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Synthesis of D- and L-*erythro* 1,5-dithiopent-1-enopyranoside sulfonium salts and their evaluation as glycosidase inhibitors

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ABSTRACT

A series of sulfonium salts derived from 1,5-dithiopent-1-enopyranosides was prepared in a three-step sequence from protected D- and L-erythrofuranoses. The key step is the nucleophilic displacement of a leaving group by a sulfur atom of carbohydrate-derived ketene dithioacetals. Such compounds were assayed for their properties as glycosidase inhibitors.

1. Introduction

Among the known bioactive thiosugars,[1] naturally occurring carbohydrate-derived sulfoniums, with an inner-salt sulfonium sulfate structure, such as salacinol **1**[2] kotalanol **2**,[3] salaprinol **3,** and ponkoranol **4**[4] (Fig. 1) were found to be potent α-glucosidase inhibitors and have exhibited anti-diabetic properties. Recently, de-O-sulfonated kotalanol **5**[5] with an external counterion, was isolated from the same plant and displayed good activity against α-glucosidase. The biological activity of these sulfonium derivatives has been related to their structural ability to mimic the shape and the charge of the glucosyl oxocarbenium-like transition state.[6] Studies on the structure–activity relationships of salacinol and analogues[7] have previously reported the essential role of the sulfonium ion structure for α-glucosidase inhibitory activity. Even *S*-methyl sulfonium have also exhibited a fair inhibition of α-glucosidase.[8] The size of the sulfur-containing heterocycle is also important: five-membered analogues generally possess more activity against α-glucosidase than six-membered sulfoniums.[7a]

Bicyclic sulfonium salts, such as thioswainsonine[9] **6** (an analogue of swainsonine, a naturally occurring α-mannosidase inhibitor) and (1*R*,6*R*,7*R*,8*S*)-7,8-dihydroxy-5-thia-1-thioniabicyclo[4.3.0]nonane chloride[10] **7** (Fig. 2) were also synthesized. The latter compound has shown a good affinity for Golgi mannosidase II, a target in anticancer therapy[11] and a greater selectivity than that of swainsonine.[10] Thioswainsonine **6** was not an effective inhibitor of *Drosophila* Golgi

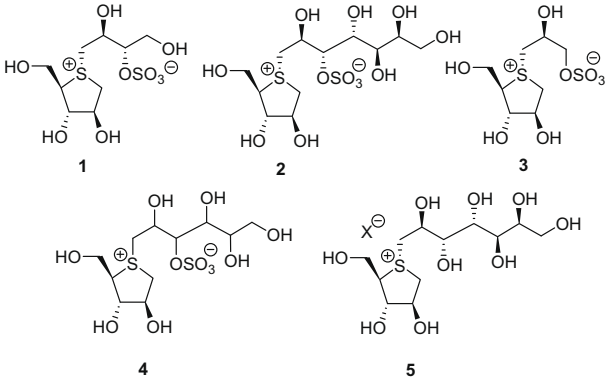

Figure 1. Structures of bioactive thiosugar-derived sulfonium salts.

α-mannosidase II (dMGII), probably due to the stereochemistry at the sulfonium center.[12]

In a recent paper, we have reported the synthesis of 1,5-dithio-1-enopyranosides from protected aldofuranoses in an efficient

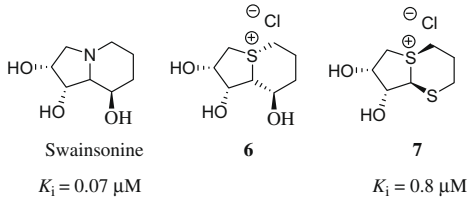

Figure 2. Structures of swainsonine and sulfonium analogues, inhibition against human lysosomal α-mannosidase.

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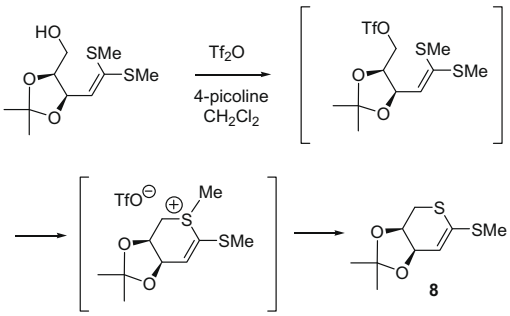


Scheme 1. Synthesis of 1,5-dithio-1-enopyranosides from carbohydrate-derived ketene dithioacetals.

two-step sequence.[13] The key step was a cyclization which involved the formation of an intermediate methyl sulfonium by displacement of a leaving group by one of the sulfur atoms of a carbohydrate-derived ketene dithioacetal (Scheme 1).

