Domino processes as a tool to recover substandard reactions. Synthesis and use of nitroacetic acid esters and amides.

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Supporting Information

General: ^1H NMR spectra were recorded at 300.00 or 200.00 MHz at 20°C with either tetramethylsilane (δ 0.00), chloroform (δ 7.25), methanol (δ 3.30), dimethylsulfoxide (δ 2.49) or acetone (δ 2.20) as the internal standard. ^{13}C NMR spectra were recorded at 75.46 or 50.3 MHz at 20°C with either chloroform (δ 77.0) methanol (δ 49.3), dimethylsulfoxide (δ 39.0) or acetone (δ 29.8) as the internal standard. Signal multiplicities were established by DEPT experiments. Melting points were determined through a *Büchi* instrument and are uncorrected. Specific optical rotations were determined at the sodium D line through a *Perkin Elmer 341* polarimeter. Flash chromatographic separations were performed over Merck Silica gel 60 (230-400 mesh), TLC analyses were performed over Merck precoated TLC plates (Silica gel 60 GF₂₅₄ 0.25 mm). GC analyses were performed on HP 6890 instrument with a split/splitless injector, a FID detector, and a 5% phenyl methyl silicone column (30 m, i.d. 0.32 mm, film thickness 0.0025 mm). Unless otherwise stated, solvents and reagents were used as received. Polymer-supported nitrite (Amberlyst A26, NO_2^- form, loading ca. 4 mequiv/g wet resin) was obtained from Fluka Co. and was dried overnight in vacuum at room temperature before use (average weight loss 14%).

Bromoacetic acid derivatives. Ethyl bromoacetate was purchased from Aldrich Chemical Co., and used as received. All other bromoacetic acid derivatives were prepared in one or two steps from the corresponding alcohol or amine and bromoacetyl bromide (Aldrich Chemical Co.). In particular, (–)-menthyl bromoacetate, (+)-4,4-dimethyl-2-oxotetrahydrofuran-3-yl bromoacetate, and *t*-butyl bromoacetate were prepared by adaptation of the procedure reported by: Smiles, J. *J. Chem. Soc.* **1905**, 87, 460; bromoacetic acid *N,N*-Diisopropyl amide and *N*-bromoacetyl proline methyl ester were prepared by adaptation of the procedure reported by: Weaver, W. E.; Whaley, W. M. *J. Am. Chem. Soc.* **1947**, 69, 515 as modified by Hand, E. S.; Johnson, S. C.; Baker, D. C. *J. Org. Chem.* **1997**, 62, 1348; 2-bromoacetyl-4,4-dimethyl-4,5-dihydrooxazole was prepared according to Breton, P.; Andre-Barres, C.; Langlois, Y. *Synth. Commun.* **1992**, 17, 2543.

General procedure for the halogen exchange reaction of bromoacetic acid derivatives with polymer supported nitrite. Polymer supported nitrite resin, commercially available from Fluka Co. (0.5g wet, ca. 4 mequiv per gram of wet resin, 2 mmol), was charged in three-necked 25-mL reaction flask equipped with a thermometer, a septum, and a nitrogen inlet and was dried overnight in vacuum at room temperature (average weight loss: 14%). Acetonitrile (5 mL) was added to resin and the suspension was stirred at room temperature for 30 min. The mixture was cooled to ca. -15 °C with the aid of a finely crushed 3 : 1 ice-salt bath. The bromoacetic acid derivative (1 mmol) was then added via syringe through a septum. The reaction was monitored by GC until disappearance of the starting material. The mixture was quickly filtered while still cold through a glass funnel and the resin was washed several times with small portions of methylene chloride. Pure samples were obtained by flash column chromatography (ethyl acetate/pet ether).

0.85, CHCl₃).

