Supporting information

Experimental

General procedure for cyclopropanation reaction: The enone **1c** (9.48 mmol) and a suitable sulfonium salt (10.5 mmol) was dissolved in toluene (8 mL). The resulting solution was cooled with ice-water and DBU (1.57 mL, 10.5 mmol) was added in a dropwise manner. The resultant mixture was stirred at indicated temperature (Table 1) until the enone disappeared mentored by TLC and then 40 mL of ethyl acetate was added to dilute the solution. After the organic layer was separated, it was washed with water and brine, and dried over Na_2SO_4. The solvent was evaporated and the residual oil was chromatographed (1/4 ~1/2 ethyl acetate/petroleum ether as eluent) to afford the corresponding cyclopropanation products.

(1*R*,2*R*,3*R*)-2-Benzoyl-3-[(*R*)-(2,2-dimethyl-[1,3]dioxolan-4-yl)]-cyclopropanecarboxylic acid, ethyl ester 3a: $[\alpha]^{14}_{D}$ -31.3 (*c* 1.35, $CHCl_3$); IR (neat) 3053, 1721, 1665 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.97 (d, *J* = 8.4 Hz, 2H), 7.59 (dd, *J* = 8.4, 8.0 Hz, 1H), 7.49 (t, *J* = 8.3 Hz, 2H), 4.32 (dt, *J* = 9.3, 6.4 Hz, 1H), 4.20 (q, *J* = 7.3 Hz, 2H), 3.73 (dd, *J* = 8.0, 6.3 Hz, 1H), 3.24 (dd, *J* = 5.6, 4.7 Hz, 1H), 2.59 (dd, *J* = 9.3, 4.7 Hz, 1H), 2.20 (ddd, *J* = 9.4, 9.4, 5.9 Hz, 1H), 1.44 (s, 3H), 1.33 (s, 3H), 1.29 (t, *J* = 7.3 Hz, 3H); MS *m/z* 319 ($M^+ + H^+$); HRMS found *m/z* 318.1489 (M^+), $C_{20}H_{21}NO_4$ requires 318.1467.

(1*S*,2*R*,3*R*)-2-Benzoyl-3-[(*R*)-(2,2-dimethyl-[1,3]dioxolan-4-yl)]-cyclopropanecarboxylic acid, ethyl ester 4a: $[\alpha]^{17}_{D}$ +74 (*c* 0.25, $CHCl_3$); IR (neat) 3053, 1721, 1665 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 8.04 (t, *J* = 8.0 Hz, 2H), 7.56 (t, *J* = 7.9 Hz, 1H), 4.22 (m, 2H), 3.99 (q, *J* = 7.1 Hz, 2H), 3.76 (dt, *J* = 9.0, 4.8 Hz, 1H), 2.92 (dd, *J* = 9.1, 6.2 Hz, 1H), 2.45-2.34 (m, 2H), 1.41 (s, 3H), 1.34 (s, 3H), 1.04 (t, *J* = 7.1 Hz, 3H); MS *m/z* 319 ($M^+ + H^+$); HRMS found *m/z* 318.1489 (M^+), $C_{20}H_{21}NO_4$ requires 318.1467.

(1*R*,2*R*,3*R*)-2-Acetyl-3-[(*R*)-(2,2-dimethyl-[1,3]dioxolan-4-yl)]-cyclopropanecarboxylic acid, ethyl ester 3b: $[\alpha]^{14}_{D}$ -65.2 (*c* 1.0, $CHCl_3$); IR (neat) 3053, 1738, ^1H NMR (300 MHz, $CDCl_3$) δ 1.19 (t, *J* = 7.1 Hz, 3H), 1.27 (s, 3H), 1.35 (s, 3H), 2.12 (m, 2H), 2.21 (s, 3H), 2.34 (m, 1H), 3.67 (m, 1H), 3.76(m, 1H), 4.11(m, 3H).

