Special Issue on "Synthetic Carbohydrate Chemistry"

J. Indian Chem. Soc.,
Vol. 97, February 2020, pp. 237-242

A concise and efficient approach to the stereoselective total synthesis of (+)-secosyrin 1 and (+)-syributin 1

Perali Ramu Sridhar*and Boddu Umamaheswara Rao

School of Chemistry, University of Hyderabad, Hyderabad-500 046, India

E-mail: prssc@uohyd.ernet.in

Manuscript received online 29 September 2019, revised and accepted 17 December 2019

A concise and stereoselective approach for the total synthesis of (+)-secosyrin 1 and (+)-syributin 1, metabolites of *Pseudomonas syringae*, is reported. The key synthetic step in this approach is a highly stereoselective construction of spiro center, through a one-pot dehydrohalogenation, intramolecular hetero-Michael addition (IHMA) and ester hydrolysis of halohydrins derived by the ring opening of 1,2-cyclopropanecarboxylated xylal derivative.

Keywords: Carbohydrates, spiro-sugars, Michael addition, secondary metabolites, plant defense.

Introduction

The defense mechanism in plants against microbial invasion initiates by the recognition of invading pathogen there by activation of a mechanism known as "hypersensitive response". This defense reaction is generally triggered by the detection of specific elicitor compounds produced by the pathogen[1]. Syringolides 1 and 2[2] (**1a** and **1b**) are the first known non-proteinaceous C-glycosidic low molecular weight signal molecules produced extracellularly from the plant pathogen *Pseudomonas syringae* pv. *tomato* expressing avirulence gene D (*avrD*)[3]. These oxygen-rich tricyclic compounds elicit the hypersensitive response specifically in soybean cultivars carrying the *Rpg4* disease resistance gene. Along with syringolides four other structurally related compounds, secosyrins 1 and 2 (**2a** and **2b**), syributins 1 and 2 (**3a** and **3b**) were also isolated (Fig. 1)[4].

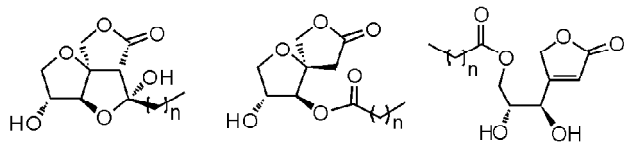


Fig. 1. Molecular structures of syringolides, secosyrins and syributins.

Although secosyrin 1 and 2, syributins 1 and 2 do not display similar biological activity like syringolides, these structures provide clues about the biosynthetic pathway for syringolide formation as well as the nature and function of *avrD* gene and its protein product, respectively. In fact, it has been proposed that secosyrins 1 and 2 are derived from syringolides via reverse-Claisen type reaction and also related to the syributins via β-elimination, followed by 1,3-acyl migration[4c].

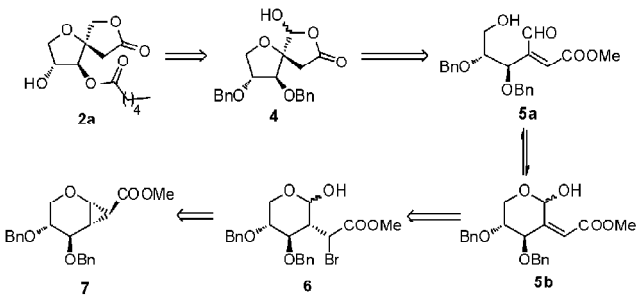
In view of the structural challenge, the synthesis of secosyrin 1 (**2a**) and syributin 1 (**3a**) has been the subject of some synthetic and biological interest. The first total synthesis of **2** and **3** was reported by Hanaoka[5], starting from diisopropyl D-tartrate and construction of the spiro-ring via an alkyne-cobalt complex as a key step. Subsequently Wong[6], in their approach utilized an intramolecular Michael addition of butenolide as a crucial step in creating the spiro framework. In 2004, Donohoe *et al.*[7], reported an interesting approach from furan substituted amide. Rao[8] and co-workers described the synthesis of **2** and **3** using a stereoselective Wittig reaction and an intramolecular Michael addition on the disubstituted butenolide as key steps. Recently, Donner[9] reported a ketyl radical cyclization of β-disubstituted acrylates to achieve the spirocyclic framework of **2** and **3**.