(1R,2S,5R)-2-Isopropyl-5-methylcyclohex-1-yl nitroacetate [(–)-menthyl nitroacetate] (1b): ¹H NMR (CDCl₃) δ 5.15 (s, 2H), 4.80 (dt, 1H, *J* = 11.0, *J* = 4.8); 2.10-1.95 (*m*, 1H); 1.90-0.70 (*m*, 8H); 0.89 (*d*, 3H, *J* = 4.4); 0.86 (*d*, 3H, *J* = 5.1); 0.74 (*d*, 3H, *J* = 7.0) ppm. ¹³C NMR (CDCl₃) δ 161.30 (*s*); 76.45 (*d*); 76.36 (*t*); 46.70 (*d*); 40.31 (*t*); 33.89 (*t*); 31.39 (*d*); 26.10 (*d*); 23.18 (*t*); 21.82 (*q*); 20.86 (*q*); 16.05 (*q*) ppm. *R*_f 0.36 (EA : PE = 9 : 1). GC 8.8 min (100 °C, 2 min then 15 °C/min). [α]_D²⁰ -67.1 (c

(1R,2S,5R)-2-Isopropyl-5-methylcyclohex-1-yl hydroxyacetate [(–)-menthyl hydroxyacetate] (3b): ¹H NMR (CDCl₃) δ 4.81 (*td*, 1H, *J* = 10.7, *J* = 4.4); 4.15 (*s*, 2H); 2.80 (*bs*, 1H); 2.10-1.95 (*m*, 1H); 1.90-0.70 (*m*, 8H); 0.92 (*d*, 3H, *J* = 6.3); 0.89 (*d*, 3H, *J* = 7.1); 0.76 (*d*, 3H, *J* = 7.1) ppm. ¹³C NMR (CDCl₃) δ 172.96 (*s*); 75.69 (*d*); 60.56 (*t*); 46.87 (*d*); 40.71 (*t*); 34.01 (*t*); 31.29 (*d*); 26.20 (*d*); 23.32 (*t*); 21.88 (*q*); 20.60 (*q*); 16.21 (*q*) ppm. *R*_f 0.22 (EA : PE = 9 : 1). GC 7.5 min (100 °C, 2 min then 15 °C/min). [α]_D²⁰ -77.5 (c 1.00, CHCl₃).

tert-Butyl nitroacetate (1d): ¹H NMR (CDCl₃) δ 5.12 (*s*, 2H); 1.51 (*s*, 9H) ppm. ¹³C NMR (CDCl₃) δ 160.89 (*s*); 84.91 (*s*); 77.11 (*t*); 27.74 (*q*) ppm. GC 6.7 min (60 °C, 2 min then 15 °C/min).

tert-Butyl hydroxyacetate (3d): ¹H NMR (CDCl₃) δ 4.0 (*s*, 2H); 2.9 (*s*, 1H); 1.48 (*s*, 9H) ppm. ¹³C NMR (CDCl₃) δ 172.49 (*s*); 82.15 (*s*); 60.81 (*t*); 27.61 (*q*) ppm. GC 3.5 min (60 °C, 2 min then 15 °C/min).

N,N-Diisopropyl nitroacetamide (1e): ¹H NMR (CDCl₃) δ 5.30 (*s*, 2H); 3.40-3.70 (*m*, 1H, *cis* and *trans* CH(CH₃)₂); 1.41 (*d*, *J* = 6.8, *cis* (CH₃)₂CH); 1.26 (*d*, *J* = 6.6, *trans* (CH₃)₂CH) ppm. ¹³C NMR (CDCl₃) δ 170.29 (*s*); 79.17 (*t*); 49.87 (*d*, *cis* CH(CH₃)₂); 47.27 (*d*, *trans* CH(CH₃)₂); 21.13 (*q*, *cis* (CH₃)₂CH); 20.60 (*q*, *trans* (CH₃)₂CH) ppm. GC 8.3 min (80 °C, 2 min then 15 °C/min).

N,N-Diisopropyl hydroxyacetamide (3e): ¹H NMR (CDCl₃) δ 4.10 (*s*, 2H); 3.75-3.40 (*m*, 1H, *cis* and *trans* CH(CH₃)₂); 1.42 (*d*, *J* = 6.8, *cis* (CH₃)₂CH); 1.21 (*d*, *J* = 6.7, *trans* (CH₃)₂CH) ppm. ¹³C NMR (CDCl₃) δ 159.7 (*s*); 60.70 (*t*); 47.27 (*d*, *cis* CH(CH₃)₂); 46.52 (*d*, *trans* CH(CH₃)₂); 20.94 (*q*, *cis* (CH₃)₂CH); 20.85 (*q*, *trans* (CH₃)₂CH) ppm. GC 6.5 min (80 °C, 2 min then 15 °C/min). *R*_f 0.23 (EA : PE = 4 : 1).

