Efficient stereoselective synthesis of 1-thio-β-mannopyranosides

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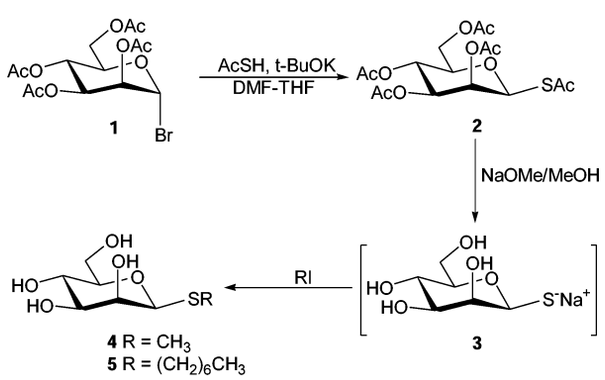
An efficient method for the synthesis of 1-thio-β-mannopyranosides is reported. This method employs the simple, easy-to-make 2,3,4,6-tetra-*O*-acetyl-1-*S*-acetyl-1-thio-β-D-mannopyranose as starting material to conduct an *in situ* selective de-*S*-acetylation, and subsequent S_N2 reaction with an acceptor bearing a leaving group. The high nucleophilicity and slow anomerization of the intermediate thiol allows the synthesis of 1-thio-β-mannopyranosides in a simple and practical manner.

Introduction

Compared with the corresponding *O*-glycosides, thioglycosides are resistant toward enzymatic hydrolysis and acid degradation,[1–4] properties that make them promising candidates as enzyme inhibitors, carbohydrate mimics and potential therapeutics. The chemical synthesis of a variety of 1-thio-oligosaccharides has appeared in the literature,[1,2,5] and recently, increased effort has been focused on the synthesis of thiosialic acid-containing oligosaccharides,[6–12] However, the synthesis of 1-thio-β-mannopyranosides has not been fully explored. Although an enormous effort has been applied to the synthesis of *O*-linked β-mannopyranosides, their synthesis remains one of the most challenging to carbohydrate chemists.[13] Sulfur isosteres of these glycosides have considerable utility and, due to the superior nucleophilicity of sulfur over oxygen, the synthesis of *S*-linked β-mannopyranosides is an attractive option. To the best of our knowledge, the examples of stereoselective synthesis of 1-thio-β-mannopyranosides in the literature are limited, and the few examples reported have been limited to simple aglycones such as thiophenyl or its analogs.[14,15] In 1984, Defaye *et al.*[16] prepared 2,3,4,6-tetra-*O*-acetyl-1-*S*-acetyl-1-thio-β-D-mannopyranose using an S_N2 approach by reaction of 2,3,4,6-tetra-*O*-acetyl-α-D-mannopyranosyl bromide with tetrabutylammonium thioacetate in toluene. More recently, Crich's group[17] reported a glycosylation approach by reaction of a rather elaborate anomeric sulfoxide, namely S-phenyl 2,3-di-*O*-benzyl-4,6-*O*-benzylidene-1-deoxy-1-thia-α-D-mannopyranoside *S*-oxide, with acceptors containing a thiol group, under the activation of triflic anhydride. Typically, this method allowed the stereoselective preparation of two 1-thio-β-mannopyranosides bearing simple alkyl aglycones in 74–77% yield, and several more elaborate 1-thio-β-*manno*-disaccharides in 61–69% yield. These developments in the synthesis of thioglycosides prompted us to explore the potential of 2,3,4,6-tetra-*O*-acetyl-1-*S*-acetyl-1-thio-β-D-mannopyranose as a convenient starting material in the stereoselective synthesis of 1-thio-β-mannosides.

Results and discussion

2,3,4,6-Tetra-*O*-acetyl-1-*S*-acetyl-1-thio-β-D-mannopyranose **2** was prepared by a simple nucleophilic displacement of the anomeric α-bromide of 2,3,4,6-tetra-*O*-acetyl-α-D-mannopyranosyl bromide **1** with thioacetate. In contrast to Defaye's procedure, we found the reaction worked equally well using the cheaper potassium thioacetate. The reaction was carried out in DMF and the potassium thioacetate was prepared *in situ* by mixing thioacetic acid and potassium *tert*-butoxide, leading to exclusive formation of the 1-thio-β-mannopyranoside **2** (Scheme 1). The reaction can be easily scaled up and compound



Scheme 1

2 was obtained in 79% isolated yield on a 30 g scale, following chromatography, or in 63% yield by crystallization.

The β-anomeric configuration of **2** was unambiguously established by different NMR experiments. As a general rule, the homonuclear three-bond coupling constants ($J_{1,2}$) in 1-thio-β-mannopyranosides are always smaller than 1.3 Hz and the heteronuclear one-bond coupling constant ($J_{C1,H1}$) at the anomeric centers range from 148 to 160 Hz; in addition, transferred nuclear Overhauser effect spectroscopy (TROESY) experiments should show dipolar coupling between H-1, H-3 and H-5 within the same pyranose ring while the corresponding 1-thio-α-mannopyranosides shows no such interactions. In fact, for compound **2**, a 1D-TROESY experiment showed strong NOEs between H-1, H-3 and H-5, and a 2D heteronuclear multiple quantum-filtered coherence (HMQC) experiment confirmed the one-bond heteronuclear coupling constant, $^1J_{CH}$ for C-1 to be 155.6 Hz.

It is well known that the some of the fully deprotected glycosyl 1-thiolates are stable, and anomerizations are so slow that in the case of 1-thio-β-D-glycopyranose and 1-thio-β-D-galactopyranose, the sodium salts can even be purchased from commercial sources. The salts can often be used to conduct S_N2 glycosylations and the corresponding thioglycosides can be obtained in pure anomeric form. In this context, we were interested in determining the stability of the fully deprotected β-manno-1-thiolate **3**. This was carried out by periodically

