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Note

Ferrier sulfonamidoglycosylation of D-glycals

Pedro A. Colinas* and Rodolfo D. Bravo

LADECOR, Departamento de Química, Facultad de Ciencias Exactas, Universidad Nacional de La Plata, 47 y 115, 1900 La Plata, Argentina

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Abstract—A series of novel *N*-glycosyl sulfonamides were prepared via Ferrier sulfonamidoglycosylation of D-glycals with good to high α-stereoselectivity. Two new glycosylsulfamides were tested as carbonic anhydrase (CA II) inhibitors and showed good properties in the micromolar range.

Keywords: Sulfonamidoglycosylation; Glycals; Sulfonamides; Ferrier rearrangement

In the development of new chemotherapeutic agents, several sulfonamides have emerged as useful therapeutics for the treatment of cancer. E7010,[1] E7070,[1] ABT751,[2] and T138067[3] have been found to be inhibitors of tumor cell proliferation, and some of them are under clinical evaluation and will soon be launched as antitumor drugs (Fig. 1). The mechanism of the antitumor action of these compounds has been studied in detail, and these compounds are shown to inhibit microtubule assembly by binding to tubulin at the colchicine binding site.[4] Other sulfonamides possessing a free sulfonamido moiety probably act as strong carbonic anhydrase (CA) inhibitors.[5] It was found that isozyme CA IX is overexpressed in a variety of tumor types and plays an important role in the growth and survival of tumor cells.[6] Thus its inhibition is the target for the development of novel antitumor therapeutics.

Only a few reports have described the synthesis of sulfonamide glycosides. Danishefsky's group reported on the reaction of glycals with iodonium di-*sym*-collidine perchlorate and benzenesulfonamide to afford stereoselectively 2-β-iodo-1-α-sulfonamidohexoses.[7] This class of glycosylsulfonamides was used for the preparation of oligosaccharides with a 2-aminohexose subunit.[8]

Recently, we have reported on the stereoselective synthesis of glycosylsulfonamides via sulfonamidoglycosylation of benzylated glycals using a catalytic amount of triphenylphosphine hydrobromide.[9] The novel method afforded the β-sulfonamidoglycosides in good to high yields. Later on we developed a novel approach to ribofuranosylsulfonamides using the reaction of methyl glycosides with sulfonamides in the presence of boron trifluoride etherate.[10] Some of the glycosylsulfonamides prepared by us showed antiproliferative activity against human hepatocellular carcinoma in the micromolar range.[9]

To the best of our knowledge, there is only one known example of the Ferrier sulfonamidoglycosylation of glycals. Chandrasekhar et al. reported the reaction of tri-*O*-acetyl-D-glucal with sulfonamides in the presence of tris(pentafluorophenyl)borane as catalyst.[11] This methodology afforded the glycosylsulfonamides as anomeric mixtures that were not separated. The authors also reported that reaction of glucal **1** with *p*-toluenesulfonamide using boron trifluoride etherate (1 mol %) as catalyst afforded a complex mixture of products. Surprisingly, in our hands, the reaction afforded the *p*-toluenesulfonamido 2,3-unsaturated glycoside **4a** in 95% yield with very good stereoselectivity (Scheme 1).

This success encouraged us to study the conditions for the Ferrier sulfonamidoglycosylation using 3,4,6-tri-*O*-acetyl-D-galactal (**1**) or 3,4,6-tri-*O*-acetyl-D-glucal (**2**)

* Corresponding author. Tel.: +54 221 424 3104; fax: +54 221 4226947; e-mail: pcolinas@quimica.unlp.edu.ar