(1*S*,2*R*,3*R*)-2-Benzoyl-3-[(*R*)-(2,2-dimethyl-[1,3]dioxolan-4-yl)]-cyclopropanecarboxylic acid, ethyl ester 4b: $[\alpha]^{17}_{D}$ +96 (*c* 0.2, $CHCl_3$); IR (neat) 3053, 1735; ^1H NMR (300 MHz, $CDCl_3$) δ 1.21 (t, *J* = 7.1 Hz), 1.30 (s, 3H), 1.37 (s, 3H), 2.13 (m, 1H), 2.17 (m, 1H), 2.25 (s, 3H), 3.68 (m, 1H), 4.00 (m, 1H), 4.11(m, 3H).

Synthesis of 9 from 3a: To a solution of **3a** (2.4 g, 7.5 mmol) in 10 mL of 95% ethanol was added NaOH (300 mg, 7.5 mmol). The mixture was stirred at 0 °C for 10 h and then ethanol was removed by rotavapor. The residue was added 10 mL of brine and NaH_2PO_4 until pH = 5, and extracted with methylene chloride (3 x 30 mL). After the combined organic layers were dried over Na_2SO_4 and concentrated, the residual oil was chromatographed eluting with 1/1 ethyl acetate/petroleum ether to provide 2.15 g of acid.

The above acid (2.1 g, 7.1 mmol) was dissolved in 20 mL of CH_2Cl_2. To this stirring solution was added HOBt (1.0 g, 7.4 mmol) and $HNEt_2$ (0.92 mL, 8.8 mmol).

The mixture was cooled in ice bath and then a solution of DCC (1.5 g, 7.4 mmol) in 5 mL of CH_2Cl_2 was added in a dropwise manner. After the resulting solution was stirred at room temperature overnight, it was diluted with 30 mL of methylene chloride and then washed with aqueous NH_4Cl, and dried over Na_2SO_4. The solvent was removed by rotavapor and the residual oil was chromatographed to afford 1.93 g (74%) of **9**.

(1*R*,2*R*,3*R*)-2-Benzoyl-3-[(*R*)-1,2-diacetoxyethyl]-cyclopropanecarboxylic acid, diethyl amide 10: A mixture of **9** (1.9 g, 5.6 mmol) in 30 mL of MeOH and 10 mL of 10% aqueous HCl was stirred overnight. After the solution was concentrated, the residue was diluted with 70 mL of methylene chloride, and washed by aqueous $NaHCO_3$. The organic layer was dried over Na_2SO_4, and concentrated to dryness to give 1.6 g of crude diol as an oil, which was dissolved in 10 mL of CH_2Cl_2. To this stirring solution was added DMAP (10 mg, 0.08 mmol), 2.17 mL of triethylamine, and Ac_2O (1.48 mL, 15.9 mmol) with cooling by ice-water. After stirring was continued for 1 h at the same temperature, the solution was diluted with 50 mL of methylene chloride, washed with aqueous NH_4Cl, and dried over Na_2SO_4. The crude product was purified by chromatography eluting with ½ ethyl acetate/petroleum ether to afford 1.72 g (79%) of **10** as an oil. $[\alpha]^{18}_D$ -78.2 (*c* 0.55, $CHCl_3$); IR (neat) 1746, 1674 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 8.02 (d, *J* = 8.5 Hz, 2H), 7.55 (t, *J* = 8.4 Hz, 1H), 7.47 (t, *J* = 8.4 Hz, 2H), 5.00 (dt, *J* = 9.5, 4.7 Hz, 1H), 4.31 (dd, *J* = 11.9, 3.8 Hz, 1H), 4.14 (dd, *J* = 11.9, 5.0 Hz, 1H), 3.62-3.49 (m, 3H), 3.30 (dt, *J* = 14.6, 7.2 Hz, 1H), 3.20 (dt, *J* = 14.4, 7.1 Hz, 1H), 2.56 (dd, *J* = 9.2, 4.5 Hz, 1H), 2.31 (m, 1H), 2.00 (s, 3H), 1.92 (s, 3H), 1.22 (t, *J* = 7.2 Hz,

3H), 1.07 (t, J = 7.2 Hz, 3H); MS *m/z* 389 ($M^+ + H^+$); HRMS found *m/z* 389.1814 ($M^+ + H^+$), $C_{21}H_{27}NO_6$ requires 389.1838.