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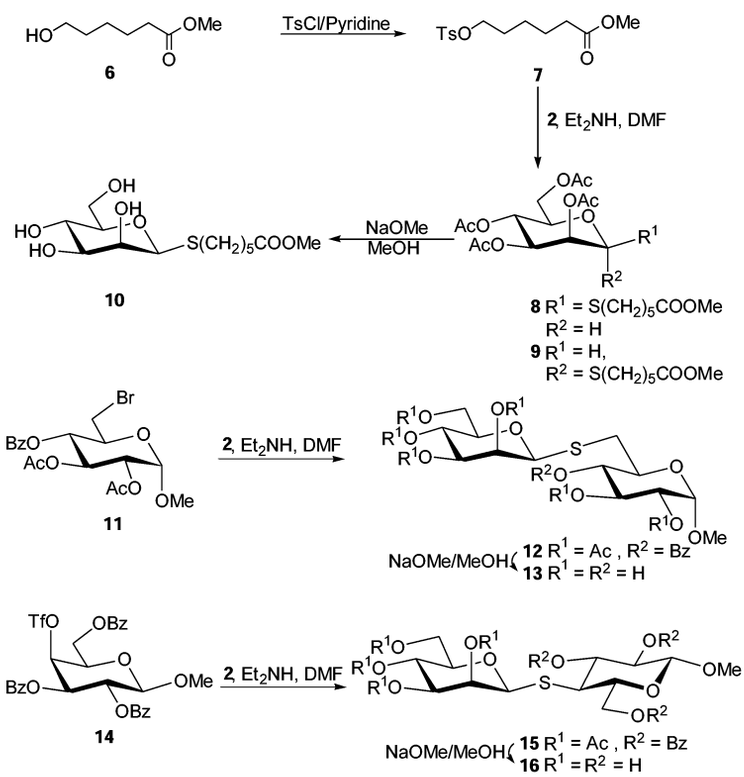
recording the NMR spectrum of a sample of compound **2** in CD_3ONa–CD_3OD. The NMR experiment clearly showed that compound **3** was relatively stable, and that anomerization to the α-thiolate proceeded at a very slow pace, such that after three days in this basic solution almost 90% of the compound remained as the β-anomer. Therefore, by exploiting the high nucleophilicity of thiolate **3** addition of simple alkyl halides to the solution should trap the corresponding 1-thio-β-mannosides to give the corresponding glycoside in high yield. In fact, the methyl (**4**) and heptyl (**5**) glycosides were both efficiently synthesized in excellent yield (⟶ **4**, 91% and ⟶ **5**, 97%) by adding iodomethane or iodoheptane directly to a solution of **2** in CH_3ONa–CH_3OH. No 1-thio-α-mannopyranosides were detected.

Glycosides bearing the ω-(methoxycarbonyl)octyl group (often called the 'Lemieux tether') are widely used in the preparation of various carbohydrate conjugates. We were interested in synthesizing a 1-thio-β-mannopyrannoside bearing this tether group. Thus 5-(methoxycarbonyl)pentan-1-ol **6** was treated with toluene-*p*-sulfonyl chloride in pyridine to afford the corresponding sulfonate ester **7** (75%) (Scheme 2). In their thiosialoside synthesis, Itzstein and co-workers[9] reported a convenient procedure to selectively deprotect the *S*-acetate in the presence of *O*-acetates *via in situ* reaction with diethylamine in DMF; the intermediate thiol can then be used directly for attacking a sugar triflate to afford the corresponding thioglycoside. We applied this procedure to prepare compound **8**. At room temperature the reaction proceeded rapidly; however, a 1 : 1 α/β mixture of glycoside was obtained. When the reaction was carried out at lower temperatures, a longer reaction time was needed to reach completion; however, the ratio of the β-mannopyranoside improved. The optimum result was obtained when the reaction was carried out at −55 °C, and under these conditions the reaction was complete after 48 h and compound **8** was obtained in 64% yield along with its α-isomer **9** in 21% yield. The relatively low β/α selectively may be due to the leaving-group properties of the tosyloxy group in compound **7**. The β-mannoside **9** was smoothly deprotected by Zemplen methanolysis (⟶ **10**, 91% yield).

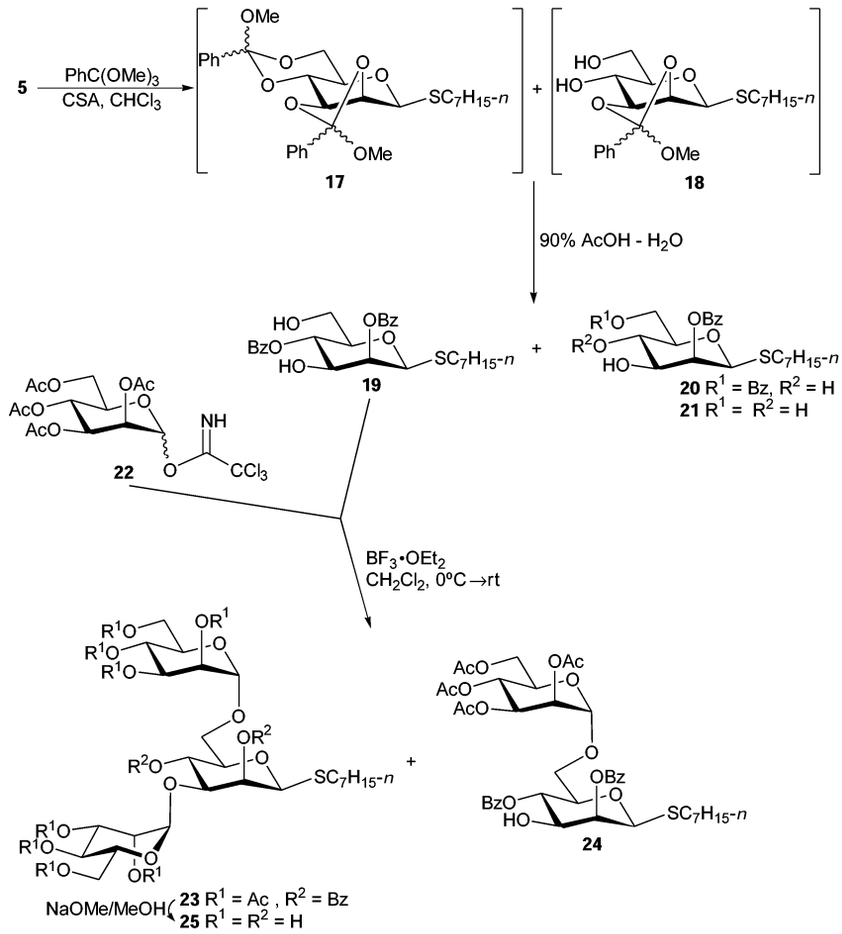
Encouraged by the initial success in synthesizing 1-thio-β-mannopyranosides bearing simple aglycones, we proceeded to explore the generality for the preparation of more complicated oligosaccharides. The preparation of a 1,6-linked disaccharide was the first choice. The 6-bromo glucoside (easily accessible) **11** was chosen. When the reaction between **2** and **11** was carried out at −15 °C under conditions reported by Itzstein,[9] the expected disaccharide **12** was obtained in 74% yield with excellent β-selectivity (α : β, 1 : 15 as judged from NMR). However, at higher temperature, poor β-selectivity was observed. Deprotection of **12** was conducted under standard Zemplen transesterification conditions, and the fully deprotected disaccharide **13** was obtained in pure form by reversed-phase chromatography in excellent yield (92%).