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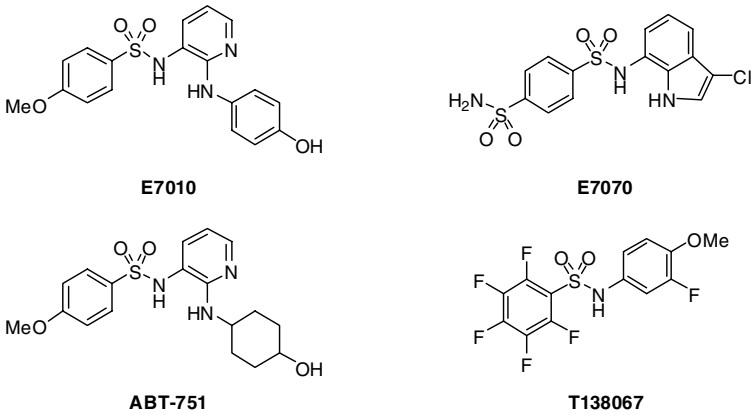
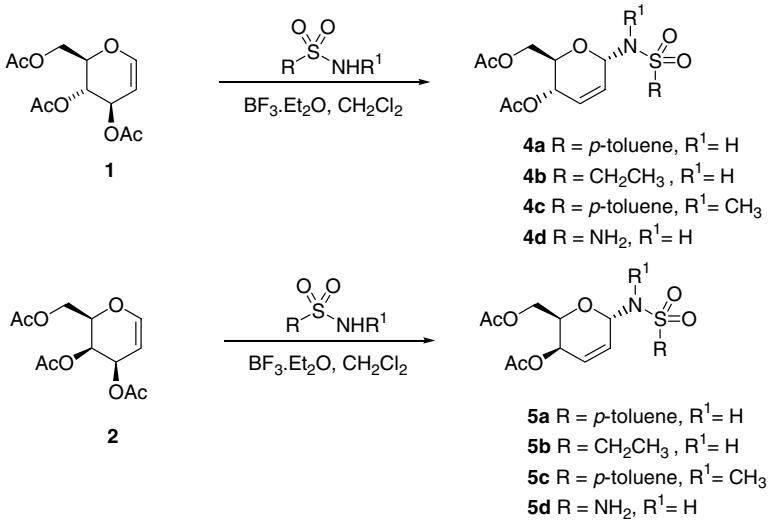


Figure 1. Antimitotic sulfonamides.



Scheme 1.

and *p*-toluenesulfonamide in the presence of a catalytic amount of different catalysts such as $BF_3{\cdot}Et_2O$, $HBF_4{\cdot}SiO_2$, $HClO_4{\cdot}SiO_2$. In all cases the α isomer was produced predominantly, and the different catalysts had little influence in the anomeric ratios. The formation of 2-deoxy glycosides was not observed. As the results summarized in Table 1 clearly show, sulfonamidoglycosylations are found to be best effected by a catalytic amount of $BF_3{\cdot}Et_2O$.

The anomeric mixtures could be easily purified by flash column chromatography and/or crystallization to afford the pure α anomer. The anomeric configuration was supported by NOESY experiments (in $CDCl_3$ or CD_3CN), for example, the configuration of **5b** is consistent with NOEs between NH and H-5, and between H-4 and H-5. To enhance the synthetic utility of this reaction, we next tested the sulfonamidoglycosylations of glycals and several sulfonamides using $BF_3{\cdot}Et_2O$ as the catalyst (Table 2). In all the cases we examined, 2,4,6-tri-*O*-acetyl-2,3-dideoxy-D-hex-2-enopyranosyl sulfonamides **4** and **5** were obtained in high yield and with very good α selectivity.

Table 1. Reaction of 3,4,6-tri-*O*-acetyl-D-glucal (**1**) and 3,4,6-tri-*O*-acetyl-D-galactal (**2**) with *p*-toluenesulfonamide[a]

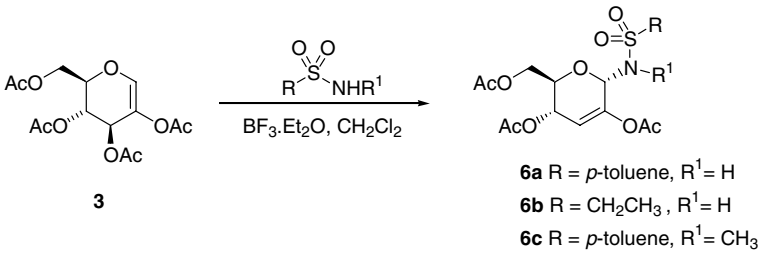
Entry	Glycal	Catalyst	*t* (h)	α:β[b]	Yield (%)
1	Glucal	$BF_3{\cdot}Et_2O$ (1 mol %)	0.5	87:13	95
2		$HClO_4{\cdot}SiO_2$ (135 mg)[c]	3	83:17	80
3		$HBF_4{\cdot}SiO_2$ (270 mg)[d]	0.5	85:15	84
4	Galactal	$BF_3{\cdot}Et_2O$ (1 mol %)	0.5	80:20	96
5		$HClO_4{\cdot}SiO_2$ (135 mg)	3	80:20	79
6		$HBF_4{\cdot}SiO_2$ (270 mg)	1.5	87:17	83

