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Supporting Information

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Stereospecific, Enantioselective Allylation of α-Hydrazono Esters Using Allyltrichlorosilanes with BINAP Dioxides as Neutral-Coordinate Organocatalysts

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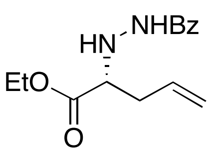
Supporting Information

General Methods. Melting points are uncorrected. IR spectra were recorded on a Jasco FT/IR-610 infrared spectrometer. ^{1}H and ^{13}C NMR spectra were recorded on a JEOL JNM-LA300 and JNM-LA400 spectrometer in $CDCl_3$ unless otherwise noted. Tetramethylsilane (TMS) served as internal standard ($\delta = 0$) for ^{1}H NMR, and $CDCl_3$ was used as internal standard ($\delta = 77.0$) for ^{13}C NMR. Column chromatography was conducted on Silica gel 60 (Merck) and preparative thin-layer chromatography (PTLC) was carried out using Wakogel B-5F. Dichloromethane was distilled from P_2O_5, and then from CaH_2 and stored over MS 4A. All other solvents were purified based on standard procedures.

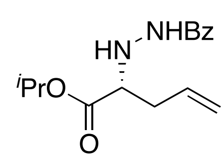
Chemicals. Allyltrichlorosilane (**5a**) was purchased from Tokyo Kasei Kogyo Co., LTD, and was used after distillation. (*S*)-BINAP and (*R*)-tol-BINAP were also purchased from Strem and they were oxidized with H_2O_2 in acetone. Allyltrichlorosilanes (**5b-f**) were prepared according to the reported procedures.[1]

A Typical Experimental Procedures of Asymmetric Allylation:

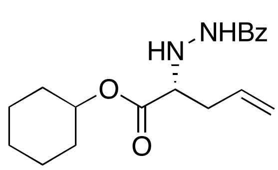
To a solution of **4a** (66.6 mg, 0.3 mmol) and (*S*)-BINAP dioxide (2.0 equiv. relative to **4a**) in dichloromethane (4 mL) was added **5a** (46 mg, 0.4 mmol) in dichloromethane (3 ml). After stirred at –78 °C for 12 h, the reaction was quenched by adding triethylamine (0.2 mL) in anhydrous ethanol (2.0 mL) at –78 °C. After warmed to room temperature and addition of brine, the mixture was extracted with dichloromethane (three times). The combined organic layers were dried over Na_2SO_4, filtered, and concentrated *in vacuo*. The residue was purified by column chromatography (silica gel) to afford **6a**.



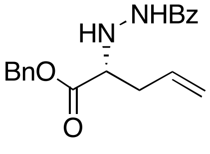
(*R*)-Ethyl 2-(*N*'-benzoylhydrazino)-4-pentenoate (6a):[2] ^{1}H NMR ($CDCl_3$) δ 1.26 (t, 3H, *J* = 7.2 Hz), 2.39-2.54 (m, 1H), 2.55-2.69 (m, 1H), 3.85 (dd, 1H, *J* = 7.6, 5.2 Hz), 4.20 (t, 2H, *J* = 7.1 Hz), 4.93 (brs), 5.10-5.24 (m, 2H), 5.87 (ddt, 1H, *J* = 16.8, 12.5, 5.0 Hz), 7.37-7.55 (m, 3H), 7.73-7.81 (m, 2H), 8.46 (brs); ^{13}C NMR ($CDCl_3$) δ 14.1, 35.1, 61.0, 62.0, 118.7, 126.9, 128.5, 131.7, 132.5, 132.8, 167.0, 172.5. HPLC (Daicel Chiralcel OD, hexane/*i*-PrOH = 9/1, flow rate = 1.0 mL/min) t_R = 10.1 min, t_R = 13.8 min.