This success encouraged us to attempt the synthesis of the 1,4-linked disaccharide **15**. Here we employed a galactosyl triflate **14**[18] as starting material; the reaction with **2** gave **15** in 80% yield. The reaction was carried out at −5 °C and the β : α ratio was 95 : 5 as judged by NMR. A similar deprotection step as described above was conducted to afford disaccharide **16** in 93% yield after reversed-phase chromatography on C-18.

With compound **5** in hand, we prepared the biologically relevant structure **25**—an analog of the core mannotrioside structure located in the glycan chains of all *N*-linked glycoproteins. In this structure, a β-mannopyranoside is branched at both the 3- and 6-position by α-mannopyranoside residues. The synthesis of the *O*-linked analogs was reported by Kaur *et al.*[19] and recently by Lichtenthaler *et al.*[20] In the former case, the *O*-linked β-mannopyranoside was synthesized from 3,6-di-*O*-acetyl-2,4-di-*O*-benzyl-α-D-mannopyranosyl bromide in 27% yield, whilst in the latter case the authors had to create the *O*-linked β-mannopyranoside in a long oxidation–reduction sequence starting from a glucose derivative. In our hands, since **5** can be easily synthesized in large quantity and in pure form, we used it as starting material. Thus, under camphor-10-sulfonic acid (CSA) catalysis, two mole equivalents of trimethyl orthobenzoate reacted with **5** to afford mainly intermediate **17**,[21] plus the mono-orthoester **18** (see Scheme 3). Without purification, the mixture of intermediates **17** and **18** was sub-



Scheme 2



Scheme 3

sequently treated with 90% acetic acid–water in order to open the 2,3- and 4,6-orthoester. The 2,3-orthoester opened in a highly regioselective fashion to give the 2-benzoate almost exclusively, whilst the 4,6-orthoester opened in a less regioselective manner to give both the 4-benzoate and 6-benzoate. Thus hydrolysis of **17** afforded the desired 2,4-dibenzoylated product **19** (32%) and the undesired 2,6-dibenzoylated product **20** (40%) while the hydrolysis of **18** led only to monobenzoylated mannoside **21** (13%). Although not of high yield, this approach to **19** was efficient since it only involved a single purification step, and a readily available starting material (**5**). Compounds **20** and **21** can be recycled to regenerate the startimg material **5**. The two α-mannopyranosyl units at the 3- and 6-position were subsequently installed after a glycosylation step with imidate **22**[22] under catalysis by boron trifluoride–diethyl ether. The desired trimannoside **23** was obtained in 51% yield together with the 1,6-linked disaccharide **24** (48%). Trisaccharide **23** was fully deprotected by methanolysis to give the free trimannoside **25** in 91% yield.

Conclusions

In summary, we have developed an efficient route for the preparation of 1-thio-β-mannopyranosides using the easily accessible 2,3,4,6-tetra-*O*-acetyl-1-*S*-acetyl-1-thio-β-D-mannopyranose **2** as starting material. The synthesis can generally be carried out in high yield and high stereoselectivity. Considering the significant difficulties in preparing the *O*-linked β-mannopyranosides, this route offers an alternative to the design and synthesis of carbohydrates analogs containing a β-mannoside linkage. The method is being extended to the synthesis of 1-thiol-β-rhamnopyranosides.

Experimental

Optical rotations were measured with a Perkin-Elmer 241 polarimeter at 22 ± 2 °C. $[\alpha]_D$-Values are given in units of 10^{-1} deg cm^2 g^{-1}. Analytical TLC was performed on Silica Gel 60-F_{254} (E. Merck, Darmstadt) with detection by quenching of fluorescence and/or by charring with sulfuric acid. All commercial reagents were used as supplied and chromatography solvents were distilled prior to use. Column chromatography was performed on Silica Gel 60 (E. Merck 40–60 μm, Darmstadt). ^{1}H NMR spectra were recorded at 300 MHz (Varian) or 600 MHz (Varian). The first-order proton chemical shifts δ_H are referenced to either residual $CHCl_3$ (δ_H 7.24, $CDCl_3$) or internal acetone (δ_H 2.225, D_2O). HMQC NMR spectra were recorded at 300 MHz (Varian) or 600 MHz (Varian). The ^{13}C chemical shifts, δ_C, are referenced to internal $CDCl_3$ (δ_C 77.00, $CDCl_3$). Organic solutions were dried prior to concentration under vacuum at <40 °C (bath). Reversed-phase chromatography was performed on a Waters 600 HPLC systems, using a Beckman semi-preparative C-18 column (10 × 250 mm, 5 μ), and the products were detected with a Waters 2487 UV detector or a Waters 2410 refractive-index monitor. Microanalyses and electrospray mass spectra were performed by the analytical services of this department.

2,3,4,6-Tetra-*O*-acetyl-1-*S*-acetyl-1-thio-β-D-mannopyranose 2

Method A. A solution of thioacetic acid (13.4 mL, 187.6 mmol) in dry DMF (130 mL) was cooled to 0 °C under argon, and potassium *tert*-butoxide (12.6 g, 112.6 mol) was added by portions. After stirring of this mixture for 15 min at room temperature, a dark red homogenous solution was obtained. A solution of 2,3,4,6-tetra-*O*-acetyl-α-D-mannopyranosyl bromide **1** (38.6 g, 93.8 mmol) in anhydrous THF (50 mL) was

added dropwise over a period of 20 min and the reaction was continued for 3 h at room temperature. The mixture was diluted with EtOAc (2000 mL), the organic phase was successively washed with water (3 × 600 mL) and brine (1 × 500 mL), dried over anhydrous Na_2SO_4, and concentrated. Chromatography on silica gel (hexane–EtOAc 4 : 1 v/v) gave compound **2** as a white solid (30.1 g, 79%).