(1*R*,2*R*,3*R*)-2-[(*R*)-1,2-diacetoxyethyl]-3-diethylcarbamoyl-cyclopropane-carboxylic acid, phenyl ester 11: To a solution of $(CF_3CO)_2O$ (1.2 mL, 8.5 mmol) in 1 mL of methylene chloride was added 95% H_2O_2 (0.35 mL, 8.4 mmol) at 0 °C. After the mixture was stirred for 10 min, a suspension solution of **10** (440 mg, 1.13 mmol) and Na_2HPO_4 (600 mg, 4.2 mmol) in 5 mL of CH_2Cl_2 was added. The resultant solution was stirred at room temperature overnight and then refluxed for 0.5 h. The cooled solution was diluted with 50 mL of CH_2Cl_2, washed by saturated aqueous $NaHCO_3$, and dried over Na_2SO_4. After removal of solvent, the residual oil was chromatographed eluting with ½ ethyl acetate/petroleum ether to afford 380 mg (83%) of **11** as a pale yellow oil. $[\alpha]^{14}_D$ -32.8 (*c* 2.8, $CHCl_3$); IR (neat) 1746, 1638 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.39 (t, J = 8.0 Hz, 2H), 7.25 (t, J = 8.0 Hz, 1H), 7.11 (d, J = 8.1 Hz, 2H), 4.93 (dt, J = 10.0, 4.4 Hz, 1H), 4.41 (dd, J = 11.9, 4.2 Hz, 1H), 4.28 (dd, J = 11.9, 4.5 Hz, 1H), 3.65-3.51 (m, 2H), 3.30 (dt, J = 14.6, 7.2 Hz, 1H), 3.22 (dt, J = 14.4, 7.1 Hz, 1H), 2.81 (t, J = 5.1 Hz, 1H), 2.53 (dd, J = 9.9, 4.6 Hz, 1H), 2.20 (ddd, J = 9.9, 9.7, 5.6 Hz, 1H), 2.08 (s, 3H), 2.03 (s, 3H), 1.24 (t, J = 7.2 Hz, 3H), 1.09 (t, J = 7.2 Hz, 3H); MS *m/z* 406 ($M^+ + H^+$); HRMS found *m/z* 406.1839 ($M^+ + H^+$), $C_{21}H_{28}NO_7$ requires 406.1866.

(1*R*,2*R*,3*R*)-2-[(*R*)-1,2-dihydroxyethyl]-3-diethylcarbamoyl-cyclopropane-carboxylic acid, methyl ester 12: To a solution of **11** (440 mg, 1.1 mmol) in 5 mL of anhydrous MeOH was added K_2CO_3 (340 mg, 2.5 mmol). The resultant mixture was stirred at room temperature overnight before 3 mL of iodomethane was added. The

stirring was continued for 12 h and then the solvent was removed by rotavapor. The residue was partitioned between 50 mL of methylene chloride and 10 mL of water. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated. Column chromatography of the residual oil afforded 210 mg (75%) of **12**. $[\alpha]^{17}_D$ 53.3 (*c* 1.2, $CHCl_3$); IR (neat) 1731, 1621 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 3.73 (m, 1H), 3.70 (s, 3H), 3.60-3.30 (m, 6H), 2.36 (dd, *J* = 9.1, 5.2 Hz, 1H), 2.29 (t, *J* = 5.3 Hz, 1H), 1.93 (m, 1H) 1.25 (t, *J* = 7.2 Hz, 3H), 1.11 (t, *J* = 7.2 Hz, 3H); MS *m/z* 260 ($M^+ + H^+$); HRMS found *m/z* 259.1414 (M^+), $C_{12}H_{21}NO_5$ requires 259.1420.