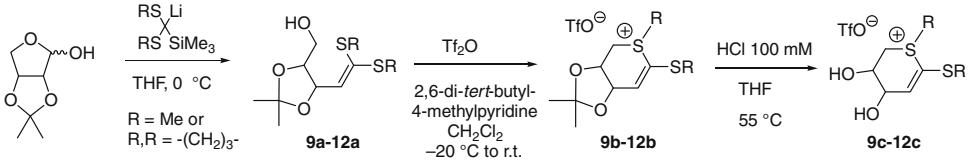
To our knowledge, unsaturated six-membered carbohydrate-derived sulfonium salts have not been described. In this paper, we present the synthesis of methyl and bicyclic 1,5-dithiopent-1-enopyranoside sulfonium as triflate salts, in the D- and L-erythro series and a preliminary evaluation of their glycosidase inhibitory activities.

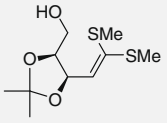
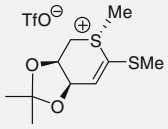
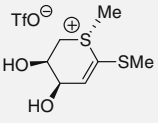
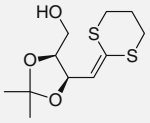
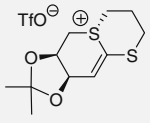
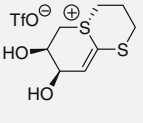
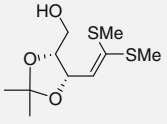
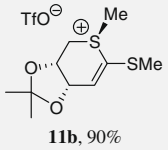
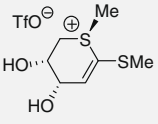
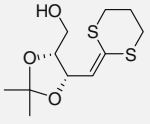
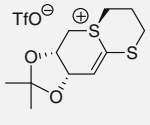
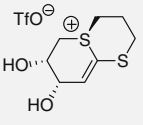
2. Results and discussion

2,3-*O*-Isopropylidene-L-erythrofuranose and 2,3-*O*-isopropylidene-D-erythrofuranose were obtained in two steps, respectively, from L- and D-arabinose as previously described.[14] Peterson olefination from the protected aldofuranoses[15] with the lithium derivatives of bis(methylsulfanyl)trimethylsilylmethane or of commercially available 2-trimethylsilyl-1,3-dithiane afforded the corresponding ketene dithioacetals **9a**–**12a** in good yields (Table 1).

The cyclization step was achieved by activation of the primary alcohol by trifluoromethanesulfonic anhydride (1.2 equiv) in the presence of a substituted pyridine (1.6 equiv) at 0 °C.[13] Only a slight excess of the substituted pyridine is required to prevent the nucleophilic substitution at the methyl group or the dithiane moiety of the sulfonium salts.[16] The intermediate triflate was not isolated and, at room temperature, cyclization occurred leading to sulfonium derivatives **9b**–**12b** (Table 1). Using 4-picoline as the substituted pyridine, purification of the target sulfonium was tedious due to the presence of the pyridinium salt formed during the reaction. The use of 2,6-di-*tert*-butyl-4-methylpyridine instead of 4-picoline led to the precipitation of the corresponding pyridinium salt, which was easily removed by filtration before purification. Deprotection of the acetal groups was easily achieved at 55 °C in a HCl 100 mM/THF 4:1 mixture. Compounds **9c**–**12c** were further purified on hydrophobic resin. Sulfonium derivatives **9b**–**12b** were

Table 1
Preparation of ketene dithioacetals **9a**–**12a** and sulfoniums **9b**–**12b** and **9c**–**12c**



Entry	Protected aldofuranoses	Ketene dithioacetals	Protected sulfonium salts	Deprotected sulfonium salts
1	2,3-*O*-Isopropylidene-L-erythrofuranose	 **9a**, 87%	 **9b**, 100%	 **9c**, 100%
2	2,3-*O*-Isopropylidene-L-erythrofuranose	 **10a**, 73%	 **10b**, 90%	 **10c**, 83%
3	2,3-*O*-Isopropylidene-D-erythrofuranose	 **11a**, 74%	 **11b**, 90%	 **11c**, 100%
4	2,3-*O*-Isopropylidene-D-erythrofuranose	 **12a**, 85%	 **12b**, 83%	 **12c**, 90%

obtained as single stereoisomers. Determination of the configuration of the asymmetric sulfur atom was achieved on compound **9c** by nuclear Overhauser experiments (Fig. 3). As expected, the methyl group at the sulfur atom is located on the opposite side of both hydroxyl groups, due to the steric hindrance of the isopropylidene acetal during the cyclization.