1f

4,4-Dimethyl-2-nitromethyl-4,5-dihydrooxazole (1f): ¹H NMR (CDCl₃) δ 1.53 (*s*, 6H); 4.32 (*s*, 2H); 5.95 (*s*, 1H); 6.57 (*s*, 1H) ppm. ¹³C NMR (CDCl₃) δ 25.12 (*q*); 58.15 (*s*); 78.71 (*t*); 93.29 (*d*); 96.18 (*s*); 157.43 (*s*) ppm. MS (EI, 70 eV) 158 (1) M⁺; 143 (24) M⁺-CH₃; 109 (20) M⁺-NO₂; 82 (60); 42 (100) CH₂OC⁺ m/z.

1g

N-Nitroacetyl proline methyl ester (1g): ¹H NMR (CD₃OD) δ 5.29 (*d*, *J* = 13.7, CH_aNO₂ *cis*); 5.23 (*d*, *J* = 13.7, CH_bNO₂ *cis*); 5.21 (*d*, *J* = 13.5, CH_aNO₂ *trans*); 5.09 (*d*, *J* = 13.5, CH_bNO₂ *trans*); 4.52-4.44 (*m*, C²H *cis*); 4.43-4.35 (*m*, C²H, *trans*); 3.90-3.30 (*m*, C⁵H₂ *cis* and *trans*); 3.72 (*s*, CH₃ *trans*); 3.65 (*s*, CH₃ *cis*); 2.30-1.70 (*m*, C³H₂ and C⁴H₂ *cis* and *trans*) ppm. ¹³C NMR (CD₃OD) δ 172.25 (*s*); 160.34 (*s*); 77.99 (*t*, CH₂NO₂ *cis* and *trans*); 59.92 (*d*, C²H *trans*); 59.82 (*d*, C²H *cis*); 53.64 (*q*, CH₃ *trans*); 52.99 (*q*, CH₃ *cis*); 47.75 (*t*, C⁵H₂N *trans*); 47.43 (*t*, C⁵H₂N *cis*); 31.49 (*t*, C³H₂ *trans*); 29.60 (*t*, C³H₂ *cis*); 25.15 (*t*, C⁴H₂ *cis*); 22.93 (*t*, C⁴H₂ *trans*) ppm. MS (EI) 186 ([M-NO]⁺); 170 (11%, [M-NO₂]⁺); 128 (10%, [M-COCH₂NO₂]⁺); 111 (38%, [M-COOMe-NO₂]⁺); 83 (100%, [C₅H₉N]⁺); 70 (44%, [C₄H₈N]⁺) m/z. GC 11.4 min (80 °C, 2 min then 15 °C/min).

General preparation of 4-hydroxy-4,5-dihydroisoxazoles 2-oxides of type 5 through the domino process. To a stirred solution of the epoxy alcohol (2 mmol) in acetonitrile (5.0 mL) 2,2,6,6-tetramethyl-1-piperidinyloxy (TEMPO) (0.2 mmol; 0.1 equiv) and bisacetoxiodobenzene (BAIB, 2.2 mmol) were successively added at room temperature. The course of the reaction was monitored by tlc (ethyl acetate/hexane = 40/60) until the alcohol was consumed (3-5 h). At this point the mixture was cooled to ca. 0 °C with the aid of a crushed ice/water bath. Then diisopropylethyl amine (DIPEA, 6.6 mmol), the bromoacetic acid derivative (2 mmol), and dried polymer-supported nitrite (4.0 g wet, 4.0 mmol) were subsequently added. The reaction mixture was set aside in a refrigerator (0 °C ± 2 °C) overnight. The reaction mixture was quickly filtered over a glass filter and the solids were carefully washed with several portions of dichloromethane. The organic layer was concentrated in vacuum, and the crude product was purified by flash chromatography.