Despite a number of racemic and stereoselective total syntheses[10] reported to date, a practically simple and highly efficient stereoselective synthesis of these molecules remains elusive. A major challenge in the total synthesis of these metabolites is the stereoselective formation of quaternary carbon spiro center. In our continuous efforts towards the application of 1,2-cyclopropanecarboxylated sugars in the construction of novel molecular architectures and natural product synthesis[11], herein we describe a concise stereoselective synthesis of (+)-secosyrin 1 (**2a**) and (+)-syributin 1 (**3a**) from D-xylal derived 1,2-cyclopropanecarboxylate.

Results and discussion

In our synthetic approach towards secosyrin 1 **2a**, we envisaged that **2a** could be synthesized from spiro-cyclic lactol **4** by sequential steps involving dehydroxylation, hydrogenolysis and regioselective acylation. Compound **4** could be obtained from hydroxyaldehyde **5a** via a one-pot stereoselective intramolecular hetero Michael addition (IHMA) followed by ester hydrolysis.

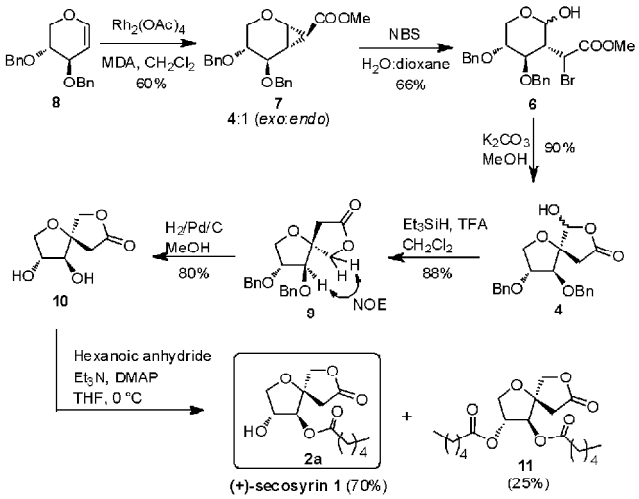
We assumed that compound **5a** could exist in equilibrium with the more stable hemi-acetal **5b** which could be synthesized from bromohydrin **6** by dehydrohalogenation. Bromohydrin **6** could be easily accessible by an electrophilic ring opening of known 3,4-di-*O*-benzyl-D-xylal derived 1,2-cyclopropanecarboxylate **7**.



Scheme 1. Retrosynthetic plan of (+)-secosyrin 1 **2a**.

Thus, the synthesis of secosyrin 1 **2a** was commenced by stereoselective cyclopropanation of 3,4-di-*O*-benzyl-D-xylal **8** using methyl diazoacetate (MDA) in presence of catalytic $Rh_2(OAc)_4$ in CH_2Cl_2 to give the 1,2-cyclopropanecarboxylate **7** in 4:1 ratio (*exo*:*endo,* respectively) in good yield (Scheme 2). Bromonium ion mediated electrophilic ring opening of **7** with *N*-bromosuccinimide in a mixture of 1,4-dioxane:water (2:1) gave the bromohydrin **6** as a mixture of diastereomers. Reaction of bromohydrin **6** with K_2CO_3/MeOH provided a diastereomeric mixture of spirocyclic lactol **4** involving a one-pot dehydrohalogenation, IHMA and ester hydrolysis. Dehydroxylation of compound **4** using Et_3SiH/TFA in CH_2Cl_2 provided a 4:1 mixture of spirolactone **9**. The stereochemistry at spirocenter in compound **9** (major isomer) was assigned based on observing strong NOE between 4-CH and 6-CH_2 (please see the Supporting Information). Interestingly, hydrogenolysis of **9** under Pd/C/H_2 in MeOH provided diol **10** as a single isolable diastereomer in excellent yield.