(1*R*,2*R*,3*R*)-2-[(*R*)-1-*tert*-butyldimethylsiloxy-2-hydroxyethyl]-3-diethyl-carbamoyl-cyclopropanecarboxylic acid, methyl ester 13: A solution of **12** (150 mg, 0.58 mmol), *tert*-butyldimethylsilyl chloride (104 mg, 0.69 mmol), DMAP (52 mg, 0.43 mmol), and triethylamine (0.25 mL, 1.8 mmol) in 2 mL of methylene chloride was stirred for 12 h. The solution was partitioned between 20 mL of methylene chloride and 5 mL of brine. After the organic layer was concentrated, the residual oil was chromatographed (1/3 ethyl acetate/petroleum as eluent) to afford 188 mg (87%) of **13**. $[\alpha]^{17}_D$ -48.6 (*c* 0.70, $CHCl_3$); IR (neat) 1733, 1623 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 3.69 (s, 3H), 3.64 (d, *J* = 5.5 Hz, 2H), 3.62-3.29 (m, 5H), 2.38 (d, *J* = 7.2 Hz, 2H), 1.95 (m, 1H), 1.24 (t, *J* = 7.1 Hz, 3H), 1.12 (t, *J* = 7.1 Hz, 3H), 0.88 (s, 9H), 0.05 (s, 6H); MS *m/z* 374 ($M^+ + H^+$); HRMS found *m/z* 373.2280 (M^+), $C_{18}H_{35}NO_5Si$ requires 373.2284.

(1*R*,2*R*,3*R*)-2-[(*S*)-1-*tert*-butyldimethylsiloxy-2-azido-ethyl]-3-diethyl-carbamoyl-cyclopropanecarboxylic acid, methyl ester 14: To a solution of **13** (180 mg, 0.48 mmol) in 8 mL of anhydrous THF was added triphenylphosphine (633 mg, 2.4