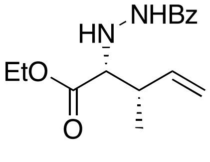
(*R*)-*iso*-Propyl 2-(*N*'-benzoylhydrazino)-4-pentenoate (6b): $[\alpha]^{27}_D$ +37.6 (c 0.30, $CHCl_3$, 97% ee) ; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.19 (d, 6H, *J* = 5.7 Hz), 2.37-2.47 (m, 1H), 2.52-2.59 (m, 2H), 3.75 (dd, 1H, *J* = 5.2, 7.2 Hz), 4.46 (brs, 1H), 4.98-5.23 (m, 2H), 5.74-5.88 (m, 1H), 7.34-7.48 (m, 3H), 7.66-7.69 (m, 2H), 8.07 (brs, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 21.8, 35.1, 62.1, 68.9, 119.0, 126.9, 128.7, 131.9, 132.4, 132.7, 166.8, 172.0; IR (neat) 3302, 2981, 1730, 1643, 1464, 1105, 694 cm^{-1}; Anal calcd for $C_{19}H_{20}N_2O_3$:



(*R*)-Cyclohexyl 2-(*N*'-benzoylhydrazino)-4-pentenoate (6c): $[\alpha]^{29}_D$ +32.3 (c 0.11, $CHCl_3$, 98% ee); ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.15-1.49 (m, 6H), 1.64-1.69 (m, 2H), 1.77-1.79 (m, 2H), 2.42-2.49 (m, 1H), 2.57-2.62 (m, 1H), 3.81 (brs, 1H), 4.76-4.83 (m, 1H), 5.12-5.23 (m, 2H), 5.76-5.86 (m, 1H), 7.34-7.39 (m, 2H), 7.42-7.48 (m, 1H), 7.67-7.70 (m, 2H), 8.18 (brs, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 23.6, 25.2, 31.5, 35.0, 62.1, 73.9, 77.2, 119.2, 120.7, 132.1, 132.2, 132.5, 162.6, 166.7; IR (neat) 3293, 1734, 1651, 1541, 1070, 669 cm^{-1}.

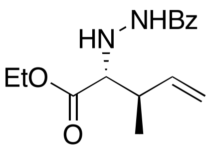


(*R*)-Benzyl 2-(*N*'-benzoylhydrazino)-4-pentenoate (6d): $[\alpha]^{24}_D$ –436.2 (c 0.04, $CHCl_3$, 91% ee); ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.43-2.50 (m, 1H), 2.56-2.65 (m, 1H), 3.87-3.91 (m, 1H), 3.83-4.02 (br, 1H), 5.06-5.24 (m, 4H), 5.71-5.82 (m, 1H), 7.20-7.62 (m, 10H), 8.11 (brs, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 34.8, 62.2, 67.9, 77.2, 119.4, 126.9, 127.0, 128.4, 128.5, 128.66, 128.69, 132.1, 132.3, 135.3, 166.8, 171.9; IR (neat) 3327, 2346, 1736, 1633, 1092, 916, 800, 752, 692 cm^{-1}; Anal calcd for $C_{19}H_{20}N_2O_3$: C, 70.35; H, 6.21; N, 8.64. Found: C, 70.31; H, 6.27; N, 8.65.

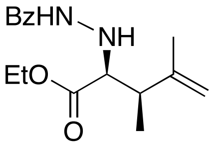


(2*R*,3*S*)-Ethyl 2-(*N*'-benzoylhydrazino)-3-methyl-4-pentenoate (6e): $[\alpha]^{27}_D$

+36.0 (c 0.11, $CHCl_3$, 89% ee); ^1H NMR (300 MHz, $CDCl_3$) δ 1.08 (d, 3H, *J* = 6.9 Hz), 1.22 (t, 3H, *J* = 7.1 Hz), 2.70-2.81 (m, 1H), 3.72 (brd, 1H, *J* = 4.2 Hz), 4.08-4.26 (m, 2H), 5.14 (brd, 1H, *J* = 10.5 Hz), 5.16 (brd, 1H, *J* = 18.5 Hz), 5.34 (brs, 1H), 5.90 (ddd, 1H, *J* = 6.5, 10.1, 17.1 Hz), 7.33-7.47 (m, 3H), 7.63-7.67 (m, 2H), 7.86 (brs, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 14.2, 14.4, 38.7, 61.0, 66.7, 116.2, 126.9, 128.6, 131.9, 132.5, 138.9, 166.8, 172.3; IR (neat) 3292, 3068, 2979, 1733, 1557, 1201, 920, 696 cm^{-1}; Anal. Calcd for $C_{20}H_{13}N_2O_3$: C, 65.20; H, 7.30; N, 10.14. Found: C, 64.95; H, 7.24; N, 10.09; HPLC (CHIRALPAK OD, 0.46 cmø × 25 cmL, hexane/2-propanol = 19/1, flow rate 1.0 mL/min, UV detection at 254 nm) t_R = 14.7 min (2*R*,3*R*), t_R = 16.5 min (2*S*,3*S*).