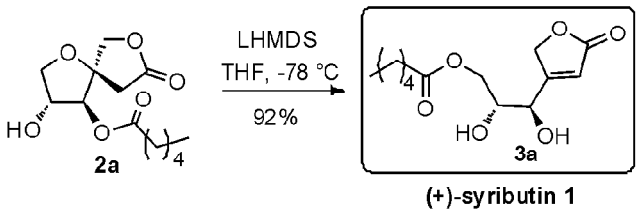
Selective acylation of **10** with one equivalent of hexanoic anhydride provided (+)-secosyrin 1 (**2a**) (lit. $[\alpha]^{20}_D$ +40.2 (*c* 1.1 in $CHCl_3$)[8], $[\alpha]^{25}_D$ +43.60 (*c* 0.45 in $CHCl_3$)) as a major product in 70% yield along with diacylated product **11** as a minor product (25% yield).



Scheme 2. Stereoselective total synthesis of (+)-secosyrin 1 (**2a**).

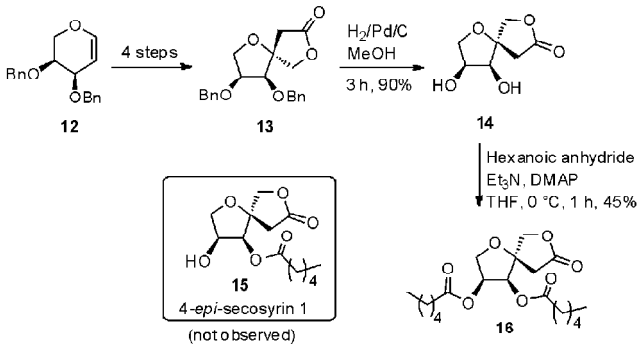
Further treatment of compound **2a** with LHMDS provided (+)-syributin 1 (**3a**) (lit. $[\alpha]^{20}_D$ +6.09 (*c* 0.8 in $CHCl_3$)[8], $[\alpha]^{25}_D$ +6.13 (*c* 0.08 in $CHCl_3$)) in 92% yield via a retro-Michael type reaction followed by migration of hexanoyl group from secondary to primary hydroxyl function (1,3-acyl migration, Scheme 3). Synthetic secosyrin 1 (**2a**) and syributin 1 (**3a**) were also confirmed by comparison with the spectral data of the previous reports of synthetic and naturally isolated compounds.

We further focused our attention towards the synthesis of 4-*epi* secosyrin 1 **15**. Thus, spirolactone **13**[11b] was pre-



Scheme 3. Stereoselective synthesis of (+)-syributin 1 (**3a**).

pared as a single diastereomer from 3,4-di-*O*-benzyl-L-arabinal **12** adopting the above mentioned protocol. Hydrogenolysis of **13** provided diol **14** in excellent yield. However, acylation of **14** with one equivalent of hexanoic anhydride provided the diacylated product **16** in 45% yield as a sole product and no trace amount of the expected monoacylated compound **15** was identified (Scheme 4).



Scheme 4. Attempted synthesis of (+)-4-*epi*-secosyrin 1 (**15**).

Conclusion

In conclusion, a concise and stereoselective approach for the total synthesis of (+)-secosyrin 1 **2a** and (+)-syribuin 1 **3a**, metabolites of *Pseudomonas syringae,* is reported. The overall yield of compounds **2a** and **3a** are 19.7% and 18.1% from easily available starting material 3,4-di-*O*-benzyl-D-xylal. In addition to that, present approach has a high access to the stereoselective synthesis of various analogues of secosyrins. Application of this approach to the synthesis of other components of this family is under progress.