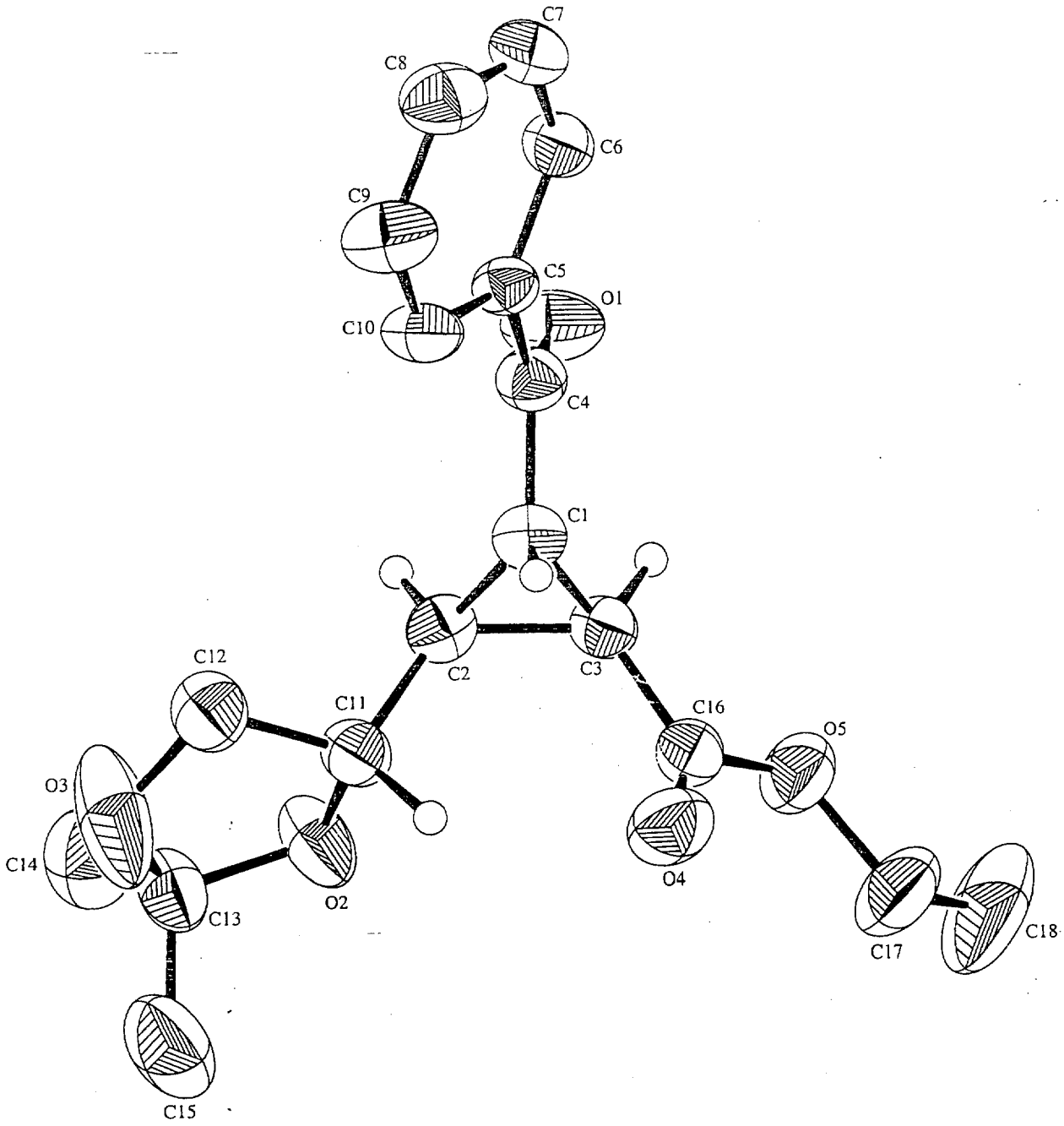
mmol), diethyl azodicarboxylate (0.93 mL, 2.4 mmol), and diphenylphosphoryl azide (0.50 mL, 2.4 mmol) at -20 °C respectively. After the stirring was continued for 6 h at the same temperature, the reaction solution was warmed to room temperature and then stirred overnight. The solvent was removed via rotavapor and the residual oil was directly loaded on a silica gel column and then eluted with 1/5 ethyl acetate/petroleum ether to provide 144 mg (75%) of **14** as a yellow oil. $[\alpha]^{24}_{D}$ -13.9 (*c* 1.0, $CHCl_3$); IR (neat) 2114, 2004, 1734 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 3.73 (s, 3H), 3.66 (m, 1H), 3.60-3.20 (m, 6H), 2.58 (t, J = 5.1 Hz, 1H), 2.40 (dd, J = 9.6, 4.8 Hz, 1H), 1.97 (m, 1H), 1.28 (t, J = 7.1 Hz, 3H), 1.10 (t, J = 7.1 Hz, 3H), 0.89 (s, 9H), 0.08 (s, 6H); MS *m/z* 399 ($M^+ + H^+$); HRMS found *m/z* 398.2344 (M^+), $C_{18}H_{34}N_4O_4Si$ requires 398.2349.

(1*R*,2*R*,3*R*)-2-[(*S*)-1-*tert*-butyldimethylsiloxy-2-ethyl]-3-diethyl-carbamoyl-cyclopropanecarboxylic acid, methyl ester 15: A suspension of 20 mg of 10% Pd/C in ethyl acetate (2 mL) was vigorously stirred under hydrogen atmosphere until the uptake of hydrogen ceased. To this was added a mixture of azide **14** (130 mg, 0.30 mmol) and di-*tert*-butyl dicarbonate (260 mg, 1.16 mmol) in ethyl acetate (1 mL). The resulting solution was stirred under H_2 (1 atm) at r.t. until disappearance of the azide as monitored by TLC. The solution was filtered and the filtrate was concentrated *in vacuo* to give the crude product. The crude product was purified by column chromatography on silica gel (1/4 ethyl acetate/petroleum ether as eluent) to give 120 mg (84%) of **15** as a pale yellow oil. $[\alpha]^{22}_{D}$ -20.8 (*c* 0.75, $CHCl_3$); IR (neat) 3378, 1714, 1620 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 4.87 (br s, 1H), 3.75 (m, 1H), 3.69 (s, 3H), 3.63-3.15 (m, 6H), 2.71 (m, 1H), 2.34 (dd, J = 9.6, 4.9 Hz, 1H), 2.03 (m, 1H), 1.48 (s, 9H), 1.26 (t, J =