[a] All the reactions were performed using 1 mmol of the glycal and 1.1 equiv of the sulfonamide.
[b] Anomeric ratios were determined by ^1H NMR spectroscopy.
[c] 0.5 mmol of $HClO_4$ g^{-1}.
[d] 0.5 mmol of HBF_4 g^{-1}.

Table 2. Reaction of 3,4,6-tri-*O*-acetyl-D-glucal (**1**) and 3,4,6-tri-*O*-acetyl-D-galactal (**2**) with different sulfonamides[a]

Entry	Glycal	Sulfonamide	*t* (h)	Product	α:β[b]	Yield (%)
1	Glucal	Ethyl	0.5	**4b**	85:15	95
2		*N*-Methyl-*p*-toluene	1	**4c**	95:5	80
3		Sulfamide[c]	0.5	**4d**	95:5	89
4	Galactal	Ethyl	1.5	**5b**	83:17	97
5		*N*-Methyl-*p*-toluene	2	**5c**	95:5	86
6		Sulfamide[c]	1	**5d**	95:5	94

[a] All reactions were performed using 1 mmol of the glycal, 1.1 equiv of the sulfonamide and 1 mol % of $BF_3{\cdot}Et_2O$ in CH_2Cl_2.
[b] Anomeric ratios were determined by ^1H NMR spectroscopy.
[c] Reaction performed in CH_3CN.



Scheme 2.

Finally we examined the reaction of 2,3,4,6-tetra-*O*-acetyl-1,5-anhydro-D-*arabino*-hex-1-enitol (**3**) with sulfonamides (Scheme 2). This type of 2-acyloxyglycal has found considerably less attention than the glycals themselves, and the Ferrier sulfonamidoglycosylations of this glycal has not been described in the literature. Also, in this case, the sulfonamidoglycosylation led to the corresponding α-glycosyl sulfonamides **6** as the major products in high yields (Table 3).

The α anomers of the 2,3-enopyranosyl systems could be present in two equilibrium conformations ($^0H_5$ and $^5H_0$). The values of $^3J_{3,4}$ 1.5–1.9 Hz (in $CDCl_3$) found in the *erythro* compounds and $^3J_{3,4}$ 5.4–5.5 Hz in the *threo* compounds indicate that the equilibrium between the two half-chair forms of the sulfonamidoglycosides lies significantly toward the $^0H_5$ conformation.

The compounds obtained in this work are novel, with the exception of **4a**.[11] The glycosylsulfamides **4d** and **5d** were tested as inhibitors of the human carbonic anhydrase (CA) isozyme II and showed good inhibitory properties (inhibition constants of 58 nM and 6 nM). (Supuran, C. T. Laboratorio di Chimica Bioinorganica, University of Florence, Florence, Italy, personal communication.)

Table 3. Reaction of 2,3,4,6-tetra-*O*-acetyl-1,5-anhydro-D-*arabino*-hex-1-enitol (**3**) with sulfonamides[a]

Entry	Sulfonamide	*t* (h)	Product	α:β[b]	Yield (%)
1	*p*-Toluene	0.5	**6a**	95:5	89
2	Ethyl	0.5	**6b**	93:7	94
3	*N*-Methyl-*p*-toluene	1	**6c**	95:5	82

[a] All reactions were performed using 1 mmol of the glycal, 1.1 equiv of the sulfonamide and 1 mol % of $BF_3{\cdot}Et_2O$ in CH_2Cl_2.
[b] Anomeric ratios were determined by ^1H NMR spectroscopy.