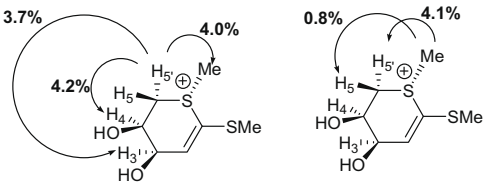


Figure 3. Nuclear Overhauser experiments on compound **9c**.

For this new series of carbohydrate-derived unsaturated sulfonium salts, evaluation of the inhibitory activities was undertaken.[17] Sulfonium salts **11c** and **12c** are especially of interest since they can be considered as six-membered unsaturated swainsonine analogues bearing a permanent positive charge, and the structure of compound **12c** is very close to that of compound **7** illustrated in Figure 2. Docking experiments were carried out using the Gold software (version 4)[18] and the X-ray structure of *Drosophila* Golgi α-mannosidase II (dGMII) co-crystallized with swainsonine (PDB: 1HWW)[11] as a target.

Initially, sulfonium salt **9c**–**12c** ligands were built with Chem3D and their energies were minimized with the semi-empirical MM2 forces field. Concerning compounds **9c** and **10c**, both the hydroxyl groups and the sulfur atom of the sulfonium group are oriented in a wrong direction (data not shown). On the other hand, the predicted binding modes of **11c** and **12c** in the active site of dGMII are comparable to swainsonine and are illustrated in Figure 4. For these two molecules, both hydroxyl groups are oriented to have interactions with the zinc ion present in the active site. The sulfur atom of the sulfonium group is located in the same position as the protonated nitrogen atom of swainsonine. Unfortunately, no inhibition against α-mannosidase from Jack beans (EC 3.2.1.24) was observed for **11c** or **12c** at 1 mM in contrast with the predictions based on docking calculations.

Compounds **9c**–**12c** were then assayed against a panel of glycosidases including α-L-fucosidase, α- and β-galactosidases, α- and β-glucosidases, amyloglucosidase, α- and β-mannosidases, β-xylosidase, and β-*N*-acetylglucosamidase.[17] Compounds **9c**–**12c** showed no or weak inhibition against the glycosidases tested (Table 2). The best result was obtained with compound **10c** and amyloglucosidase (93% inhibition at 1 mM, K_i = 55 μM) although its configuration is not in accordance with that of the natural substrate of α-glucosidases. Such situation has been observed for glucosidase inhibitors possessing a pyrrolidine ring[19] and for (−)-conduramine B-1 that inhibits α-mannosidase from Jack beans much better than α- and β-glucosidases.[20]

3. Conclusion

In summary, a straightforward and efficient strategy was applied to generate a series of methyl and bicyclic sulfonium salts derived from 1,5-dithiopent-1-enopyranosides. Biological assays of these analogues of salacinol showed little inhibitory activity toward glycosidases, except for the bicyclic sulfonium **10c** which revealed an inhibitory activity in the micromolar range against an α-glucosidase (amyloglucosidase). Preparation of new sulfonium derivatives is currently investigated and will be reported in due course.

4. Experimental

4.1. General

All reactions were performed under argon. The solvents were dried and distilled prior to use. THF was distilled from sodium benzophenone ketyl and dichloromethane from calcium hydride. Merck silica gel F254 (0.2 mm) was used for TLC plates. Flash column chromatography was performed over silica gel Merck 9385 (40–63 μm) Kieselgel 60. NMR spectra were recorded on Bruker spectrometers (250 MHz for ^{1}H, 63 MHz for ^{13}C). Chemical shifts are expressed in parts per million (ppm) using TMS as an internal standard. Coupling constants are in hertz and splitting pattern abbreviations are: br, broad; s, singlet; d, doublet; t, triplet; q, quartet; and m, multiplet. Optical rotations were determined at 20 °C with a Perkin–Elmer Model 241 polarimeter. High resolution mass spectra (HRMS) were performed on Q-TOF Micro micromass positive ESI (CV = 30 V).