4,5-Dihydroisoxazoles (–)-4,5-*trans*-5b and (–)-4,5-*cis*-5b. The reaction was performed using (2*S*,3*S*)-*trans*-3-phenylglycidol as the epoxy alcohol and *l*-(–)-menthyl bromoacetate. The two diastereoisomers were separated by flash chromatography (dichloromethane : diethyl ether = 92 : 8) obtaining 380 mg of 4,5-*cis*-5b and 253 mg of 4,5-*trans*-5b (clear oil, 633 mg combined, 81% yield).

(–)-4,5-*trans*-5b. ¹H NMR (CDCl₃) δ 0.75 (*d*, 3H, *J* = 6.7); 0.88 (*d*, 3H, *J* = 7.1); 0.92 (*d*, 3H, *J* = 6.6); 1.01-1.15 (*m*, 2H); 1.22-1.34 (*m*, 1H); 1.41-1.58 (*m*, 2H); 1.63-1.77 (*m*, 2H); 1.78-1.91 (*m*, 1H); 1.98-2.10 (*m*, 1H); 2.73 (*bs*, 1H); 2.78 (*bd*, 1H, *J* = 3.6); 4.67 (*dd*, 1H, *J* = 2.8, *J* = 4.2); 4.88 (*dt*, 1H, *J* = 4.4, *J* = 10.9); 5.05 (*bs*, 1H); 5.53 (*bs*, 1H); 7.32-7.47 (*m*, 5H) ppm. ¹³C NMR (CDCl₃) δ 16.09 (*q*); 20.80 (*q*); 21.93 (*q*); 23.18 (*t*); 26.12 (*d*); 31.43 (*d*); 34.00 (*t*); 40.75 (*t*); 46.81 (*d*); 71.95 (*d*); 73.30 (*d*); 76.47 (*d*); 85.46 (*d*); 110.73 (*s*); 126.16 (*d*); 128.62 (*d*); 128.83 (*d*); 137.13 (*s*); 158.52 (*s*) ppm. R_f 0.18 (CH₂Cl₂ : Et₂O = 92 : 8). IR (KBr) ν 3464, 2959, 2929, 2871, 1711, 1617, 1242, 1041 cm⁻¹. MS (EI, 70 eV) 360 (M⁺ - 31); 195, 139, 107, 83 (100), 69, 55 *m/z*. [α]_D²³ -79.2 (*c* 0.795, CHCl₃). Mp. 122-126 °C. Anal. Calcd for C₂₁H₂₉NO₆: C, 64.43; H, 7.47; N, 3.58. Found: C, 64.31; H, 7.46; N, 3.53.

(–)-4,5-*cis*-5b. ¹H NMR (CDCl₃) δ 0.76 (*d*, 3H, *J* = 7.1); 0.91 (*d*, 3H, *J* = 7.1); 0.92 (*d*, 3H, *J* = 6.3); 1.02-1.18 (*m*, 2H); 1.22-1.38 (*m*, 1H); 1.41-1.58 (*m*, 2H); 1.65-1.77 (*m*, 2H); 1.85-1.96 (*m*, 1H); 2.01-2.12 (*m*, 1H); 3.30 (*bs*, 1H); 3.59 (*bs*, 1H); 4.67 (*dd*, 1H, *J* = 6.4, *J* = 8.1); 4.90 (*dt*, 1H, *J* = 4.6, *J* = 10.8); 5.22 (*bd*, 1H, *J* = 8.0); 5.55 (*bd*, 1H, *J* = 6.3); 7.32-7.47 (*m*, 5H) ppm. ¹³C NMR (CDCl₃) δ 16.21 (*q*); 20.77 (*q*); 21.93 (*q*); 23.27 (*t*); 26.19 (*s*); 31.43 (*s*); 34.02 (*t*); 40.65 (*t*); 46.83 (*d*); 70.32 (*d*); 73.36 (*d*); 76.58 (*d*); 80.93 (*d*); 111.26 (*s*); 126.62 (*d*); 128.67 (*d*); 128.70 (*d*); 138.83 (*s*); 158.60 (*s*) ppm. R_f 0.29 (CH₂Cl₂ : Et₂O = 92 : 8). IR (KBr) ν 3464, 2958, 2928, 2872, 1723, 1617, 1241, 1019 cm⁻¹. [α]_D²⁰ -41.2 (*c* 0.868, CHCl₃). Mp 48-51 °C. Anal. Calcd for C₂₁H₂₉NO₆: C, 64.43; H, 7.47; N, 3.58. Found: C, 64.50; H, 7.44; N, 3.59.