1. Experimental

1.1. General methods

All melting points are uncorrected. ^1H and ^{13}C NMR spectra were recorded on a Varian Mercury 200 (200.055 and 50.309 MHz, respectively) using Me_4Si as the internal standard in $CDCl_3$ or CD_3CN. Optical rotations were measured by a Perkin–Elmer 343 instrument in solution in a 1-dm cell. High-resolution mass spectra were recorded on a Finnigan Model MAT 95 mass spectrometer. CH_2Cl_2 and CH_3CN were distilled from P_4O_{10}. $HClO_4{\cdot}SiO_2$ and $HBF_4{\cdot}SiO_2$ were prepared as described previously.[12,13] The reactions were monitored by TLC on Silica Gel 60 F_{254} with detection by charring with sulfuric acid. Flash column chromatography was performed on Silica Gel 60 (230–400 mesh).

1.2. Procedure using $BF_3{\cdot}Et_2$ O as catalyst

To a solution or suspension of the glycal **1**,[14] **2**[14] or **3**[15] (1 mmol) and the sulfonamide (1.1 mmol) in 5 mL of dry CH_2Cl_2 was added, under argon, 1 mol % of $BF_3{\cdot}Et_2O$ at room temperature. After stirring for the time indicated, the mixture was quenched with satd aq $NaHCO_3$. The organic layer was separated and washed with brine,

dried over anhyd Na_2SO_4, and concentrated in vacuo to afford a colorless syrup. The residue was chromatographed on silica gel (eluent hexane–EtOAc) and/or crystallized (EtOAc–hexane) to afford the products.

1.3. Procedure using $HClO_4{\cdot}SiO_2$ or $HBF_4{\cdot}SiO_2$ as catalyst

To a solution or suspension of the glycal **1** or **2** (1 mmol) and the sulfonamide (1.1 mmol) in 5 mL of dry CH_2Cl_2 was added the catalyst at room temperature. After stirring for the time indicated, the reaction mixture was filtered through Celite, and the solvent was evaporated in vacuo. The residue was chromatographed on silica gel (eluent hexane–EtOAc) and/or crystallized (EtOAc–hexane) to afford the sulfonamidoglycosides.

1.4. 4,6-Di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranosyl *p*-toluenesulfonamide (4a)[†]

Colorless syrup: $[\alpha]_D$ +122.5 (*c* 1.1, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.73 (d, 2H, *J* 8.3 Hz, CH_3Ph), 7.24 (d, 2H, *J* 8.3 Hz, CH_3Ph), 6.53 (br d, 1H, *J* 8.9 Hz, NH), 5.80 (dt, 1H, *J* 10.2, 1.9 Hz, H-3), 5.76 (dd, 1H, *J* 10.2, 1.7 Hz, H-2), 5.48 (br d, 1H, *J* 10.2 Hz, H-1), 5.18 (dd, 1H, *J* 9.3, 1.9 Hz, H-4), 3.80 (m, 3H, H-5, 2xH-6a), 2.36 (s, 1H, CH_3Ph), 1.94 (s, 1H, CH_3COO), 1.93 (s, 1H, CH_3COO); ^{13}C NMR ($CDCl_3$) δ 170.41 (CH_3COO), 170.93 (CH_3COO), 130.42 (C-3), 126.91-138.93 (Ph), 126.48 (C-2), 77.33 (C-1), 66.84 (C-5), 64.56 (C-4), 62.09 (C-6), 21.64 (CH_3Ph), 21.05 (CH_3COO), 20.85 (CH_3COO). Anal. Calcd for $C_{17}H_{21}NO_7S$: C, 53.25; H, 5.52; N, 3.65; O, 29.21; S, 8.36. Found: C, 53.31; H, 5.50; N, 3.68; O, 29.17; S, 8.34.