Method B. The reaction was carried out as above starting from bromide **1** (35.0 g, 93.3 mmol), thioacetic acid (12.5 ml, 174.9 mmol) and potassium *tert*-butoxide (11.8 g, 105.1 mmol). After washing of the organic phase with water and brine, the organic solution was dried with Na_2SO_4, decolorized with charcoal, and filtered through a thin Celite pad. *Compound* **2** (23.9 g, 63%) was obtained by crystallization from EtOAc and hexane; $[\alpha]_D^{22}$ −23.6 (*c* 3.6, $CHCl_3$); mp 128 °C (from hexane – EtOAc) (Found: C, 47.1; H, 5.1; S, 8.05. $C_{16}H_{22}O_{10}S$ requires C, 47.3; H, 5.4; S, 7.9%); δ_H (600 MHz; $CDCl_3$) 5.47 (m, 2H, H-1, H-2), 5.24 (t, 1H, *J* 10.1, H-4), 5.13 (dd, 1H, *J* 3.5, 10.3, H-3), 4.24 (dd, 1H, *J* 5.3, 12.5, H^a-6), 4.10 (dd, 1H, *J* 2.2, H^b-6), 3.80 (ddd, 1H, H-5), 2.34 (s, 3H, SAc), 2.16 (s, 3H, OAc), 2.06 (s, 3H, OAc), 2.02 (s, 3H, OAc), 1.96 (s, 3H, OAc); δ_C (600 MHz; $CDCl_3$, from HMQC) 79.3 (C-1, $J_{C1,H1}$ 155.6), 76.4 (C-5), 71.5 (C-3), 70.4 (C-2), 65.1 (C-4), 62.4 (C-6), 30.9 (SAc), 20.8 (4 × OAc); *m*/*z* (high-resolution ES-MS) 429.0830. $C_{16}H_{22}O_{10}S{\cdot}Na^+$ requires *m*/*z*, 429.0826.

Methyl 1-thio-β-D-mannopyranoside 4

Compound **2** (100 mg, 246 μmol) was dissolved in anhydrous methanol (1.5 mL) and a solution of dry NaOMe–MeOH (700 μL; 3.5 M) was added under argon. The mixture was stirred for 30 min. Iodomethane (28 μL, 615 μmol) was then added dropwise to the mixture and the reaction was continued under argon for 1 h at room temperature. The mixture was neutralized with Dowex 50W (H^+) resin and concentrated. *Compound* **4** was purified by reversed-phase chromatography using MeOH–water gradient (100%–20% MeOH) as eluent (47 mg, 91%); $[\alpha]_D^{22}$ −129.1 (*c* 1.1, MeOH) (Found: C, 38.3; H, 6.5. $C_7H_{14}O_5S{\cdot}0.5\ H_2O$ requires C, 38.35; H, 6.4%); δ_H (600 MHz; D_2O) 4.78 (d, 1H, *J* 0.9, H-1), 4.04 (dd, 1H, *J* 3.5, H-2), 3.92 (dd, 1H, *J* 2.4, 12.3, H^a-6), 3.73 (dd, 1H, *J* 6.2, H^b-6), 3.66 (dd, 1H, *J* 3.5, H-3), 3.60 (t, 1H, *J* 9.7, H-4), 3.41 (ddd, 1H, H-5), 2.27 (s, 3H, OMe); δ_C (600 MHz; D_2O, from HMQC) 86.8 (C-1, $J_{C1,H1}$ 156.4), 81.3 (C-5), 75.0 (C-3), 72.7 (C-2), 67.4 (C-4), 62.3 (C-6), 15.2 (OMe); *m*/*z* (HR ES-MS) 233.0456. $C_7H_{14}O_2S{\cdot}Na^+$ requires *m*/*z*, 233.0454.

Heptyl 1-thio-β-D-mannopyranoside 5

Under argon, a solution of anhydrous NaOMe–MeOH (840 μL; 3.5 M) was added to compound **2** (100 mg, 246 μmol) in MeOH (1.5 mL) and stirred for 30 min, 1-iodoheptane (162 μL, 984 μmol) was added dropwise, and the reaction was continued for 1 h at room temperature. After neutralization with Dowex 50W (H^+) resin, the residue was purified by reversed-phase chromatography using a MeOH–water gradient (100–50% MeOH) to afford *compound* **5** (70 mg, 97%); $[\alpha]_D^{22}$ −73.0 (*c* 2.7, MeOH) (Found: C, 52.6; H, 9.1. $C_{13}H_{26}O_5$ requires C, 53.0; H, 8.9%); δ_H (600 MHz; D_2O) 4.84 (s, 1H, H-1), 4.02 (d, 1 H, *J* 3.5, H-2), 3.91 (dd, 1H, *J* 2.2, 12.3, H^a-6), 3.73 (dd, 1H, *J* 6.2, H^b-6), 3.66 (dd, 1H, *J* 9.7, H-3), 3.60 (t, 1H, H-4), 3.40 (ddd, 1H, *J* 9.5, H-5), 2.75 (m, 2H, SCH_2), 1.64 (m, 2H, SCH_2CH_2), 1.38 [m, 2H, $S(CH_2)_2CH_2$], 1.35–1.24 [m, 6H, $(CH_2)_3CH_3$], 0.87 (t, 3H, *J* 6.8, CH_3); δ_C (600 MHz; D_2O, from HMQC) 85.0 (C-1, $J_{C1,H1}$ 153.7), 81.0 (C-5), 74.8 (C-3), 73.2 (C-2), 67.5 (C-4), 62.0 (C-6), 31.7 (SCH_2), 30.0 (SCH_2CH_2), 28.5–13.3 [$(CH_2)_4CH_3$]; *m*/*z* (HR ES-MS) 317.1384. $C_{13}H_{26}O_5S{\cdot}Na^+$ requires *m*/*z*, 317.1393.

Methyl 6-(*p*-tolylsulfonyloxy)hexanoate 7

A solution of 5-(methoxycarbonyl)pentan-1-ol (**6**, 0.5 g, 3.4 mmol) in anhydrous pyridine (10 mL) was ice-cooled, toluene-*p*-sulfonyl chloride (1.3 g, 6.8 mmol) was added, and the mixture was left at room temperature for 1 h. The mixture was then ice-cooled and water (1 mL) was added. The organic solvent was removed and the resulting residue was purified by chromatography on silica with hexane–EtOAc (4 : 1 v/v) to give compound **7** (0.77 g, 75%); δ_H (300 MHz; $CDCl_3$) 7.76 (d, 2H, *J* 8.2, OTs), 7.32 (d, 2H, *J* 8.1 OTs), 4.00 (t, 2H, *J* 6.4, $TsOCH_2$), 3.63 (s, 3H, OMe), 2.43 (s, 3H, OTs), 2.22 (t, 2H, *J* 7.5, CH_2COOMe), 1.64 (m, 2H, $TsOCH_2CH_2$), 1.56 (m, 2H, CH_2CH_2COOMe), 1.33 [m, 2H, $CH_2(CH_2)_2COOMe$]; *m*/*z* (HR, ES-MS) 323.0934. $C_{14}H_{20}O_5S{\cdot}Na^+$ requires *m*/*z*, 323.0924.