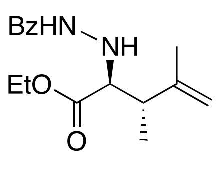


(2*R*,3*R*)-Ethyl 2-(*N*'-benzoylhydrazino)-3-methyl-4-pentenoate (6f): $[\alpha]^{27}_{D}$ +117.1 (c 0.13, $CHCl_3$, 95% ee); ^1H NMR (300 MHz, $CDCl_3$) δ 1.10 (d, 3H, *J* = 6.9 Hz), 1.22 (t, 3H, *J* = 7.1 Hz), 2.60 (sext, 1H, *J* = 6.8 Hz), 3.59 (d, 1H, *J* = 6.8 Hz), 3.88-3.95 (br, 1H), 4.09-4.29 (m, 2H), 5.07 (brd, 1H, *J* = 10.5 Hz), 5.08 (brd, 1H, *J* = 17.3 Hz), 5.78 (ddd, 1H, *J* = 8.5, 10.5, 17.5 Hz), 7.33-7.57 (m, 3H), 7.64-7.83 (m, 2H), 7.90 (brs, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 14.3, 16.9, 39.8, 61.0, 67.9, 108.3, 116.7, 126.9, 128.7, 131.9, 138.9, 167.1, 172.4; IR (neat) 3288, 2981, 1733, 1705, 1404, 1200, 1029, 921, 694 cm^{-1}; HRMS calcd for $C_{15}H_{20}N_2O_3$ (M^+) 276.1474, Found:276.1465; HPLC (CHIRALPAK OD, 0.46 cmø × 25 cmL, hexane/2-propanol = 9/1, flow rate 1.0 mL/min, UV detection at 254 nm) t_R = 9.1 min (2*R*,3*S*), t_R = 10.7 min (2*S*,3*R*).

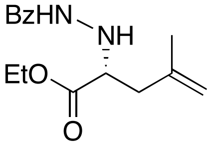


(2*S*,3*R*)-Ethyl 2-(*N*'-benzoylhydrazino)-3,4-dimethyl-4-pentenoate (6g): $[\alpha]^{28}_{D}$–64.1 (c 0.10, $CHCl_3$, 96% ee); ^1H NMR (300 MHz, $CDCl_3$) δ 1.09 (d, 3H, *J* = 7.0 Hz), 1.23 (t, 3H, *J* = 7.0 Hz), 1.87 (s, 3H), 2.68 (qd, 1H, *J* = 7.0 Hz), 3.26 (br, 1H), 3.87 (d, 1H, *J* = 4.8 Hz), 4.08-4.26 (m, 2H), 4.87 (brs, 1H), 4.97 (brs, 1H), 7.33-7.54 (m, 3H), 7.63-7.66 (m, 2H), 7.89 (brs, 1H) ; ^{13}C NMR (75 MHz, $CDCl_3$) δ 13.6, 14.2, 21.5, 41.6, 61.1, 64.1, 77.2, 113.0, 126.8, 128.7, 132.0, 145.5, 166.7, 172.5; IR (neat) 3296, 2976, 1734, 1647, 1460, 1198, 901, 712 cm^{-1}; Anal. Calcd for $C_{16}H_{22}N_2O_3$: C, 65.88; H, 7.63; N, 9.52. Found: C, 66.18; H, 7.64; N, 9.65; HPLC (CHIRALPAK OD, 0.46 cmø × 25 cmL, hexane/2-propanol = 9/1, flow rate 0.8 mL/min, UV detection at 254 nm) t_R = 8.7 min (2*S*,3*R*), t_R = 10.0 min (2*R*,3*S*).