1.5. 4,6-Di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranosyl ethanesulfonamide (4b)

Colorless syrup: $[\alpha]_D$ +81.9 (*c* 0.7, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 6.00 (br d, 1H, *J* 8.9 Hz, NH), 5.90 (dt, 1H, *J* 10.1, 1.6 Hz, H-3), 5.80 (dd, 1H, *J* 10.1, 1.8 Hz, H-2), 5.46 (br d, 1H, *J* 8.9 Hz, H-1), 5.19 (dc, 1H, *J* 9.0, 1.6 Hz, H-4), 4.11 (m, 3H, H-5, H-6a), 3.18 (dc, 2H, *J* 6.8, 2.2 Hz, CH_3CH_2), 2.06 (s, 1H, CH_3COO), 2.03 (s, 1H, CH_3COO), 1.37 (t, 3H, *J* 6.8 Hz, CH_3CH_2); ^{13}C NMR ($CDCl_3$) δ 170.83 (CH_3COO), 170.34 (CH_3COO), 130.26 (C-3), 127.09 (C-2), 76.66 (C-1), 67.73 (C-5), 64.87 (C-4), 63.46 (C-6), 49.44 (CH_3CH_2), 21.10 (CH_3COO), 20.91 (CH_3COO), 8.33 (CH_3CH_2). Anal. Calcd for $C_{12}H_{19}NO_7S$: C, 44.85; H, 5.96; N, 4.36; O, 34.85; S, 9.98. Found: C, 44.87; H, 5.92; N, 4.39; O, 34.87; S, 9.95.

1.6. 4,6-Di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranosyl *N*-methyl-*p*-toluenesulfonamide (4c)

Colorless syrup: $[\alpha]_D$ +55.1 (*c* 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.72 (d, 2H, *J* 8.3 Hz, CH_3Ph), 7.25 (d, 2H, *J* 8.3 Hz, CH_3Ph), 5.91 (dt, 1H, *J* 10.2, 1.9 Hz, H-3), 5.65 (dt, 1H, *J* 10.2, 1.9 Hz, H-2), 5.10 (m, 1H, H-4), 4.65 (br d, 1H, *J* 4.9 Hz, H-1), 3.90 (m, 3H, H-5, 2 × H-6), 2.53 (s, 3H, CH_3N), 2.34 (s, 3H, CH_3Ph) 2.01 (s, 1H, CH_3COO), 1.99 (s, 1H, CH_3COO); ^{13}C NMR ($CDCl_3$) δ 170.77 (CH_3COO), 170.46 (CH_3COO), 129.90 (C-3), 143.85, 136.07, 131.55, 129.43, 128.50 (*Ph*) 127.47 (C-2), 82.91 (C-1), 74.08 (C-5), 64.77 (C-4), 63.26 (C-6), 29.04 (CH_3N), 21.72 (CH_3Ph), 21.12 (CH_3COO), 20.89 (CH_3COO). HRFABMS: calcd for $C_{18}H_{23}NNaO_7S$, 420.1093; found, 420.1096.

1.7. 4,6-Di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranosyl sulfamide (4d)

White needles: mp 150–151 °C; $[\alpha]_D$ +73.1 (*c* 1.2, CH_3CN); ^1H NMR (CD_3CN) δ 6.43 (br d, 1H, *J* 9.8 Hz, NH), 5.97 (dt, 1H, *J* 10.3, 1.6 Hz, H-3), 5.86 (ddd, 1H, *J* 10.3, 2.7 1.9 Hz, H-2), 5.45 (br d, 1H, *J* 9.8 Hz, H-1), 5.35 (br s, 1H, NH_2), 5.23 (dc, 1H, *J* 9.0, 1.6 Hz, H-4), 4.29 (dd, 1H, *J* 15.2, 6.7 Hz, H-6a), 4.07 (m, 1H, H-6b), 4.02 (m, 1H, H-5), 2.08 (s, 1H, CH_3COO), 2.02 (s, 1H, CH_3COO); ^{13}C NMR (CD_3CN) 171.30 (CH_3COO), 171.10 (CH_3COO), 130.43 (C-3), 126.70 (C-2), 78.45 (C-1), 67.93 (C-5), 65.49 (C-4), 64.13 (C-6), 21.17 (CH_3COO), 20.86 (CH_3COO). Anal. Calcd. for $C_{10}H_{16}N_2O_7S$: C, 38.96; H, 5.23; N, 9.09; O, 36.33; S, 10.40. Found: C, 38.95; H, 5.20; N, 9.10; O, 36.36; S, 10.39.