5-(Methoxycarbonyl)pentyl 2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-mannopyranoside 8 and 5-(methoxycarbonyl)pentyl 2,3,4,6-tetra-*O*-acetyl-1-thio-α-D-mannopyranoside 9

A solution of compound **2** (150 mg, 369 μmol) and tosylester **7** (140 mg, 503 μmol) in anhydrous DMF (2 mL) was cooled to −55 °C, diethylamine (200 μL) was added dropwise under argon, and the mixture was stirred for 48 h. The mixture was then diluted with EtOAc (30 mL) and the organic phase was washed successively with water (1 × 20 mL) and brine (1 × 20 mL), dried over anhydrous Na_2SO_4, and concentrated. Chromatography on silica gel using hexane–AcOEt (7 : 3 v/v) as eluent gave, first, *compound* **9** (39 mg, 21%), then the β-*isomer* **8** (115 mg, 64%). Data for β-isomer **8**: $[\alpha]_D^{22}$ −55.4 (*c* 3.9, $CHCl_3$) (Found: C, 50.8; H, 6.7. $C_{21}H_{32}O_{11}S$ requires C, 51.2, H, 6.55%); δ_H (600 MHz; $CDCl_3$) 5.48 (d, 1H, *J* 3.5, H-2), 5.23 (t, 1H, *J* 10.1, H-4), 5.04 (dd, 1H, *J* 10.3, H-3), 4.72 (s, 1H, H-1), 4.24 (dd, 1H, *J* 5.9, 12.3, H^a-6), 4.12 (dd, 1H, *J* 2.4, H^b-6), 3.67 (ddd, 1H, H-5), 3.64 (s, 3H, OMe), 2.68 (t, 2H, *J* 7.5, SCH_2), 2.28 (t, 2H, *J* 7.5, CH_2COOMe), 2.16 (s, 3H, OAc), 2.06 (s, 3H, OAc), 2.02 (s, 3H, OAc), 1.95 (s, 3H, OAc), 1.61 (m, 4H, SCH_2CH_2-CH_2CH_2), 1.40 [m, 2H, $CH_2(CH_2)_2COOMe$]; δ_C (600 MHz; $CDCl_3$, from HMQC) 82.7 (C-1, $J_{C1,H1}$ 151.7), 76.8 (C-5), 72.0 (C-3), 70.4 (C-2), 66.0 (C-4), 62.9 (C-6), 51.8 (OMe), 34.0 (CH_2COOMe), 3.17 (SCH_2), 29.2 (CH_2CH_2COOMe), 28.1 [$CH_2(CH_2)_2COOMe$], 24.6 (SCH_2CH_2), 20.5 (4 × OAc); *m*/*z* (HR ES-MS) 515.1556. $C_{21}H_{32}O_{11}S{\cdot}Na^+$ requires *m*/*z*, 515.1558.

Data for α-isomer **9**: $[\alpha]_D^{22}$ +44.7 (*c* 3.6, $CHCl_3$) (Found: C, 51.2; H, 6.5. $C_{21}H_{32}O_{11}S$ requires C, 51.2; H, 6.55%); δ_H (600 MHz; $CDCl_3$) 5.31 (dd, 1H, *J* 3.3, H-2), 5.29 (t, 1H, *J* 9.9, H-4), 5,24 (dd, 1H, *J* 10.1, H-3), 5.23 (d, 1H, *J* 1.7, H-1), 4.35 (ddd, 1H, H-5), 4.29 (dd, 1H, *J* 5.3, 12.3, H^a-6), 4.07 (dd, 1H, *J* 2.4, 12.3, H^b-6), 3.65 (s, 3H, OMe), 2.60 (m, 2H, SCH_2), 2.29 (t, 2H, *J* 7.3, CH_2COOMe), 2.14 (s, 3H, OAc), 2.07 (s, 3H, OAc), 2.02 (s, 3H, OAc), 1.97 (s, 3H, OAc), 1.62 (m, 4H, SCH_2CH_2-CH_2CH_2), 1.39 [m, 2H, $S(CH_2)_2CH_2$]; *m*/*z* (HR ES-MS) 515.1556. $C_{21}H_{32}O_{11}S{\cdot}Na^+$ requires *m*/*z*, 515.1558.

5-(Methoxycarbonyl)pentyl 1-thio-β-D-mannopyranoside 10

Compound **8** (100 mg, 203 μmol) was deprotected by transesterification in anhydrous methanol (20 mL) containing a catalytic amount of NaOMe, and the *product* **10** was purified by reversed-phase chromatography using MeOH–water gradient (100–50% MeOH) as eluent (60 mg, 91%); $[\alpha]_D^{22}$ −73.1 (*c* 1.3, MeOH) (Found: C, 48.5; H, 7.0. $C_{13}H_{24}O_7S$ requires C, 48.1; H, 7.5%); δ_H (600 MHz; D_2O) 4.74 (d, 1H, *J* 0.9, H-1), 3.96 (dd, 1H, *J* 3.5, H-2), 3.84 (dd, 1H, *J* 2.2, 12.3, H^a-6), 3.66 (dd, 1H, *J* 6.2, H^b-6), 3.63 (s, 3H, OMe), 3.60 (dd, 1H, *J* 9.7, H-3), 3.53 (t, 1H, *J* 9.9, H-4), 3.34 (ddd, 1H, H-5), 2.69 (m, 2H, SCH_2), 2.34 (t, 2H, *J* 7.3, CH_2COOMe), 1.58 (m, 4H, $SCH_2CH_2CH_2CH_2$), 1.35 [m, 2H, $S(CH_2)_2CH_2$]; δ_C (600 MHz; $CDCl_3$, from HMQC) 85.3 (C-1, $J_{C1,H1}$ 154.0), 79.0 (C-5), 74.8 (C-3), 73.2 (C-2), 67.5 (C-4), 62.0 (C-6), 53.0 (OMe), 34.7 (CH_2COOMe), 31.2 (SCH_2), 29.6 (CH_2CH_2COOMe), 28.2 [$S(CH_2)_2CH_2$], 24.6 (SCH_2CH_2); *m*/*z* (HR ES-MS) 347.1143. $C_{13}H_{24}O_7S{\cdot}Na^+$ requires *m*/*z*, 347.1135.