Experimental

*Methyl 4,5-bis(benzyloxy)-2-oxabicyclo[4.1.0]heptane-7-carboxylate (**7**):* To a stirred suspension of glycal **8** (3.5 g, 11.80 mmol) and $Rh_2(OAc)_4$ (100 mg, 0.23 mmol) in anhydrous CH_2Cl_2 (15 mL) was added dropwise, over a period of 1 h, a solution of methyl diazoacetate (3.5 mL, 35.4 mmol) in CH_2Cl_2 (20 mL). After cessation of the nitrogen evolution (5–10 min), the reaction mixture was concentrated *in vacuo* and the remaining residue was purified by silica gel column chromatography (eluent: 10–30% EtOAc in hexane) to afford the desired 1,2-cyclopropanecarboxylate adduct **7** as a colorless gum (2.20 g, 60% yield). R_f (20% EtOAc/hexane) = 0.49; for major isomer; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.29–7.39 (10H, m), 4.68 (1H, d, *J* 12.0 Hz), 4.60 (1H, d, *J* 12.0 Hz), 4.58 (1H, d, *J* 12.0 Hz), 4.51 (1H, d, *J* 12.0 Hz), 4.01 (1H, dd, *J* 1.6, 7.2 Hz), 3.95 (1H, d, *J* 2.0 Hz), 3.75 (1H, dd, *J* 1.6, 12.0 Hz), 3.69 (s, 3H), 3.49–3.50 (m, 1H), 2.30 (1H, dd, *J* 2.0, 6.4 Hz), 1.93 (1H, dd, *J* 6.4, 7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ 172.5, 137.7, 128.5, 128.4, 127.9, 127.8, 127.7, 74.4, 71.6, 70.9, 70.4, 62.3, 58.7, 51.8, 24.4, 23.9; MS (EI): *m/z:* 368 (M^+).

*Methyl-2-(4,5-bis(benzyloxy)-2-hydroxytetrahydro-2H-pyran-3-yl)-2-bromoacetate (**6**):* To a stirred solution of 1,2-cyclopropanecarboxylate **7** (2.10 g, 5.70 mmol) in 1,4-dioxane:water (20 mL (2:1)) was added *N*-bromosuccinimide (1.22 g, 6.84 mmol) and the stirring was continued until the reaction mixture showed the absence of starting material on TLC. The reaction mixture was then concentrated to half its volume *in vacuo* and extracted with CH_2Cl_2 (3×30 mL). The combined extracts were dried over anhydrous Na_2SO_4, filtered and concentrated. Purification by column chromatography over silica gel using EtOAc:hexane provided the bromohydrin **6** as a colorless gum (1.75 g, 66% yield). R_f (20% EtOAc/hexane) = 0.35; (diastereomeric mixture); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.38–7.28 (10H, m), 5.48 (bt, 1H), 4.99–4.87 (2H, m), 4.80 (1H, m), 4.77–4.58 (3H, m), 4.21 (1H, m), 4.11–4.01 (3H, m), 3.90–3.80 (1H, m), 3.75 (1H, s), 3.68 (1H, m), 3.57 (1H, m), 3.50 (3H, s), 3.43 (1H, m), 2.47 (1H, m); ^{13}C NMR (100 MHz, $CDCl_3$): δ 169.6, 168.5, 138.2, 137.9, 137.7, 137.6, 128.5, 128.4, 128.3, 128.2, 127.9, 127.89, 127.82, 127.7, 94.9, 92.4, 78.5, 74.3, 74.1, 72.5, 61.8, 61.6, 53.2, 53.1, 50.1, 49.0, 47.8, 45.0; MS (EI): *m/z:* 465 (M^+).

*3,4-Bis(benzyloxy)-6-hydroxy-1,7-dioxaspiro[4.4]nonan-8-one (**4**):* To a stirred solution of bromohydrin **6** (1.50 g, 3.22 mmol) in CH_3OH (15 mL) under nitrogen was added K_2CO_3 (0.89 g, 6.44 mmol) at 25°C. The reaction mixture was stirred for a period of 6 h. Solvent was evaporated, and the reaction

mixture was diluted with CH_2Cl_2 (50 mL) and washed with 1% HCl (30 mL) and water (30 mL). The organic layer was dried over anhydrous Na_2SO_4 and concentrated. Column chromatography of the crude product with EtOAc:hexane afforded the pure spirocyclic lactol **4** as a colorless gum (1.07 g, 90% yield). R_f (30% EtOAc/hexane) = 0.42; (diastereomeric mixture); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.40–7.28 (20H, m), 5.61 (0.8H, bs), 5.54 (1H, d, *J* 10.0 Hz), 4.69 (1H, d, *J* 12.0 Hz), 4.63 (1H, d, *J* 2.4 Hz), 4.56–4.50 (5H, m), 4.42–4.38 (3H, m), 4.13–4.10 (3H, m), 4.05 (1H, d, *J* 4.8 Hz), 4.01–3.98 (3H, m), 3.76 (1H, bs), 3.04 (2H, t, *J* 18.4 Hz), 2.58 (2H, dd, *J* 18.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ 175.1, 172.7, 137.38, 137.32, 137.0, 136.7, 128.7, 128.6, 128.1, 128.0, 127.8, 127.7, 102.0, 99.8, 90.3, 87.3, 82.9, 81.8, 81.6, 72.8, 71.9, 71.5, 71.4, 71.2, 35.0, 34.7; MS (EI): *m/z:* 370 (M^+).