1.8. 4,6-Di-*O*-acetyl-2,3-dideoxy-α-D-*threo*-hex-2-enopyranosyl *p*-toluenesulfonamide (5a)

White needles: mp 154–155 °C; $[\alpha]_D$ −195.6 (*c* 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.81 (d, 2H, *J* 8.4 Hz, CH_3Ph), 7.30 (d, 2H, *J* 8.4 Hz, CH_3Ph), 6.35 (br d, 1H, *J* 9.0 Hz, NH), 6.12 (ddd, 1H, *J* 10.0, 5.4, 1.5 Hz, H-3), 5.95 (dc, 1H, *J* 10.0, 3.2 Hz, H-2), 5.59 (ddd, 1H, *J* 9.0, 3.2, 1.5 Hz, H-1), 4.93 (dd, 1H, *J* 5.4, 2.1 Hz, H-4), 3.89 (m, 2H, H-5, H-6a), 3.37 (dd, 1H, *J* 14.3, 9.0 Hz, H-6b), 2.42 (s, 1H, CH_3Ph), 2.03 (s, 1H, CH_3COO), 1.98 (s, 1H, CH_3COO); ^{13}C NMR ($CDCl_3$) δ 170.64 (CH_3COO), 170.57 (CH_3COO), 129.81 (C-3), 143.98, 138.75, 129.81, 129.63, 126.64, 126.56 (*Ph*), 127.28 (C-2), 76.93 (C-1), 66.60 (C-5), 61.88 (C-4), 61.49 (C-6), 21.74 (CH_3Ph), 20.97 (CH_3COO), 20.86 (CH_3COO). Anal. Calcd for $C_{17}H_{21}NO_7S$: C, 53.25;

[†] The preparation of compound **4a** is mentioned in Ref. 11 but no physical nor spectral data were reported.

H, 5.52; N, 3.65; O, 29.21; S, 8.36. Found: C, 53.28; H, 5.49; N, 3.62; O, 29.29; S, 8.32.

1.9. 4,6-Di-*O*-acetyl-2,3-dideoxy-α-D-*threo*-hex-2-enopyranosyl ethanesulfonamide (5b)

White needles: mp 131–132 °C; $[\alpha]_D$ −180.5 (*c* 1.1, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 6.18 (ddd, 1H, *J* 10.0, 5.4, 1.7 Hz, H-3), 6.02 (dd, 1H, *J* 10.0, 3.2 Hz, H-2), 5.90 (br d, 1H, *J* 8.7 Hz, NH), 5.56 (ddd, 1H, *J* 8.7, 3.2, 1.7 Hz, H-1), 5.02 (dd, 1H, *J* 5.4, 1.9 Hz, H-4), 4.21 (m, 3H, H-5, 2 × H-6), 3.20 (dc, 2H, *J* 7.3, 3.3 Hz, CH_3CH_2), 2.07 (s, 1H, CH_3COO), 2.03 (s, 1H, CH_3COO), 1.39 (t, 3H, *J* 7.3 Hz, CH_3CH_2); ^{13}C NMR ($CDCl_3$) δ 170.74 (CH_3COO), 170.55 (CH_3COO), 129.79 (C-3), 126.52 (C-2), 76.69 (C-1), 67.49 (C-5), 63.27 (C-4), 62.44 (C-6), 49.69 (CH_3CH_2), 20.95 (CH_3COO), 20.93 (CH_3COO), 8.35 (CH_3CH_2). Anal. Calcd for $C_{12}H_{19}NO_7S$: C, 44.85; H, 5.96; N, 4.36; O, 34.85; S, 9.98. Found: C, 44.88; H, 5.95; N, 4.40; O, 34.81; S, 9.96.