Methyl 2,3-di-*O*-acetyl-4-*O*-benzoyl-6-*S*-(2,3,4,6-tetra-*O*-acetyl-β-D-mannopyranosyl)-6-thio-α-D-glucopyranoside 12

A mixture of compound **2** (60 mg, 148 μmol) and methyl 2,3-di-*O*-acetyl-6-bromo-4-*O*-benzoyl-6-deoxy-α-D-glucopyranside **11** (100 mg, 225 μmol) in anhydrous DMF (2 mL) was cooled to −15 °C under argon, diethylamine (300 μL) was added dropwise, and the mixture was stirred for 24 h. The reaction mixture was diluted with EtOAc (30 mL) and the organic phase was washed with water (2 × 15 mL), dried over anhydrous Na_2SO_4, and concentrated. *Compound* **12** was obtained by chromatography on silica gel using toluene–AcOEt (7 : 3 v/v) as eluent (80 mg, 74%). This compound was contaminated with a trace amount of the α-isomer (≈6%, as judged from NMR); $[\alpha]_D^{22}$ +18.4 (*c* 5.7, $CHCl_3$) (Found: C, 52.3; H, 5.7; S, 4.6. $C_{32}H_{40}O_{17}S$ requires C, 52.7; H, 5.5; S, 4.4%); δ_H (600 MHz; $CDCl_3$) 7.94–7.42 (m, 5H, Bz), 5.63 (t, 1H, *J* 9.7, H-3), 5.50 (d, 1H, *J* 3.5, H-2′), 5.19 (t, 1H, *J* 10.1, H-4′), 5.12 (t, 1H, *J* 9.7, H-4), 5.00 (dd, 1H, *J* 10.1, H-3′), 4.98 (d, 1H, *J* 3.7, H-1), 4.92 (dd, 1H, *J* 10.1, H-2), 4.91 (s, 1H, H-1′), 4.19 (dd, 1H, *J* 6.2, 12.5, H^a-6′), 4.08–4.05 (m, 2H, H^b-6′, H-5), 3.63 (ddd, 1H, H-5′), 3.46 (s, 3H, OMe), 2.88 (dd, 1H, *J* 9.3, 14.3, H^a-6), 2.83 (dd, 1H, *J* 2.8, H^b-6), 2.13 (s, 3H, OAc), 2.07 (s, 3H, OAc), 2.02 (s, 6H, 2 × OAc), 1.94 (s, 3H, OAc), 1.86 (s, 3H, OAc); δ_C (600 MHz; $CDCl_3$, from HMQC) 133.8–128.2 (Bz), 96.5 (C-1, $J_{C1,H1}$ 171.9), 83.6 (C-1′, $J_{C1,H1'}$ 154.0), 76.6 (C-5′), 72.4 (C-4), 71.8 (C-3′), 70.8 (C-2), 70.2 (C-2′, C-5), 69.4 (C-3), 65.5 (C-4′), 62.8 (C-6′), 56.0 (Me), 33.9 (C-6), 20.7 (8 × OAc); *m*/*z* (HR ES-MS) 751.1874. $C_{32}H_{40}O_{17}S{\cdot}Na^+$ requires *m*/*z*, 751.1884.

Methyl 6-*S*-(β-D-mannopyranosyl)-6-thio-α-D-glucopyranoside 13

Compound **12** (54 mg, 74.1 μmol) was transesterified and purified as described for **8** to yield *compound* **13** in pure form (25 mg, 92%); $[\alpha]_D^{22}$ +23.3 (*c* 3.0, MeOH) (Found: C, 40.2; H, 6.5. $C_{13}H_{24}O_{10}S{\cdot}H_2O$ requires C, 40.0; H, 6.7%); δ_H (600 MHz; D_2O) 4.95 (d, 1H, *J* 0.7, H-1′), 4.79 (d, 1H, *J* 3.8, H-1), 4.07 (dd, 1H, *J* 3.5, H-2′), 3.92 (dd, 1H, *J* 12.3, H^a-6′), 3.82 (m, 1H, H-5), 3.75 (dd, 1H, *J* 6.1, H^b-6′), 3.66 (dd, 1H, *J* 3.5, 9.5, H-3′), 3.64 (t, 1H, *J* 8.6, H-4′), 3.61 (t, 1H, *J* 9.7, H-3), 3.58 (dd, 1H, *J* 9.7, H-2), 3.45 (s, 3H, OMe), 3.41 (ddd, 1H, H-5′), 3.33 (t, 1H, *J* 9.2, H-4), 3.25 (dd, 1H, *J* 14.1, H^a-6), 2.93 (dd, 1H, *J* 8.6, H^b-6); δ_C (600 MHz; $CDCl_3$, from HMQC) 100.1 (C-1, $J_{C1,H1}$ 168.2), 86.5 (C-1′, $J_{C'1,H'1}$ 154.1), 81.4 (C-5′), 74.7 (C-3′), 74.0 (C-4′), 73.7 (C-2′), 72.2 (C-5, C-2), 67.5 (C-3), 62.0 (C-6′), 56.0 (Me), 33.9 (C-6); *m*/*z* (HR ES-MS) 395.0984. $C_{13}H_{24}O_{10}S{\cdot}Na^+$ requires *m*/*z*, 395.0982.

Methyl 2,3,6-tri-*O*-benzoyl-4-*S*-(2,3,4,6-tetra-*O*-acetyl-β-D-mannopyranosyl)-4-thio-β-D-glucopyranoside 15