*3,4-Bis(benzyloxy)-1,7-dioxaspiro[4.4]nonan-8-one (**9**):* To a stirred solution of spirolactol **4** (0.50 g, 1.35 mmol) in CH_2Cl_2 at 0°C was added triethylsilane (0.86 mL, 5.40 mmol) and trifluoroacetic acid (0.20 mL, 2.70 mmol) dropwise respectively and continued stirring while allowing the reaction to RT. After completion of reaction (~4 h), solvent was evaporated and the crude product was purified by column chromatography over silica gel using EtOAc:hexane to afford pure spirolactone **9** as a colorless gum (0.42 g, 88% yield). R_f (30% EtOAc/hexane) = 0.55; (major diastereomer); ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.32–7.44 (10H, m), 4.71 (1H, d, *J* 12.0 Hz), 4.58 (1H, d, *J* 11.6 Hz), 4.56 (1H, d, *J* 12.0 Hz), 4.51 (1H, d, *J* 12.0 Hz), 4.35 (1H, d, *J* 6.0 Hz), 4.25 (1H, d, *J* 6.0 Hz), 4.15–4.18 (1H, m), 4.09 (1H, dd, *J* 4.4, 10.0 Hz), 4.00 (1H, bs), 3.92 (1H, bs), 3.00 (1H, d, *J* 18.0 Hz), 2.61 (1H, d, *J* 18.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$): δ 175.0, 137.2, 137.0, 128.7, 128.6, 128.3, 127.8, 127.6, 87.3, 84.2, 81.7, 76.0, 72.4, 71.8, 70.9, 35.1; MS (EI): *m/z:* 355 (M+1).

*3,4-Dihydroxy-1,7-dioxaspiro[4.4]nonan-8-one (**10**):* A solution of compound **9** (300 mg, 0.84 mmol) in ethylacetate (10 mL) and MeOH (0.4 mL) in the presence of one drop of 1 *N* HCl was hydrogenated over 10% Pd-C (30 mg) under a hydrogen atmosphere for 3 h at 25°C. After completion of reaction (TLC), the catalyst was filtered off and the filtrate was concentrated. The crude product was purified by silica gel column chromatography using hexane-ethyl acetate (1:1) to provide compound **10** (117.0 mg, 80%) as colorless solid. R_f (50% EtOAc/hexane) = 0.21; $[\alpha]_D^{25}$ = –26 (*c* 0.35, CH_3OH); IR (neat): 3463, 3345, 1767, 1361, 1265, 736 cm^{-1}; ^{1}H NMR (400 MHz, CD_3OD): δ 4.80 (2H, bs), 4.72 (1H, s), 4.34 (1H, d, *J* 3.2 Hz), 4.01 (1H, dd, *J* 3.6, 6.8 Hz), 3.90 (1H, d, *J* 10.0 Hz), 3.71 (2H, q, *J* 8.8, 11.2 Hz), 2.95 (1H, d, *J* 18.8 Hz), 2.54 (1H, d, *J* 18.8 Hz); ^{13}C NMR (100 MHz, CD_3OD): δ 177.3, 90.2, 90.0, 75.5, 74.9, 64.0, 37.9.