4.2. General procedure for the preparation of ketene dithioacetals

A solution of *n*-BuLi in hexane (2.1 equiv) was added dropwise to a solution of trimethylsilyl bis(methylthio) methane (2 equiv) in anhydrous THF (2 mL per mmol) at −30 °C or to a solution of 2-trimethylsilyl-1,3-dithiane (2 equiv) at 0 °C. The resulting mixture was stirred for 2 h at −30 °C (or 0 °C) and was cooled to −78 °C for trimethylsilyl bis(methylthio)methane. Simultaneously, a solution of the protected sugar (1 equiv) in anhydrous THF (1.2 mL per

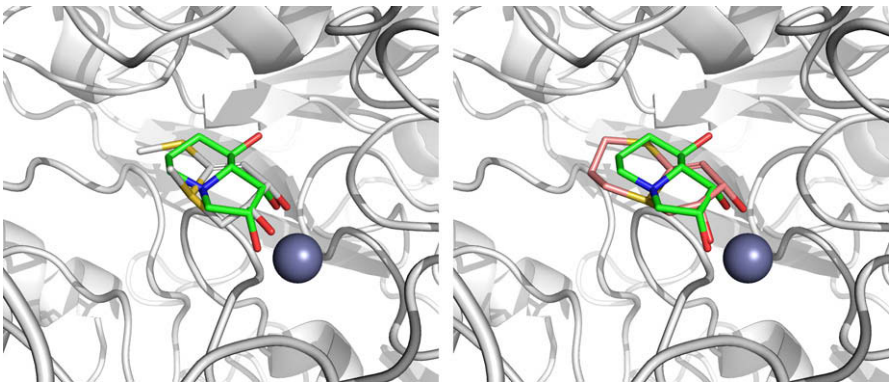


Figure 4. Predicted binding modes for **11c** and **12c** in the active site of dGMII: the active site zinc ion is represented as a blue sphere, swainsonine as appearing in the swainsonine:dMGII complex is represented in green, **11c** and **12c** in white and pink, respectively.

Table 2
Evaluation of compounds **9c**–**12c** as glycosidase inhibitors. % inhibition at [inhibitor] = 1 mM

	9c	10c	11c	12c
α-L-Fucosidase EC 3.2.1.51 human placenta	None	16	None	None
Amyloglucosidase EC 3.2.1.3 *Aspergillus niger*	24	93 (K_i = 55 μM)	None	None
β-Glucosidase EC 3.2.1.21 almonds	55	None	None	None
β-Mannosidase EC 3.2.1.25 snail	None	None	None	21

mmol) was added dropwise to a suspension of NaH 60% (1.2 equiv) in anhydrous THF (2 mL per mmol) at 0 °C. After 2 h, the silyl reagent solution was slowly added to the sugar solution and the mixture was stirred overnight while the temperature was allowed to rise to r.t. Saturated aqueous NH_4Cl was then added and the aqueous phase was extracted with Et_2O (2 × 15 mL). The combined organic layers were dried over $MgSO_4$ and concentrated in vacuo. The crude product was purified by flash chromatography over silica gel (petroleum ether/EtOAc, 75:25) to afford the pure ketene dithioacetals.

4.2.1. 2-Deoxy-3,4-*O*-isopropylidene-L-*erythro*-pent-1-enose dimethyldithioacetal 9a[13]

Yellow oil, yield 87% (1.38 g). ^{1}H NMR (250 MHz, $CDCl_3$): δ 5.72 (d, *J* = 8.1 Hz, 1 H, H-2), 5.35 (dd, *J* = 6.8 Hz, *J* = 8.1 Hz, 1 H, H-3), 4.28 (dt, *J* = 4.4 Hz, *J* = 6.8 Hz, 1 H, H-4), 3.52 (m, 2 H, H-5), 2.34 (s, 3 H, S*CH*$_3$), 2.30 (s, 3 H, S*CH*$_3$), 1.50 (s, 3 H, C(*CH*$_3$)), 1.40 (s, 3 H, C(*CH*$_3$)). ^{13}C NMR (63 MHz, acetone-d_6): δ 139.0 (C-1), 128.6 (C-2), 109.6 (*C*(CH$_3$)$_2$), 80.5 (C-4), 76.7 (C-3), 62.9 (C-5), 28.9 and 26.3 (2C, C(*CH*$_3$)$_2$), 18.1 and 17.3 (2C, S*CH*$_3$).