Under argon, diethylamine (500 μL) was added dropwise to a stirred solution of triflate **14** (202 mg, 316 μmol) and thioacetate **2** (117 mg, 288 μmol) in anhydrous DMF (4 mL) at −5 °C, and reaction was continued for 12 h. EtOAc (100 mL) was added and the resulting solution was washed successively with water (1 × 30 mL) and brine (1 × 30 mL), dried over anhydrous Na_2SO_4, and concentrated. The residue was purified by chromatography on silica using toluene–EtOAc (7 : 3 v/v) as eluent to give *compound* **15** (196 mg, 80%). This compound was contaminated with the α-isomer (≈5%, as judged from NMR); $[\alpha]_D^{22}$ − 3.4 (*c* 8.3, $CHCl_3$) (Found: C, 58.9; H, 5.3. $C_{42}H_{44}O_{17}S$ requires C, 59.15; H, 5.2%); δ_H (600 MHz; C_6D_6) 8.20–6.86 (m, 15H, Bz), 5.99–5.92 (m, 2H, H-3, H-2), 5.82 (dd, 1H, *J* 3.5, H-2′), 5.50 (t, 1H, *J* 10.1, H-4′), 5.42 (dd, 1H, *J* 10.1, H-3′), 5.14 (d, 1H, *J* 1.1, H-1′), 5.09 (dd, 1H, *J* 2.4, 12.1, H^a-6), 4.95 (dd, 1H, *J* 5.3, H^b-6), 4.67 (d, 1H, *J* 7.5, H-1), 4.16 (dd, 1H, *J* 2.4, 12.3, H^a-6′), 4.07 (dd, 1H, *J* 6.9, H^b-6′), 4.00 (ddd, 1H, H-5), 3.26 (s, 3H, OMe), 3.21 (ddd, 1H, H-5′), 3.10 (t, 1H, *J* 10.6, H-4), 1.75 (s, 3H, OAc), 1.69 (s, 3H, OAc), 1.64 (s, 3H, OAc), 1.56 (s, 3H, OAc); δ_C (600 MHz; $CDCl_3$, from HMQC) 132.5–129.5 (Bz), 102.0 (C-1, $J_{C1,H1}$ 157.7), 80.5 (C-1′, $J_{C1,H1}$, 150.5), 76.5 (C-5′), 74.3 (C-5), 73.3 (C-2), 71.6 (C-3′), 71.2 (C-3), 70.2 (C-2′), 65.8 (C-4′), 64.0 (C-6), 62.0 (C-6′), 55.3 (OMe), 46.6 (C-4), 20.0 (4 × OAc); *m*/*z* (HR ES-MS) 875.2199. $C_{42}H_{44}O_{17}S{\cdot}Na^+$ requires *m*/*z*, 875.2197.

Methyl 4-*S*-(β-D-mannopyranosyl)-4-thio-β-D-glucopyranoside 16

Compound **15** (50 mg, 58.6 μmol) was deprotected and purified as described for **8** to yield *compound* **16** in pure form (20 mg, 93%); $[\alpha]_D^{22}$ −40.2 (*c* 2.5, MeOH) (Found: C, 37.3; H, 6.9. $C_{13}H_{24}O_{10}S{\cdot}2.5H_2O$ requires C, 37.4; H, 7.0%); δ_H (600 MHz; D_2O) 4.95 (s, 1H, H-1′), 4.36 (d, 1H, *J* 8.1, H-1), 4.15 (dd, 1H, *J* 2.0, 12.3, H^a-6), 4.07 (d, 1H, *J* 3.5, H-2′), 3.90 (dd, 1H, *J* 5.1, H^b-6), 3.89 (dd, 1H, *J* 2.4, 12.4, H^a-6′), 3.73–3.68 (m, 2H, H^b-6, H-5), 3.67 (dd, 1H, *J* 9.7, H-3′), 3.63 (dd, 1H, *J* 10.4, H-3), 3.59 (t, 1H, *J* 9.9, H-4′), 3.57 (s, 3H, OMe), 3.42 (ddd, 1H, *J* 2.2, 6.4, 9.3, H-5′), 3.3 (t, 1H, *J* 8.6, H-2), 2.82 (t, 1H, *J* 10.8, H-4); δ_C (600 MHz; D_2O, from HMQC) 104.0 (C-1, $J_{C1,H1}$ 160.8), 86.0 (C-1′, $J_{C1,H1}$, 153.5), 81.1 (C-5′), 77.2 (C-5), 75.3 (C-2), 74.5 (C-3′), 73.5 (C-2′), 67.5 (C-4′), 62.0 (C-6, C-6′), 57.9 (OMe), 48.5 (C-4); *m*/*z* (HR ES-MS) 395.0980. $C_{13}H_{24}O_{10}S{\cdot}Na^+$ requires *m*/*z*, 395.0982.

Heptyl 2,4-di-*O*-benzoyl-1-thio-β-D-mannopyranoside 19, heptyl 2,6-di-*O*-benzoyl-1-thio-β-D-mannopyranoside 20 and heptyl 2-*O*-benzoyl-1-thio-β-D-mannopyranoside 21

CSA (40 mg, 0.17 mmol) was added to a stirred suspension of **5** (300 mg, 1.02 mmol) and trimethyl orthobenzoate (700 μL, 4.1 mmol) in $CHCl_3$ (60 mL). After the mixture became clear, the solution was concentrated on a rotovapor to ≈ 10 mL, $CHCl_3$ (50 mL) was added, and the solution was concentrated again to ≈ 10 mL volume. This process was repeated until TLC showed that all the starting material was consumed. Triethylamine (3 mL) was added to the reaction mixture and the solution was evaporated to dryness. A solution of 90% acetic acid–water (10 mL) was added to the reaction flask and reaction was continued for 30 min. After evaporation, the mixture was purified by column chromatography (toluene – EtOAc 4 : 1→1 : 1 v/v) to give, first, **19** (166 mg, 32%), then **20** (204 mg, 40%), and last **21** (51 mg, 13%).

Data for *dibenzoate* **19**: $[\alpha]_D^{22}$ −94.0 (*c* 5.7, $CHCl_3$) (Found: C, 64.4; H, 6.7. $C_{27}H_{34}O_7S$ requires C, 64.5; H, 6.8%); δ_H (600 MHz; $CDCl_3$) 8.06–7.44 (m, 10H, Bz), 5.75 (dd, 1H, *J* 3.6, H-2), 5.38 (t, 1H, *J* 9.5, H-4), 4.88 (d, 1H, *J* 0.7, H-1), 4.18 (dd, 1H, *J* 9.8, H-3), 3.86–3.68 (m, 3H, H-5, H-6), 2.70 (t, 2H, *J* 7.5, SCH_2), 1.60 (m, 2H, SCH_2CH_2), 1.38–1.20 [m, 8H, $(CH_2)_4CH_3$], 0.85 (t, 3H, *J* 6.8, CH_3); δ_C (600 MHz; $CDCl_3$, from HMQC) 133.8–128.6 (Bz), 83.3 (C-1, $J_{C1,H1}$ 149.2), 78.8 (C-5), 73.9 (C-2), 73.0 (C-3), 70.4 (C-4), 62.1 (C-6), 31.9 (SCH_2), 31.7 (SCH_2CH_2), 29.8 [$S(CH_2)_2CH_2$], 28.9 [$S(CH_2)_3CH_2$], 22.6 ($CH_2CH_2CH_3$), 21.0 (CH_2CH_3), 14.1 (CH_3); *m*/*z* (HR ES-MS) 525.1932. $C_{27}H_{34}O_7S{\cdot}Na^+$ requires *m*/*z*, 525.1932.