*3-Hydroxy-8-oxo-1,7-dioxaspiro[4.4]nonan-4-yl hexanoate (or) ((+)-secosyrin 1) (**2a**) and 8-oxo-1,7-dioxaspiro [4.4]nonane-3,4-diyl dihexanoate (**11**):* To a solution of compound **10** (100 mg, 0.57 mmol) in dry THF (7.0 mL), was added dry Et_3N (80 μL, 0.57 mmol), DMAP (10 mg) and hexanoic anhydride (120 μL, 0.52 mmol) at 0°C sequentially. After stirring for 1 h at 0°C, the reaction mixture was diluted with saturated $NaHCO_3$ solution (20 mL) and extracted with ether (3×10 mL). The combined organic layers were washed with water (20 mL), brine (10 mL) and solvent was evaporated *in vacuo*. The crude product was purified by column chromatography using hexane-ethyl acetate (5:1) gave compound **11** (52.0 mg, 25% yield) as a colorless oil. Further elution with hexane-ethyl acetate (2:1) afforded compound **2a** (109 mg, 70% yield) as a colorless oil. (**2a**): R_f (40% EtOAc/hexane) = 0.43; $[\alpha]_D^{25}$ = +43 (*c* 1.2, $CHCl_3$); IR (neat): 3485, 1778, 1737, 1265, 1087, 736 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$): δ 4.99 (1H, d, *J* 1.5 Hz), 4.46 (2H, d, *J* 10.5 Hz), 4.39 (1H, d, *J* 10.5 Hz), 4.33 (ddd, 1H, *J* 1.5, 3.5, 5.5 Hz), 4.15 (1H, dd, *J* 5.5, 10.5 Hz), 3.88 (1H, dd, *J* 2.5, 10.0 Hz), 2.79 (1H, d, *J* 18.0 Hz), 2.61 (1H, d, *J* 18.0 Hz), 2.37 (2H, t, *J* 7.5 Hz), 1.67–1.61 (2H, m), 1.36–1.30 (4H, m), 0.91 (3H, t, *J* 7.0 Hz); ^{13}C NMR (125 MHz, $CDCl_3$): δ 174.4, 173.7, 86.6, 81.7, 75.8, 75.7, 72.8, 35.4, 34.0, 31.1, 24.4, 22.2, 13.8; HRMS (ESI): Calcd. for $C_{13}H_{21}O_6$+H 273.1338, Found: 273.1341. (**11**): R_f (20% EtOAc/hexane) = 0.75; $[\alpha]_D^{25}$ = –14 (*c* 0.35, $CHCl_3$); IR (neat): 2974, 1786, 1754, 1264, 738 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$): 5.27 (d, 1H, *J* 1.5 Hz), 5.18 (dd, 1H, *J* 1.5, 2.0 Hz), 4.38 (2H, m), 4.23 (1H, dd, *J* 5.0, 11.0 Hz), 3.87 (1H, dd, *J* 2.5, 11.0 Hz), 2.74 (1H, d, *J* 18.0 Hz), 2.59 (1H, d, *J* 18.0 Hz), 2.40–2.33 (4H, ddd, *J* 7.5, 8.0, 15.0 Hz), 1.66–1.63 (4H, m), 1.33–1.25 (8H, m), 0.92 (6H, t, *J* 7.0 Hz); ^{13}C NMR (125 MHz, $CDCl_3$): δ 173.7, 172.46, 172.43, 87.1, 77.7, 76.9, 75.2, 71.3, 35.2, 33.95, 33.91, 33.86, 31.16, 31.15, 24.43, 24.39, 22.23, 22.21, 13.85; HRMS (ESI): Calcd.

for $C_{19}H_{31}O_7$+H 371.2070, Found: 371.2070.