4.2.2. 2-Deoxy-3,4-*O*-isopropylidene-L-*erythro*-pent-1-enose propane-1,3-diyl dithioacetal 10a

Oil, yield 73% (646 mg). $[\alpha]_D^{20} = -96.1$ (*c* 0.86, $CHCl_3$); ^{1}H NMR (250 MHz, CD_3OD) δ 5.81 (d, 1H, $J_{2,3}$ = 8.6 Hz, H-2), 5.18 (dd, 1H, $J_{3,4}$ = 6.6 Hz, $J_{3,2}$ = 8.6 Hz, H-3), 4.16 (dt, 1H, $J_{4,5}$ = 5.0 Hz, $J_{4,3}$ = 6.6 Hz, H-4), 3.44 (m, 2H, H-5), 3.06–2.80 (m, 4H, S–*CH*$_2$–CH$_2$–*CH*$_2$–S), 2.20–2.10 (m, 2H, S–CH$_2$–*CH*$_2$–CH$_2$–S), 1.45 (s, 3H, CH$_3$), 1.35 (s, 3H CH$_3$); ^{13}C NMR (63 MHz, CD_3OD) δ 135.1 (C-1), 127.0 (C-2), 109.9 (*C*(CH$_3$)$_2$), 80.0 (C-4), 75.4 (C-3), 62.5 (C-5), 30.1, 30.4 (S–*CH*$_2$–CH$_2$–*CH*$_2$–S), 28.2 (CH$_3$), 25.7 (S–CH$_2$–*CH*$_2$–CH$_2$–S), 25.5 (CH$_3$); HRMS (ES): Calcd for $C_{11}H_{18}O_3NaS_2^+$: 285.0595, found 285.0605.

4.2.3. 2-Deoxy-3,4-*O*-isopropylidene-D-*erythro*-pent-1-enose dimethyldithioacetal 11a

Yellow oil, yield 74% (1.14 g). $[\alpha]_D^{20} = +168.2$ (*c* 1.15, $CHCl_3$); MS (ES): 273.1 $[M+Na]^+$.

4.2.4. 2-Deoxy-3,4-*O*-isopropylidene-D-*erythro*-pent-1-enose propane-1,3-diyl dithioacetal 12a

Yellow oil, yield 85% (1.25 g). $[\alpha]_D^{20} = +121.2$ (*c* 1.09, $CHCl_3$); MS (ES): 285.1.

4.3. General procedure for the synthesis of unsaturated sulfonium salts

To a solution of ketene dithioacetal (1 equiv) in dichloromethane (10 mL per mmol) was added 2,6-di-*tert*-butyl-4-methylpyridine (1.6 equiv). The mixture was cooled to –20 °C and trifluoromethanesulfonic anhydride was added dropwise (1.2 equiv). The resulting mixture was stirred for 10 min at –20 °C and then allowed to warm up to 0 °C and stirred for 45 min. After filtration of the pyridinium salt, dichloromethane was evaporated in vacuo. The crude product was purified by flash chromatography over silica gel (dichloromethane/methanol: 14:1.5) to give pure cyclized sulfonium salts.

4.3.1. Methyl 2-deoxy-3,4-*O*-isopropylidene-5-[(*S*)-methyl episulfonium]-1-thio-L-*erythro*-pent-1-enopyranoside trifluoromethanesulfonate 9b

Oil, yield 100% (700 mg). $[\alpha]_D^{20} = +32.5$ (*c* 1.35, MeOH). ^{1}H NMR (250 MHz, $CDCl_3$) δ 6.82 (d, 1H, $J_{2,3}$ = 4.2 Hz, H-2), 4.91–4.81 (m, 2H, H-3, H-4), 4.25 (dd, 1H, $J_{5,4}$ = 5.3 Hz, $J_{5,5'}$ = 12.9 Hz, H-5), 3.99 (dd, 1H, $J_{5',4}$ = 2.0 Hz, $J_{5',5}$ = 12.9 Hz, H-5′), 3.22 (s, 3H, S$^+$*CH*$_3$), 2.57 (s, 3H, S*CH*$_3$), 1.42 (s, 6H, 2 × CH$_3$); ^{13}C NMR (63 MHz, CD_3OD) δ 139.2 (C-2), 124.3 (C-1), 111.9 (*C*(CH$_3$)$_2$), 71.6 (C-3), 68.8 (C-4), 42.7 (C-5), 27.7 (CH$_3$), 26.1 (CH$_3$), 25.6 (S$^+$CH$_3$), 18.5 (SCH$_3$); ^{19}F NMR (235.4 MHz, CD_3OD) δ −78.8 (CF_3); HRMS (ES): Calcd for $C_{10}H_{17}O_2S_2^+$: 233.0670, found 233.0678.

