C). IR (neat)(cm^{-1}): 2063, 1919. Due to partial decomposition and formation of chromium (III) byproducts, we were unable to pulse this sample long enough to observe the signal for the carbene carbon predicted in the range of 330-370 ppm; excessive acquisition time is normally required using the wider sweep width. This carbene complex was stored in the refrigerator and used within two weeks of synthesis.

⁴ Hart, D.J.; Yang, T.K. *J. Org. Chem.* **1985**, *50*, 235-242.

Coupling of Carbene Complex 2B with *o*-alkynylbenzamide derivative 11B. The General Procedure from the main manuscript was followed using carbene complex **2B** (0.23 g, 0.79 mmol) and *o*-alkynylbenzamide derivative **11B** (0.16 g, 0.55 mmol) with the exception is that in this experiment, after the thermolysis the crude product was purified using column chromatography (silica gel/ hexanes: ethyl acetate 9:1) to yield the products, which were subsequently hydrolyzed by using 5% aqueous hydrochloric acid in methanol at 0° C for 5 h. After neutralization with 10% aqueous sodium bicarbonate solution, the mixture was extracted with dichloromethane. The crude product was purified using column chromatography (silica gel/ hexanes: ethyl acetate 9:1) to yield the product, mostly **23E-H** contaminated by the β,γ -unsaturated alkene cis and trans isomers (0.087 g, 44%). These compounds could not be separated, however repeated attempts were led to samples enriched in the γ,δ -unsaturated isomer. The ratio of γ,δ :trans- β,γ :cis- β,γ : α,β isomers was 48:32:17:3 as determined by integration of key peaks in the proton NMR spectrum. ¹H NMR (CDCl₃): the following peaks are common to all isomers δ 8.01 (d, 1 H, J = 8.0 Hz), 7.85 (d, 1 H, J = 8.0 Hz), 7.50 (d, 2 H, J = 8.0 Hz), 7.46-7.30 (m, 5 H), 7.25 (s, 1 H), 4.61 (s, 2 H), 3.65 (t, 2 H, J = 8.8 Hz); the following peaks are unique to the major (γ,δ -unsaturated) isomer **23E-H** δ 5.75 (ddt, 1 H, J = 16.6, 10.2, 6.4 Hz), 4.99 (d, 1 H, J = 16.6 Hz), 4.96 (d, 1 H, J = 10.2 Hz), 4.08 (s, 2 H), 3.16 (t, 2 H, J = 8.8 Hz), 2.55 (t, 2 H, J = 7.2 Hz), 2.31 (td or apparent br q, 2 H, J = 7.2, 6.4 Hz); the following peaks have been attributed to the 2nd-most abundant component, the trans β,γ isomer: δ 5.62-5.45 (m, 2H), 4.06 (s, 1 H), 3.19 (t, 2 H, J = 8.8 Hz), 1.71 (d, 3 H, J = 5.2 Hz); the following peaks have been attributed to the minor component, the cis β,γ -isomer: δ 5.62-5.45 (m, 2 H), 4.09 (s, 1 H), 3.21 (t, 2 H, J = 8.8 Hz), 1.56 (d, 3 H, J = 5.6 Hz); the following peaks have been attributed to a trace amount of the α,β -unsaturated isomer: δ 6.11 (br d, 1 H, J = 14.0 Hz), 1.03 (t, 3 H, J = 1.2 Hz). ¹³C NMR (CDCl₃): δ 207.97, 137.12, 132.72, 129.65, 128.49 (2C), 127.47 (2C), 127.10, 125.70, 125.66, 125.43, 124.86, 124.85, 124.69, 123.23, 123.17, 123.08, 115.11, 59.39, 54.94, 47.67, 45.19, 40.36, 29.71; Minor isomers (partial): 208.70, 207.50, 127.69, 126.70, 125.66, 124.85, 121.96, 48.52, 47.86, 39.94, 31.54, 27.72, 22.62 17.97, 14.07, 12.99; IR (cm⁻¹): 1713, 1575; MS: (m/e) 355 (M⁺, 6), 353 (M⁺-2, 14) 287 (3), 270 (75), 180 (18), 91 (100); HRMS: Calcd. for C₂₅H₂₅NO is 355.194747, found 355.193615.

Coupling of Carbene Complex 2B with *o*-alkynylbenzamide derivative 11D. The General Procedure from the main manuscript was followed using carbene complex **2B** (0.162 g, 0.56 mmol) and *o*-alkynylbenzamide derivative **11D** (0.121 g, 0.40 mmol) with the exception is that in this experiment, after the thermolysis the crude product was purified using column chromatography (silica gel/ hexanes: ethyl acetate 9:1) to yield the products, which were subsequently hydrolyzed by using 5% aqueous hydrochloric acid in methanol at 0° C for 5 h. After neutralization with 10% aqueous sodium bicarbonate solution, the mixture was extracted with dichloromethane. The crude product was purified using column chromatography (silica gel/ hexanes: ethyl acetate 9:1) to yield the product (0.050 g, 34%). The product appears to be a mixture of the γ,δ -unsaturated (**23F-H**), trans β,γ , and cis β,γ isomers in a 64:24:12 ratio as determined through integration of key peaks in the proton NMR spectrum. ¹H NMR (CDCl₃): the following peaks are

overlapping in all isomers δ 8.23 (m, 1 H), 7.80 (m, 1 H), 7.65 (d, 2 H, $J = 7.4$ Hz), 7.30-7.55 (m, 5 H), 7.10 (s, 1 H), 4.36 (s, 2H), 3.15 (m, 2 H), 2.96 (t, 2 H, $J = 6.6$ Hz), 1.92 (m, 2 H); the following peaks are unique to the γ,δ -unsaturated isomer **23F-H** δ 5.76 (ddt, 1 H, $J = 16.6, 10.2, 6.4$ Hz), 4.98 (br d, 1 H, $J = 16.6$ Hz), 4.96 (br d, 1 H, $J = 10.2$ Hz), 4.04 (s, 2H), 2.54 (t, 2 H, $J = 6.6$ Hz), 2.32 (br q, 2 H, $J = 6.6$ Hz); the following peaks have been attributed to the 2nd most abundant compound, the trans β,γ -unsaturated ketone isomer: δ 5.54 (m, 2 H), 1.71 (d, 3 H, $J = 4.4$ Hz); the following peaks have been attributed to the minor compound, the cis β,γ -unsaturated ketone isomer: δ 5.54 (m, 2 H), 1.56 (d, 3 H, $J = 6.0$ Hz); ^{13}C NMR (CDCl_3): δ 208.39, 144.14, 139.62, 137.16, 132.09, 130.56, 129.32, 128.64 (2C), 127.36 (2C), 127.00, 125.54, 125.24, 124.92, 124.68, 124.35, 123.61, 115.14, 59.23, 48.12, 46.96, 40.57, 27.78 (2C), 16.53; Minor isomers (partial): 207.90, 129.68, 123.14, 47.28, 45.36, 31.56, 22.63, 17.95, 14.06; IR (cm^{-1}): 2933, 1712, 1573; MS: (m/e) 370 ($M^+ + 1$, 7), 369 (M^+ , 24), 286 (94), 196 (32), 91 (100); HRMS: Calcd. for $\text{C}_{26}\text{H}_{27}\text{NO}$ is 369.209265, found 369.209667.