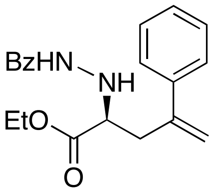
(2*S*,3*S*)-Ethyl 2-(*N*'-benzoylhydrazino)-3,4-dimethyl-4-pentenoate (6h):



$[\alpha]^{25}_{D}$ –74.8 (c 0.15, $CHCl_3$, 72% ee); ^1H NMR (300 MHz, $CDCl_3$) δ 1.04 (d, 3H, *J* = 7.1 Hz), 1.22 (t, 3H, *J* = 7.1 Hz), 1.80 (s, 3H), 2.62 (qd, 1H, *J* = 7.1, 9.2 Hz), 3.77 (d, 1H, *J* = 9.2 Hz), 4.27 (qd, 2H, *J* = 1.1, 7.1 Hz), 4.90 (d, 1H, *J* = 6.1 Hz), 4.91 (d, 1H, *J* = 6.1 Hz), 7.34-7.48 (m, 4H), 7.64-7.68 (m, 2H), 8.06 (br, 1H) ; ^{13}C NMR (75 MHz, $CDCl_3$) δ 14.3, 16.3, 18.3, 42.8, 61.1, 65.8, 77.2, 114.1, 127.0, 128.7, 132.1, 145.3, 167.4, 172.5; IR (neat) 3311, 1734, 1651, 1458, 1093, 903, 696 cm^{-1}; HPLC (CHIRALPAK OD, 0.46 cmø × 25 cmL, hexane/2-propanol = 9/1, flow rate 0.8 mL/min, UV detection at 254 nm) t_R = 8.7 min (2*R*,3*R*), t_R = 10.4 min (2*S*,3*S*).



(*R*)-Ethyl 2-(*N*'-benzoylhydrazino)-4-methyl-4-pentenoate (6i): $[\alpha]^{25}_{D}$ +65.5 (c 1.07, $CHCl_3$, 77% ee); ^1H NMR (300 MHz, $CDCl_3$) δ 1.20 (d, 3H, *J* = 7.3 Hz), 1.81 (s, 3H), 2.33 (dd, 1H, 9.7, 14.0 Hz), 2.98 (dd, 1H, *J* = 4.1, 14.0 Hz), 3.88 (brs, 1H), 4.03-4.20 (m, 2H), 4.85 (brd, 2H, *J* = 12.7 Hz), 7.33-7.46 (m, 3H), 7.66-7.69 (m, 2H), 8.14 (br, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 14.1, 21.6, 39.4, 60.2, 61.1, 114.6, 126.9, 128.6, 131.9, 132.5, 140.6, 167.0, 173.0; IR (neat) 3297, 2924, 1726, 1639, 1466, 1384, 1027, 693, 610 cm^{-1}; HRMS calcd for $C_{15}H_{20}N_2O_3$ (M^+) 276.1474, Found:276.1487; HPLC (CHIRALPAK OD, 0.46 cmø × 25 cmL, hexane/2-propanol = 9/1, flow rate 1.0 mL/min, UV detection at 254 nm) t_R = 8.7 min (*R*), t_R = 11.4 min (*S*).



(*S*)-Ethyl 2-(*N*'-benzoylhydrazino)-4-phenyl-4-pentenoate (6j): $[\alpha]^{28}_{D}$ –36.5 (c 0.11, $CHCl_3$, 97% ee); ^1H NMR (300 MHz, $CDCl_3$) δ 1.19 (t, 3H, *J* = 7.1 Hz), 2.82 (dd, 1H, *J* = 8.3, 14.3 Hz), 3.05 (dd, 1H, 4.6, 14.3 Hz), 3.70-3.83 (m, 1H), 3.70-4.03 (br, 1H), 4.07 (q, *J* = 7.1 Hz, 2H), 5.26 (brs, 1H), 5.38 (brs, 1H), 7.19-7.45 (m, 8H), 7.59-7.62 (m, 2H), 7.88 (brs, 1H) ; ^{13}C NMR (75 MHz, $CDCl_3$) δ 14.1, 36.8, 61.3, 77.2, 116.3, 126.9, 127.9, 128.5, 128.6, 132.0, 132.3, 139.9, 143.7, 162.3, 166.6; IR (neat) 3342, 2927, 1655, 1460, 1093, 474 cm^{-1}; Anal. Calcd for $C_{20}H_{22}N_2O_3$: C, 70.50; H, 6.68; N, 8.27. Found: C, 70.99; H, 6.55; N, 8.28; HPLC (CHIRALPAK OD, 0.46 cmø × 25 cmL, hexane/2-propanol = 9/1, flow rate 2.0 mL/min, UV detection at 254 nm) t_R = 5.9 min (*R*), t_R = 17.1 min (*S*).