4-(1,2-Dihydroxy-5-oxodecyl)furan-2(5H)-one (or) ((+)-*syributin 1) (**3a**):* To a solution of compound **2a** (35 mg, 0.128 mmol) in dry THF (4.0 mL) was added a 1 *M* solution of LHMDS (0.15 mL, 0.15 mmol) dropwise at –78°C. The reaction mixture was stirred at –78°C for 30 min, and then warmed to 0°C. The reaction was quenched with saturated aqueous solution of NH_4Cl and extracted with diethyl ether (3×10 mL). The combined extracts were dried over anhydrous Na_2SO_4 and concentrated *in vacuo*. The crude product was purified by column chromatography over silica gel using ethyl acetate-hexane (2:1) to afford compound **3a** (32 mg, 92%) as a colorless oil. R_f (50% EtOAc/hexane) = 0.25; $[\alpha]_D^{25}$ = +6 (*c* 0.08, $CHCl_3$); IR (neat): 3438, 1778, 1737, 1097, 736 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$): 6.09 (1H, q, *J* 1.5 Hz), 4.97 (1H, d, *J* 2.0 Hz), 4.94 (1H, d, *J* 2.0 Hz), 4.64 (1H, d, *J* 2.0 Hz), 4.34 (1H, dd, *J* 5.0, 12.0 Hz), 4.19 (dd, 1H, *J* 6.0, 11.5 Hz), 3.97 (dddd, 1H, *J* 3.0, 5.5, 6.0, 8.5 Hz), 2.38 (2H, t, *J* 7.5 Hz), 1.68–1.62 (2H, m), 1.35–1.30 (4H, m), 0.91 (3H, t, *J* 7.0 Hz); ^{13}C NMR (125 MHz, $CDCl_3$): δ 174.6, 173.4, 169.1, 116.8, 71.6, 71.5, 68.8, 64.7, 34.0, 31.2, 24.5, 22.2, 13.8; HRMS(ESI): Calcd. for $C_{13}H_{21}O_6$+H 273.1338, Found: 273.1337.

*(3S,4S,5R)-3,4-Dihydroxy-1,7-dioxaspiro[4.4]nonan-8-one (**14**):* R_f (50% EtOAc/Hexane) = 0.23; IR (neat): 3459, 3341, 1759, 1263 cm^{-1}; ^1H NMR (500 MHz, CD_3OD): δ 4.81 (d, 1H, *J* 5.0 Hz), 4.41 (m, 1H), 4.05 (m, 1H), 3.69 (dd, 1H, *J* 2.0, 7.0 Hz), 3.61 (dd, 2H, *J* 11.5, 15.0 Hz), 2.82 (d, 1H, *J* 18.5 Hz), 2.60 (d, 1H, *J* 18.5 Hz); ^{13}C NMR (125 MHz, CD_3OD): δ 176.3, 87.7, 84.1, 75.9, 70.9, 63.5, 37.7.

*(3S,4S,5R)-8-Oxo-1,7-dioxaspiro[4.4]nonane-3,4-diyl dipropionate (**16**):* By following the same procedure for compound **2a**, compound **16** was prepared from **14** (26.0 mg, 0.15 mmol). The crude product was purified by silica gel column chromatography using ethyl acetate-hexane (1:9) to provide compound **16** (25.0 mg, 45%) as a colorless oil. R_f (10% EtOAc/hexane) = 0.54; $[\alpha]_D^{25}$ = –37 (*c* 0.2, $CHCl_3$); IR (neat): 2974, 1786, 1754, 1264 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$): δ 5.26 (dd, 1H, *J* 6.0, 12.0 Hz), 4.98 (d, 1H, *J* 5.5 Hz), 4.28 (d, 1H, *J* 11.5 Hz), 4.21 (dd, 1H, *J* 3.5, 6.0 Hz), 4.14 (d, 1H, *J* 12.0 Hz), 3.91 (dd, 1H, *J* 2.5, 7.0 Hz), 2.78 (s, 2H), 2.37 (m, 4H), 1.64 (m, 4H), 1.32 (m, 8H), 0.92 (t, 6H, *J* 6.0 Hz); ^{13}C NMR (125 MHz, $CDCl_3$): δ 173.6, 173.0, 172.9, 85.7, 81.4, 71.7, 69.3, 64.7, 38.2, 33.9, 33.7, 31.2, 31.1, 24.4, 24.3, 22.2, 13.8; HRMS(ESI): Calcd. for $C_{19}H_{31}O_7$+H 371.2070, Found: 371.2069.

Supplementary Information

Supplementary data associated with this article is available with the Indian Chemical Society.

Acknowledgements

The authors sincerely thank Council of Scientific and Industrial Research (CSIR), New Delhi, India for grant No. 01(2408)/10/EMR-II.