1.10. 4,6-Di-*O*-acetyl-2,3-dideoxy-α-D-*threo*-hex-2-enopyranosyl *N*-methyl-*p*-toluenesulfonamide (5c)

Colorless syrup $[\alpha]_D$ −70.3 (*c* 1.2, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.72 (d, 2H, *J* 8.3 Hz, CH_3Ph), 7.25 (d, 2H, *J* 8.3 Hz, CH_3Ph), 6.20 (ddd, 1H, *J* 10.1, 5.5, 2.1 Hz, H-3), 5.88 (dd, 1H, *J* 10.1, 1.5 Hz, H-2), 5.00 (br d, 1H, *J* 5.3 Hz, H-1), 4.80 (br d, 1H, *J* 5.5 Hz, H-4), 4.03 (m, 3H, H-5, 2 × H-6), 2.61 (CH_3N), 2.39 (s, 1H, CH_3Ph), 2.04 (s, 1H, CH_3COO), 2.01 (s, 1H, CH_3COO); ^{13}C NMR ($CDCl_3$) δ 170.77 (CH_3COO), 170.48 (CH_3COO), 129.87 (C-3), 143.82, 136.10, 132.77, 129.43, 128.52 (*Ph*) 127.43 (C-2), 82.87 (C-1), 72.63 (C-5), 62.89 (C-4), 62.86 (C-6), 29.32 (CH_3N), 21.68 (CH_3Ph), 20.98 (CH_3COO), 20.90 (CH_3COO). HRFABMS: calcd for $C_{18}H_{23}NNaO_7S$, 420.1093; found, 420.1090.

1.11. 4,6-Di-*O*-acetyl-2,3-dideoxy-α-D-*threo*-hex-2-enopyranosyl sulfamide (5d)

White needles: mp 141–142 °C; $[\alpha]_D$ −216.2 (*c* 1.0, CH_3CN); ^1H NMR (CD_3CN) δ 6.35 (br d, 1H, *J* 9.7 Hz, NH), 6.17 (ddd, 1H, *J* 10.1, 5.5, 1.5 Hz, H-3), 6.05 (dd, 1H, *J* 10.1, 3.2 Hz, H-2), 5.50 (dc, 1H, *J* 9.7, 3.2, 1.5 Hz, H-1), 5.36 (br s, NH_2), 5.07 (dd, 1H, *J* 5.3, 2.4 Hz, H-4), 4.29 (m, 1H, H-5, H-6a), 4.09 (dd, 1H, *J* 12.3, 9.1 Hz, H-6b), 2.04 (s, 1H, CH_3COO), 2.01 (s, 1H, CH_3COO); ^{13}C NMR (CD_3CN) 171.18 (CH_3COO), 171.07 (CH_3COO), 130.08 (C-3), 126.68 (C-2), 78.21 (C-1), 67.92 (C-5), 64.04 (C-4), 63.32 (C-6), 20.87 (CH_3COO), 20.86 (CH_3COO). Anal. Calcd. for $C_{10}H_{16}N_2O_7S$: C, 38.96; H, 5.23; N, 9.09; O, 36.33; S, 10.40. Found: C, 38.92; H, 5.20; N, 9.12; O, 36.34; S, 10.42.

1.12. 2,4,6-Tri-*O*-acetyl-3-deoxy-α-D-*erythro*-hex-2-enopyranosyl *p*-toluenesulfonamide (6a)

Colorless syrup: $[\alpha]_D$ +72.9 (*c* 0.2, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.73 (d, 2H, *J* 8.3 Hz, CH_3Ph), 7.28 (d, 2H, *J* 8.3 Hz, CH_3Ph), 6.25 (br d, 1H, *J* 8.4 Hz, NH), 5.65 (d, 1H, *J* 2.7 Hz, H-3), 5.43 (br d, 1H, *J* 8.4 Hz, H-1), 5.36 (ddd, 1H, *J* 9.2, 2.3, 1.5 Hz, H-4), 4.10 (dd, 1H, *J* 14.3, 7.2 Hz, H-6a), 3.65 (dd, 1H, *J* 14.3, 3.9 Hz, H-6b), 3.73 (m, 3H, H-5), 2.40 (s, 1H, CH_3Ph), 2.05 (s, 1H, CH_3COO), 2.01 (s, 1H, CH_3COO), 2.00 (s, 1H, CH_3COO); ^{13}C NMR ($CDCl_3$) δ 170.83 (CH_3COO), 170.20 (CH_3COO), 169.37 (CH_3COO), 144.95 (C-2), 126.60-144.00 (*Ph*), 118.13 (C-3), 77.48 (C-1), 67.36 (C-5), 64.82 (C-4), 61.80 (C-6), 21.71 (CH_3Ph), 21.04 (CH_3COO), 20.86 (CH_3COO), 20.81 (CH_3COO). Anal. Calcd for $C_{19}H_{23}NO_9S$: C, 51.69; H, 5.25; N, 3.17; O, 32.62; S, 7.26. Found: C, 51.72; H, 5.28; N, 3.14; O, 32.64; S, 7.22.