4.3.2. (5*S*,7*R*,8*R*) 7,8-Isopropylidenedioxy-2,3,4,6,7,8-hexahydrothiopyrano[1,2-*a*][1,3]dithiin-5-ium trifluoromethanesulfonate 10b

Oil, yield 90% (673 mg). $[\alpha]_D^{20} = +156.6$ (*c* 1.13, MeOH); MS (ES) 245.1.

4.3.3. Methyl 2-deoxy-3,4-*O*-isopropylidene-5-[(*R*)-methyl episulfonium]-1-thio-D-*erythro*-pent-1-enopyranoside trifluoromethanesulfonate 11b

Yellow oil, yield 90% (766 mg). $[\alpha]_D^{20} = -32.2$ (*c* 0.97, MeOH); HRMS (ES): Calcd for $C_{10}H_{17}O_2S_2^+$: 233.0670, found 233.0666.

4.3.4. (5*R*,7*S*,8*S*) 7,8-Isopropylidenedioxy-2,3,4,6,7,8-hexahydrothiopyrano[1,2-*a*][1,3]dithiin-5-ium trifluoromethanesulfonate 12b

Oil, yield 81% (1.52 g). $[\alpha]_D^{20} = -146.5$ (*c* 1.01, MeOH), ^{1}H NMR (250 MHz, CD_3OD) δ 6.98 (d, 1H, $J_{2,3}$ = 2.1 Hz, H-2), 5.02–4.92 (m, 2H, H-3, H-4), 4.38 (dd, 1H, $J_{5',4}$ = 3.1 Hz, $J_{5',5}$ = 12.8 Hz, H-5′), 4.09 (d, 1H, $J_{5,5'}$ = 12.8 Hz, H-5), 4.06–3.93 (m, 1H, S$^+$C*H*$_2$), 3.73 (td, 1H, *J* = 1.9 Hz, *J* = 12.2 Hz, S$^+$C*H*$_2$), 3.33–3.27 (m, 1H, S$^+$CH$_2$CH$_2$*CH*$_2$), 3.02 (dt, 1H, *J* = 3.5 Hz, *J* = 13.4 Hz, S$^+$CH$_2$CH$_2$*CH*$_2$), 2.80–2.50 (m, 2H, S$^+$CH$_2$*CH*$_2$), 1.48 (s, 3H, CH$_3$), 1.42 (s, 3H, CH$_3$); ^{13}C NMR (63 MHz, CD_3OD) δ 145.9 (C-1), 140.7 (C-2), 111.3 (*C*(CH$_3$)$_2$), 71.0 (C-3), 68.9 (C-4), 43.5 (C-5), 41.9 (S$^+$–*CH*$_2$–CH$_2$–CH$_2$–S), 31.5 (S$^+$–CH$_2$–*CH*$_2$–CH$_2$–S), 27.7 (CH$_3$), 26.4 (CH$_3$), 25.9 (S$^+$–CH$_2$–CH$_2$–*CH*$_2$–S); ^{19}F NMR (235.4 MHz, CD_3OD) δ −79.2 (CF_3); HRMS (ES): Calcd for $C_{10}H_{17}O_2S_2^+$: 245.0670, found 245.0674.

4.4. General method for deprotection of the acetal

The sulfonium salt is dissolved in a THF/HCl 100 mM 1:4 mixture (1 mL per 0.1 mmol). The resulting mixture is allowed to warm up to 55 °C and stirred for 6 h. Solvents were evaporated in vacuo. The crude product was purified over hydrophobic resin HP 20 SS (DIAION) using water as eluant and was lyophilized.