4,5-Dihydroisoxazoles (±)-4,5-*trans*-5e and (±)-4,5-*cis*-5e. The reaction was performed using racemic *trans*-3-phenylglycidol as the epoxy alcohol and *N,N*-diisopropyl bromoacetamide. The two diastereoisomers were separated by flash chromatography (ethyl acetate : pet ether = 50 : 50) obtaining 274 mg of 4,5-*cis*-5e and 224 mg of 4,5-*trans*-5e (498 mg combined, 74% yield). The isolated isomers were found to be only sparingly soluble in any deuterated solvent. Acceptable spectra were obtained in acetone-*d*₆. Better spectra were obtained for the corresponding bis-*O*-(*tert*-butyldimethylsilyl) ethers prepared according to a procedure described elsewhere.¹

(±)-4,5-*trans*-5e. ¹H NMR (acetone-*d*₆) δ 1.20-1.50 (*m*, 12H); 3.60 (*m*, 1H); 3.90 (*m*, 1H); 4.58 (*dd*, *J* = 4.8, *J* = 2.4); 4.98 (*d*, 1H, *J* = 4.8); 5.10-5.40 (*bs*, 2H); 5.46 (*d*, 1H, *J* = 2.4); 7.20-7.60 (*m*, 5H) ppm. ¹³C NMR (acetone-*d*₆) δ 20.77 (*q*), 21.54 (*q*), 21.80 (*q*); 47.16 (*d*), 51.82 (*d*); 73.04 (*d*), 76.13 (*d*), 88.51 (*d*); 114.44 (*s*); 127.9 (*d*), 128.9 (*d*), 129.5 (*d*); 141.09 (*s*); 159.4 (*s*) ppm. R_f 0.29 (EA : PE = 1 : 1). IR (KBr) ν 3363, 3172, 2973, 2938, 1654, 1617, 1031 cm⁻¹. Mp 155-157 °C.

(±)-4,5-*cis*-5e. ¹H NMR (acetone-*d*₆) δ 1.20-1.50 (*m*, 12H); 3.60 (*m*, 1H); 3.90 (*m*, 1H); 4.70 (*dd*, *J* = 8.6, *J* = 6.0); 5.15 (*d*, 1H, *J* = 8.7); 4.8-5.4 (*bs*, 2H); 5.45 (*d*, 1H, *J* = 6.1); 7.20-7.50 (*m*, 5H) ppm. ¹³C NMR (acetone-*d*₆) δ 20.72 (*q*), 21.34 (*q*), 21.82 (*q*); 47.21 (*d*), 52.05 (*d*); 70.39 (*d*), 75.42 (*d*), 84.03 (*d*); 115.61 (*s*); 128.43 (*d*), 129.06 (*d*), 129.26 (*d*); 142.64 (*s*); 159.49 (*s*) ppm. R_f 0.23 (EA : PE = 1 : 1). IR (KBr) ν 3313, 2973, 2934, 1637, 1608, 1021 cm⁻¹. Mp 157-159 °C.