7.1 Hz, 3H), 1.08 (t, J = 7.1 Hz, 3H), 0.88 (s, 9H), 0.04 (s, 6H); MS *m/z* 473 ($M^+ + H^+$); HRMS found *m/z* 472.2942 (M^+), $C_{23}H_{44}N_2O_6Si$ requires 472.2967.

(1*R*,2*R*,3*R*)-2-[(*S*)-1-*tert*-butyldimethylsiloxy-2-ethyl]-3-diethyl-carbamoyl-cyclopropanecarboxylic acid, methyl ester 16: To a solution of **15** (100 mg, 0.21 mmol) in THF (5 mL) was added tetrabutylammonium fluoride hydrate (266 mg, 1 mmol) and HOAc (0.1 mL, 1.7 mmol) at 0 °C. The resulting solution was stirred at r.t. for 4 h and poured into saturated $NaHCO_3$ solution (10 mL). The mixture was extracted with methylene chloride three times and the combined organic layers were washed with water, brine, dried over anhydrous Na_2SO_4 and then concentrated. The crude product was purified by column chromatography on silica gel (1/3 ethyl acetate/petroleum ether as eluent as eluent) to provide 75 mg of alcohol, which was dissolved in 7 mL of acetone. This resultant solution was cooled with ice-water and 80 μL of Jones reagent was added. After the reaction mixture was stirred at the same temperature for 3 h it was allowed to warm to r.t. The reaction was quenched with 2-propanol and extracted with EtOAc three times. The combined organic layers were washed with brine, dried over anhydrous Na_2SO_4, and then concentrated *in vacuo* to give an oily residue. This oil was purified by column chromatography (1/3 ethyl acetate/petroleum as eluent) to afford 50 mg (71%) of **16**. $[\alpha]^{20}_D$ +23.3 (*c* 0.45, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.75 (br d, J = 6.9 Hz, 1H), 4.42 (dd, J = 11.0, 7.1 Hz, 1H), 3.74 (s, 3H), 3.51-3.34 (m, 6H), 2.59 (t, J = 5.5 Hz, 1H), 2.42 (dd, J = 8.5, 6.2 Hz, 1H), 1.83 (m, 1H), 1.43 (s, 9H), 1.23 (t, J = 7.2 Hz, 3H), 1.16 (t, J = 7.1 Hz, 3H); MS *m/z* 372 (M^+); HRMS found *m/z* 372.1901 (M^+), $C_{17}H_{28}N_2O_7$ requires 372.1897.

(2*S*,1'*R*,2'*R*,3'*R*)-2-(2',3'-dicarboxycyclopropyl)glycine: A mixture of **16** (50 mg, 0.14 mmol) and 2 mL of 6 N HCl was heated in a sealed tube at 80 °C for 24 h. The cooled solution was concentrated to dryness and the residue was purified with DOWEX-50W (elution with 1% NH_3) to give 20 mg (65% yield) of L-DCG-IV as an ammonium salt. $[\alpha]^{20}_D$ -19.6 (*c* 0.56, H_2O) [lit.[3] $[\alpha]^{20}_D$ -20.2 (*c* 0.44, H_2O)]; ^1H NMR (300 MHz, D_2O) δ 3.94 (d, *J* = 9.9 Hz, 1H), 2.17 (dd, *J* = 9.5, 4.9 Hz, 1H), 2.05 (t, *J* = 5.6 Hz, 1H), 1.86 (ddd, *J* = 9.9, 9.5, 5.3 Hz, 1H).



X-ray structure of **3a**