References

1. (a) A. F. Bent, B. N. Kunkel, D. Dahlbeck, K. L. Brown, R. Schmidt, J. Girauda, J. Leung and B. J. Staskawicz, *Science,* 1994, **265**, 1856; (b) H. N. C. Wong, *Eur. J. Org. Chem.,* 1999, **1999**, 1757; (c) F. Alonso, B. Dacunha, J. Melendez and M. Yus, *Tetrahedron*, 2005, **61**, 3437.
2. (a) R. Chenevert and M. Dasser, *J. Org. Chem*., 2000, **65**, 4529; (b) J. Ishihara, T. Sugumoto and A. Murai, *Tetrahedron*, 1997, **53**, 16029; (c) S. Kuwahara, M. Moriguchi, K. Miyagawa, M. Konno and O. Kodama, *Tetrahedron Lett*., 1995, **36**, 3201; (d) T. Tsurushima, S. L. Midland, C. Zeng, C. Ji, J. J. Sims and N. T. Keen, *Phytochemistry*, 1996, **43**, 1219; (e) S. Kuwahara, M. Moriguchi, K. Miyagawa, M. Konno and O. Kodama, *Tetrahedron*, 1995, **51**, 8809; (f) P. Yu, Q. G. Yang, T. C. W. Mak and H. N. C. Wong, *Tetrahedron*, 1998, **54**, 1783; (g) J. P. Henschke and R. W. Rickards, *Tetrahedron Lett*., 1996, **37**, 3557.
3. (a) T. Honda, H. Mizutani and K. Kanai, *J. Org. Chem*., 1996, **61**, 9374; (b) M. Carda, E. Castillo, S. Rodrïguez, E. Falomir and J. A. Marco, *Tetrahedron Lett*., 1998, **39**, 8895; (c) A. E. Koumbis and A. A. C. Varvogli, *Synlett.*, 2006, 3340; (d) A. A. C. Varvogli, I. N. Karagiannis and A. E. Koumbis, *Tetrahedron*, 2009, **65**, 1048.
4. (a) M. J. Smith, E. P. Mazzola, J. J. Sims, S. L. Midland, N. T. Keen, V. Burton and M. M. Stayton, *Tetrahedron Lett.*, 1993, **34**, 223; (b) S. L. Midland, N. T. Keen, J. J. Sims, M. M. Midland, M. M. Stayton, V. Burton, M. J. Smith, E. P. Mazzola, K. J. Gragam and J. Clardy, *J. Org. Chem.*, 1993, **58**, 2940; (c) S. L. Midland, N. T. Keen and J. J. Sims, *J. Org. Chem*., 1995, **60**, 1118.
5. (a) C. Mukai, S. M. Moharram and M. Hanaoka, *Tetrahedron Lett*., 1997, **38**, 2511; (b) C. Mukai, S. M. Moharram, S. Azukizawa and M. Hanaoka, *J. Org. Chem*., 1997, **62**, 8095.
6. P. Yu, Y. Yang, Z. Y. Zhang, T. C. W. Mak and H. N. C. Wong, *J. Org. Chem*., 1997, **62**, 6359.
7. T. J. Donohoe, J. W. Fisher and P. J. Edwards, *Org. Lett*., 2004, **6**, 465.

8. D. Gautam and B. V. Rao, *Tetrahedron Lett*., 2009, **50**, 1693.

9. C. D. Donner, *Org. Lett*., 2013, **15**, 1258.

10. (a) D. Gautam and B. V. Rao, *Tetrahedron Asymmetry*, 2010, **21**, 2087; (b) M. N. Villalobos, J. L. Wood, S. Jeong, C. L. Benson, S. M. Zeman, C. McCarty, M. M. Weiss, A. Salcedo and J. Jenkins, *Tetrahedron*, 2009, **65**, 8091; (c) J. L. Wood and M. N. Villalobos, *Tetrahedron Lett*., 2009, **50**, 6450.

11. (a) P. R. Sridhar, K. Seshadri and G. M. Reddy, *Chem. Commun*., 2012, **48**, 756; (b) P. R. Sridhar and K. Seshadri, *Tetrahedron*, 2012, **68**, 3725; (c) P. R. Sridhar, K. C. Ashalu and S. Chandrasekaran, *Org. Lett*., 2004, **6**, 1777.