(±)-Bis-*O*-(*tert*-butyldimethylsilyl)-4,5-*trans*-5e. ¹H NMR (CDCl₃) δ -0.54 (*s*, 3H), -0.19 (*s*, 3H), -0.07 (*s*, 3H), 0.15 (*s*, 3H); 0.67 (*s*, 9H), 0.90 (*s*, 9H); 1.17 (*d*, 3H, *J* = 6.7); 1.34 (*d*, 3H, *J* = 6.3); 1.41 (*d*, 3H, *J* = 6.8); 1.46 (*d*, 3H, *J* = 6.8); 3.48 (*hept*, 1H, *J* = 6.9); 3.90 (*hept*, 1H, *J* = 6.4); 4.37 (*dd*, 1H, *J* = 1.5, *J* = 2.8); 5.07 (*d*, 1H, *J* = 2.7); 5.60 (*d*, 1H, *J* = 1.5); 7.20-7.50 (*m*, 5H) ppm. ¹³C NMR (CDCl₃) δ -5.67 (*q*), -4.72 (*q*), -4.55 (*q*), -4.29 (*q*), 18.08 (*s*), 18.54 (*s*); 20.17 (*q*), 20.69 (*q*), 21.09 (*q*), 22.33 (*q*); 25.92 (*q*), 26.14 (*q*); 46.98 (*d*), 50.97 (*d*); 74.43 (*d*); 75.45 (*d*); 88.71 (*d*); 114.93 (*s*); 126.97 (*d*), 128.56 (*d*), 129.16 (*d*); 138.68 (*s*); 157.70 (*s*) ppm. Mp 124°C-125°C R_f 0.36 (PE : Et₂O = 9 : 1). IR (KBr) ν 2961, 2932, 2859, 1635, 1259, 1086 cm⁻¹. Anal calcd for C₂₉H₅₂N₂O₅Si₂: C, 61.66; H, 9.28; N, 4.96. Found: C, 61.39; H, 9.32; N, 5.01.

¹ Marotta, E.; Micheloni, L. M.; Scardovi, N.; Righi, P. *Org. Lett.* **2001**, *3*, 727.

(±)-Bis-*O*-(*tert*-butyldimethylsilyl)-4,5-*cis*-**5e**. ^1H NMR (CDCl_3) δ -0.25 (s, 3H), -0.03 (s, 3H), 0.16 (s, 3H), 0.25 (s, 3H); 0.76 (d, 3H, J = 6.5), 0.83 (s, 9H); 0.87 (d, 3H, J = 6.6); 1.00 (s, 9H); 1.23 (d, 3H, J = 6.7); 1.26 (d, 3H, J = 6.7), 2.14 (*hept*, 1H, J = 6.7), 3.28 (*hept*, 1H, J = 6.7); 5.00 (dd, 1H, J = 1.5, J = 9.3); 5.15 (d, 1H, J = 1.5); 5.95 (d, 1H, J = 9.3); 7.20-7.50 (*m*, 3H); 7.65 (dd, 2H, J = 1.6, J = 7.8) ppm. ^{13}C NMR (CDCl_3) δ -4.63 (q), -4.48 (q), -4.39 (q), -4.20 (q); 18.47 (s), 18.74 (s); 20.08 (q), 20.71 (q), 20.76 (q); 22.71 (q); 26.13 (q), 26.38 (q); 46.73 (d), 50.77 (d); 74.09 (d); 76.14 (d); 84.69 (d); 112.81 (s); 128.15 (d), 129.70 (d); 139.25 (s); 157.99 (s) ppm. Mp 124°C-126°C R_f 0.14 (PE : Et₂O = 9 : 1). IR (KBr) ν 2959, 2930, 2859, 1635, 1260, 1091 cm^{-1} . Anal calcd for C₂₉H₅₂N₂O₅Si₂: C, 61.66; H, 9.28; N, 4.96. Found: C, 61.78; H, 9.29; N, 4.93.

4,5-Dihydroisoxazoles (±)-4,5-*trans*-5f and (±)-4,5-*cis*-5f. The reaction was performed using racemic glycidol as the epoxy alcohol and 2-(bromomethyl)-4,4-dimethyl-4,5-dihydroisoxazole. The two diastereoisomer were separated by flash chromatography (dichloromethane : methanol = 94 : 6) obtaining 246 mg of 4,5-*cis*-**5f** and 164 mg of 4,5-*trans*-**5f** (410 mg combined, 89% yield). The isolated isomers were found to be only sparingly soluble in any deuterated solvent. Acceptable spectra were obtained in acetone-*d*₆. Better spectra were obtained for the corresponding bis-*O*-(*tert*-butyldimethylsilyl) ethers prepared as described elsewhere.¹