4.4.1. Methyl 2-deoxy-5-[(*S*) methyl episulfonium]-1-thio-L-*erythro*-pent-1-enopyranoside trifluoromethanesulfonate 9c

Oil, yield 100% (89 mg). $[\alpha]_D^{20} = -47.4$ (*c* 0.90, MeOH), ^{1}H NMR (250 MHz, CD_3OD) δ 6.79 (d, 1H, $J_{2,3}$ = 2.8 Hz, H-2), 4.44 (t, 1H, $J_{3,4}$ = 3.1 Hz, H-3), 4.39 (dd, 1H, $J_{4,3}$ = 3.1 Hz, $J_{4,5}$ = 6.4 Hz, H-4), 4.17

(dd, 1H, $J_{5,4}$ = 6.4 Hz, $J_{5,5'}$ = 12.4 Hz, H-5), 3.81 (dd, 1H, $J_{5',4}$ = 1.0 Hz, $J_{5',5}$ = 12.4 Hz, H-5′), 3.17 (s, 3H, S^+CH_3); 2.52 (s, 3H, SCH_3); ^{13}C NMR (63 MHz, CD_3OD) δ 147.0 (C-2), 124.2 (C-1), 67.8 (C_3), 64.4 (C-4), 46.3 (C-5), 26.3 (S^+CH_3), 18.5 (SCH_3); ^{19}F NMR (235.4 MHz, CD_3OD) δ −80.4 (CF_3). HRMS (ES): Calcd for $C_7H_{13}O_2S_2^+$: 193.0357, found 193.0360.

4.4.2. (5*S*,7*R*,8*R*)-7,8-Dihydroxy-2,3,4,6,7,8-hexahydrothiopyrano-[1,2-*a*][1,3]dithiin-5-ium trifluoromethanesulfonate 10c

White solid (decomposition 140 °C), yield 83%, (83 mg). $[\alpha]_D^{20}$ = +92.2 (*c* 1.65, MeOH), HRMS (ES): Calcd for $C_8H_{13}O_2S_2^+$: 205.0357, found 205.0354.

4.4.3. Methyl 2-deoxy-5-[methylsulfonium]-1-thio-D–erythro-pent-1-enopyranoside trifluoromethanesulfonate 11c

Oil, yield 100% (177 mg). $[\alpha]_D^{20}$ = +47.2 (*c* 0.87, MeOH); HRMS (ES): Calcd for $C_7H_{13}O_2S_2^+$: 193.0357, found 193.0354.

4.4.4. (5*R*,7*S*,8*S*)-7,8-Dihydroxy-2,3,4,6,7,8-hexahydrothiopyrano-[1,2-*a*][1,3]dithiin-5-ium trifluoromethanesulfonate 12c

White solid, Yield 90% (90 mg). $[\alpha]_D^{20}$ = −96.0 (*c* 0.60, MeOH); ^{1}H NMR (250 MHz, CD_3OD) δ 6.85 (br s, 1H, H-2), 4.45 (m, 1H, H-3), 4.42 (m, 1H, H-4), 4.06 (dd, 1H, $J_{5,4}$ = 5.8 Hz, $J_{5,5'}$ = 12.2 Hz, H-5′), 3.84–3.81 (m, 1H, S^+CH_2), 3.74 (d, 1H, $J_{5,5'}$ = 12.2 Hz, H-5), 3.58 (ddd, 1H, *J* = 2.4 Hz, *J* = 7.5 Hz, *J* = 11.5 Hz, S^+CH_2), 3.17 (ddd, 1H, *J* = 2.4 Hz, *J* = 7.5 Hz, *J* = 13.5 Hz, $S^+CH_2CH_2$), 2.95–2.92 (m, 1H, $S^+CH_2CH_2$), 2.70–2.67 (m, 1H, $S^+CH_2CH_2CH_2$), 2,53–2,47 (m, 1H, $S^+CH_2CH_2CH_2$). ^{13}C NMR (63 MHz, CD_3OD) δ 145.9 (C-1), 118.3 (C-2), 67.9 (C-3); 63.9 (C-4), 48.0 (C-5), 44.5 ($S^+CH_2CH_2$), 32.8 ($S^+CH_2CH_2$), 27.0 ($S^+CH_2CH_2CH_2$); ^{19}F NMR (235.4 MHz, CD_3OD) δ −80.5 (CF_3). HRMS (ES): Calcd for $C_8H_{13}O_2S_2^+$: 205.0357, found 205.0351.

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