Transformation to D-alloisoleucine[3]

PI-Pd[4] (0.40 mmol/g, 50.9 mg, 0.02 mmol) was added to (2*R*,3*S*)-ethyl 2-(*N*'-benzoylhydrazino)-3-methyl-4-pentenoate (116 mg, 0.4 mmol) in ethanol (5 mL). After stirred for 12 h under hydrogen atmosphere, the reaction mixture was filtrated and PI-Pd was washed with ethanol (15 mL). The filtrate was concentrated *in vacuo* and purified by preparative TLC (hexane/ethylacetate = 2/1) to afford (2*R*,3*S*)-ethyl 2-(*N*'-benzoylhydrazino)-4-pentanoate (80mg, 70 %). $[\alpha]^{27}_{D}$ +88.8 (c 0.23, $CHCl_3$, 97% ee); ^1H NMR (400 MHz, $CDCl_3$) δ 0.92 (d, 3H, *J* = 7.1 Hz), 0.94 (t, 3H, *J* = 7.3 Hz), 1.17-1.33 (m, 1H), 1.21 (t, 3H, *J* = 7.3 Hz), 1.52-1.62 (m, 1H), 1.83-1.92 (m, 1H), 3.63 (d, 1H, *J* = 4.15 Hz), 4.07-4.22 (m, 2H), 4.22-5.00 (brs, 1H), 7.32-7.36 (m, 2H), 7.41-7.45 (m, 1H), 7.65-7.70 (m, 2H), 8.02 (brs, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 11.8, 14.2, 14.9, 26.2, 36.7, 60.9, 67.0, 126.8, 128.6, 131.8, 132.6, 166.8, 173.2; IR (neat) 3311, 2968, 1732, 1651, 1604, 1579, 1403, 1201, 1094, 845, 694 cm^{-1} ; HRMS calcd for $C_{15}H_{22}N_2O_3$ (M^+) 278.1630, Found 278.1618; HPLC (CHIRALPAK OD, 0.46 cmø × 25 cmL, hexane/2-propanol = 19/1, flow rate 1.0 mL/min, UV detection at 254 nm) t_R = 15.4 min (*R*), t_R = 17.5 min (*S*). Samarium iodide (0.1 M THF solution, 8.0 mL) was added to (2*R*,3*S*)-ethyl 2-(*N*'-benzoylhydrazino)-4-methylpentanoate (106.2 mg, 0.38 mmol) in THF-EtOH (2 mL). After stirred for 30 min at room temperature, the reaction mixture was evaporated to remove the solvents, extracted with dichloromethane, and washed with water and brine. The organic layer was then dried over Na_2SO_4, filtered and concentrated *in vacuo*. LiOH (9.1 mg, 0.38 mmol) was added to the crude mixture in EtOH (2 mL), and the mixture was stirred for 30 min at room temperature. The crude mixture was then charged to Dowex 50 (H^+, 50 g), which was beforehand prepared by washing with 6 N HCl aq. (50 mL) and then filling with 1 N HCl aq. (50 mL). After washing with 1 N HCl aq. (100 mL), 10% NH_3 aq. was flowed away, and D-alloisoleicine was isolated by checking with a ninhydrine reagent (50 mg, quant (2 steps). ^1H NMR (D_2O, 1,4-dioxane as an internal standard: δ 3.75 ppm) δ 3.73 (d, *J* = 3.6 Hz, 1H), 2.06 (dtq, *J* = 3.6, 7.3, 6.6 Hz, 1H), 1.43 (ddt, *J* = 14.0, 7.3, 7.6 Hz, 1H), 1.32 (ddt, *J* = 14.0, 7.3, 7.6 Hz, 1H), 0.95 (t, *J* = 7.6 Hz 3H), 0.93 (d, *J* = 6.6 Hz, 3H); ^{13}C NMR (100 MHz, D_2O, 1,4-dioxane as an internal standard: δ 67.19 ppm) δ 175.2, 59.1, 36.2, 26.1, 13.9, 11.6; HRMS calcd for $C_6H_{13}NO_2$ (M^+) 131.0946, Found 131.0938.

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