(±)-4,5-*trans*-**5f**. ^1H NMR (acetone-*d*₆) δ 1.27 (s, 6H); 3.63 (dd, 1H, J = 11.8, J = 5.8); 3.74 (dd, 1H, J = 11.8, J = 4.7); 4.00 (s, 2H); 4.57 (ddd, 1H, J = 2.0, J = 5.8, J = 4.2); 5.50 (d, 1H, J = 2.0) ppm. ^{13}C NMR (acetone-*d*₆) δ 24.32 (q); 61.15 (t); 68.30 (s); 75.39 (t); 75.39 (d); 85.90 (d); 109.83 (s); 154.58 (s) ppm.

(±)-4,5-*cis*-**5f**. ^1H NMR (acetone-*d*₆) δ 1.29 (s, 6H); 3.78 (dd, 1H, J = 11.7, J = 6.3); 4.04 (s, 2H); 4.68 (ddd, 1H, J = 5.5, J = 6.3, J = 5.8); 5.58 (d, 1H, J = 5.8) ppm. ^{13}C NMR (acetone-*d*₆) δ 28.08 (q); 58.80 (t); 67.39 (s); 73.62 (t); 79.55 (d); 83.77 (d); 112.30 (s); 154.55 (s) ppm.

(±)-Bis-*O*-(*tert*-butyldimethylsilyl)-4,5-*trans*-**5f**. ^1H NMR (CDCl_3) δ 0.08 (s, 6H), 0.14 (s, 3H), 0.16 (s, 3H), 0.85 (s, 9H), 0.87 (s, 9H), 1.33 (s, 6H), 3.70 (dd, 1H, J = 5.1, J = 11.3), 3.76 (dd, 1H, J = 4.0, J = 11.3), 4.07 (s, 1H), 4.08 (s, 1H), 4.38 (ddd, 1H, J = 1.1, J = 4.0, J = 5.1), 5.47 (d, 1H, J = 1.1) ppm. ^{13}C NMR (CDCl_3) δ -5.11 (q); -4.33 (q); -4.27 (q); 18.45 (s); 18.59 (s); 25.06 (q); 26.20 (q); 28.75 (q); 62.37 (t); 68.60 (s); 76.90 (d); 79.38 (t); 84.68 (d); 109.60 (s); 153.65 (s) ppm. Anal calcd for C₂₁H₄₂N₂O₅Si₂: C, 54.98; H, 9.23; N, 6.11. Found: C, 55.12; H, 9.31; N, 6.19.

(±)-Bis-*O*-(*tert*-butyldimethylsilyl)-4,5-*cis*-**5f**. ^1H NMR (CDCl_3) δ 0.09 (s, 6H), 0.11 (s, 3H), 0.16 (s, 3H), 0.88 (s, 9H), 0.90 (s, 9H), 1.34 (s, 3H), 1.35 (s, 3H), 3.95 (dd, 1H, J = 6.6, J = 11.3), 4.04 (s, 2H), 4.04 (dd, 1H, J = 5.2, J = 11.3), 4.55 (dt, 1H, J = 5.2, J = 6.6), 5.33 (d, 1H, J = 5.2) ppm. ^{13}C NMR (CDCl_3) δ -5.46 (q), -5.49 (q), -5.12 (q), -4.23 (q); 18.52 (s); 25.99 (q); 26.07 (q); 28.30 (q); 28.51 (q); 59.52 (t); 68.47 (s); 74.31 (t); 79.24 (d); 82.56 (d); 111.00 (s); 153.35 (s) ppm. Anal calcd for C₂₁H₄₂N₂O₅Si₂: C, 54.98; H, 9.23; N, 6.11. Found: C, 55.13; H, 9.25; N, 6.01.

4,5-trans-5b

4,5-trans-5b

(±)-4,5-*cis*-**5e**

(±)-Bis-O-TBDMS-4,5-trans-5e

(±)-Bis-*O*-TBDMS-4,5-*trans*-**5e**

(±)-Bis-O-TBDMS-4,5-cis-5e

(±)-Bis-O-TBDMS-4,5-trans-5f

(±)-Bis-*O*-TBDMS-4,5-*cis*-**5f**