1.13. 2,4,6-Tri-*O*-acetyl-3-deoxy-α-D-*erythro*-hex-2-enopyranosyl ethanesulfonamide (6b)

White needles: mp 153–154 °C; $[\alpha]_D$ +95.7 (*c* 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 5.80 (br d, 1H, *J* 8.1 Hz, NH), 5.74 (m, 1H, H-3), 5.44 (br d, 1H, *J* 8.1 Hz, H-1), 5.36 (ddd, 1H, *J* 8.8, 2.3, 1.5 Hz, H-4), 4.15 (m, 3H, H5, 2 × H-6), 3.17 (dc, 2H, *J* 7.3, 1.2 Hz, CH_3CH_2), 2.20 (s, 1H, CH_3COO), 2.09 (s, 1H, CH_3COO), 2.07 (s, 1H, CH_3COO), 1.39 (t, 3H, *J* 7.3, CH_3CH_2); ^{13}C NMR ($CDCl_3$) 170.67 (CH_3COO), 170.15 (CH_3COO), 169.58 (CH_3COO), 144.91 (C-2), 118.17 (C-3), 77.21 (C-1), 68.07 (C-5), 65.19 (C-4), 63.01 (C-6), 49.63 (CH_3CH_2), 21.09 (CH_3COO), 20.97 (CH_3COO), 20.89 (CH_3COO), 8.37 (CH_3CH_2). Anal. Calcd for $C_{14}H_{21}NO_9S$: C, 44.32; H, 5.58; N, 3.69; O, 37.95; S, 8.45. Found: C, 44.28; H, 5.57; N, 3.72; O, 37.96; S, 8.47.

1.14. 2,4,6-Tri-*O*-acetyl-3-dideoxy-α-D-*erythro*-hex-2-enopyranosyl *N*-methyl-*p*-toluenesulfonamide (6c)

Colorless syrup: $[\alpha]_D$ +80.6 (*c* 1.4, $CHCl_3$); ^1H NMR ($CDCl_3$) δ 7.72 (d, 2H, *J* 8.3 Hz, CH_3Ph), 7.25 (d, 2H, *J* 8.3 Hz, CH_3Ph), 6.16 (dd, 1H, *J* 1.8, 2.3 Hz, NH), 5.78 (t, 1H, *J* 1.3 Hz, H-3), 5.53 (m, 1H, H-1), 5.30 (m, 1H, H-4), 4.15 (m, 3H, H5, 2 × H-6), 2.60 (CH_3N), 2.40 (s, 1H, CH_3Ph), 2.05 (s, 1H, CH_3COO), 2.04 (s, 1H, CH_3COO), 2.01 (s, 1H, CH_3COO); ^{13}C NMR ($CDCl_3$) δ 171.35 (CH_3COO), 170.67 (CH_3COO), 170.28 (CH_3COO), 169.37 (CH_3COO), 145.22 (C-2), 127.10–143.82 (*Ph*), 118.91 (C-3), 78.74 (C-1), 67.36 (C-5), 66.54 (C-4), 62.80 (C-6), 29.22 (CH_3N), 21.72 (CH_3Ph), 21.06 (CH_3COO), 20.85 (CH_3COO), 20.80

(CH_3COO). Anal. Calcd for $C_{20}H_{25}NO_9S$: C, 52.74; H, 5.53; N, 3.08; O, 31.61; S, 7.04. Found: C, 52.70; H, 5.54; N, 3.10; O, 31.59; S, 7.07.

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