Data for *dibenzoate* **20**: $[\alpha]_D^{22}$ −70.9 (*c* 3.4, $CHCl_3$) (Found: C, 64.4; H, 6.7. $C_{27}H_{34}O_7S$ requires C, 64.5; H, 6.8%); δ_H (600 MHz, $CDCl_3$) 8.11–7.24 (m, 10H, Bz), 5.63 (d, 1H, *J* 3.5, H-2), 4.83 (s, 1H, H-1), 4.79 (dd, 1H, *J* 4.8, 12.1, H^a-6), 4.62 (dd, 1H, *J* 2.0, H^b-6), 3.93 (dd, 1H, *J* 9.3, H-3), 3.82 (t, 1H, *J* 9.5, H-4), 3.67 (ddd, 1H, *J* 2.2, 4.8, 9.5, H-5), 2.69 (m, 2H, SCH_2), 1.61–1.20 [m, 10H, $SCH_2(CH_2)_5$], 0.83 (t, 3H, *J* 7.0, CH_3); δ_C (600 MHz; $CDCl_3$, from HMQC) 130.0–128.2 (Bz), 83.0 (C-1, $J_{C1,H1}$ 153.7), 79.0 (C-5), 75.0 (C-3), 72.8 (C-2), 68.0 (C-4), 64.4 (C-6), 31.5 (SCH_2), 28.9–14.2 [$SCH_2(CH_2)_5$]; *m*/*z* (HR ES-MS) 635.1070. $C_{27}H_{34}O_7S{\cdot}Cs^+$ requires *m*/*z*, 635.1074.

Data for *monobenzoate* **21**: $[a]_D^{22}$ −51.2 (*c* 4.3, $CHCl_3$) (Found: C, 60.1; H, 7.7; S, 7.9. $C_{20}H_{30}O_6S$ requires C, 60.3; H, 7.6; S, 8.05%); δ_H (600 MHz; $CDCl_3$) 8.08–7.42 (m, 5H, Bz), 5.60 (s, 1H, H-2), 4.83 (s, 1H, H-1), 3.97 (dd, 1H, *J* 3.7, 12.1, H^a-6), 3.89–3.87 (m, 3H, H-3, H-4, H^b-6), 3.44 (m, 1H, H-5), 2.69 (t, 2H, *J* 7.5, SCH_2), 1.93 (br, 3H, 3 × OH), 1.58 (m, 2H, SCH_2CH_2), 1.35–1.22 [m, 8H, $(CH_2)_4CH_3$], 0.85 (t, 3H, *J* 7.0, CH_3); δ_C (600 MHz; $CDCl_3$, from HMQC) 167.1, 133.6, 130.2, 129.2, 128.6 (Bz), 83.2 (C-1), 79.8 (C-5), 77.5 (C-2), 74.1 (C-3), 68.6 (C-4), 62.8 (C-6), 31.9 (SCH_2), 31.7 (SCH_2CH_2), 29.9 [$S(CH_2)_2CH_2$], 28.9 [$S(CH_2)_3CH_2$], 28.8 ($CH_2CH_2CH_3$), 22.6 (CH_2CH_3), 14.1 (CH_3); *m*/*z* (HR ES-MS) 421.1658. $C_{20}H_{30}O_6S{\cdot}Na^+$ requires *m*/*z*, 421.1655.

Heptyl 2,4-di-*O*-benzoyl-3,6-bis-*O*-(2,3,4,6-tetra-*O*-acetyl-α-D-mannopyranosyl)-1-thio-β-D-mannopyranoside 23 and heptyl 2,4-di-*O*-benzoyl-6-*O*-(2,3,4,6-tetra-*O*-acetyl-α-D-mannopyranosyl)-1-thio-β-D-mannopyranoside 24

A solution of compound **19** (100 mg, 199 μmol) and 2,3,4,6-tetra-*O*-acetyl-α-D-mannopyranosyl trichloroacetimidate **22** (262 mg, 531 μmol) in anhydrous CH_2Cl_2 (6 mL) was cooled to 0 °C under argon. Boron trifluoride–diethyl ether (40 μL, 316 μmol) was added dropwise to the solution and the reaction mixture was allowed to warm slowly and stirred for 5 h at room temperature. The reaction was quenched with triethylamine (2 mL) and the solvent was evaporated. The mixture was purified by chromatography on silica gel using hexane–EtOAc (7 : 3 v/v) as eluent to afford, first, disaccharide **24** (80 mg, 48%) and then the *trisaccharide* **23** (119 mg, 51%).

Data for *compound* **23**: $[a]_D^{22}$ −30.5 (*c* 2.1, $CHCl_3$) (Found: C, 56.6; H, 5.9. $C_{55}H_{70}O_{25}S$ requires C, 56.8; H, 6.1%); δ_H (600 MHz; $CDCl_3$) 8.12–7.41 (m, 10H, Bz), 5.78 (dd, 1H, *J* 3.5, H-2), 5.51 (t, 1H, *J* 9.9, H-4), 5.28 (dd, 1H, *J* 10.1, H-3″), 5.24 (t, 1H, *J* 9.9, H-4″), 5.17 (dd, 1H, *J* 1.8, 3.3, H-2″), 5.12 (t, 1H, *J* 9.7, H-4′), 5.01 (dd, 1H, *J* 9.7, H-3′), 4.92 (d, 1H, *J* 2.6, H-1′), 4.89 (d, 1H, *J* 0.9, H-1), 4.83 (dd, 1H, *J* 3.5, H-2′), 4.77 (d, 1H, *J* 1.7, H-1″), 4.30 (dd, 1H, *J* 2.2, 4.8, H-5′), 4.26 (dd, 1H, *J* 12.3, H^a-6′), 4.23 (dd, 1H, *J* 10.2, H-3), 4.21 (dd, 1H, *J* 4.8, 11.9, H^a-6″), 4.17 (dd, 1H, *J* 2.0, H^b-6), 4.07 (ddd, 1H, H-5″), 4.03 (dd, 1H, *J* 2.4, H^b-6″), 3.95 (dd, 1H, *J* 7.1, 10.8, H^a-6), 3.85 (ddd, 1H, *J* 2.4, H-5), 3.60 (dd, 1H, H^b-6), 2.72 (m, 2H, SCH_2), 2.11 (s, 3H, OAc), 2.10 (s, 3H, OAc), 2.02 (s, 3H, OAc), 2.00 (s, 3H, OAc), 1.99 (s, 3H, OAc), 1.95 (s, 3H, OAc), 1.79 (s, 3H, OAc), 1.78 (s, 3H, OAc), 1.60 [m, 4H, $SCH_2(CH_2)_2$], 1.36–1.19 [m, 6H, $(CH_2)_3CH_3$], 0.85 (t, 3H, *J* 7.1, CH_3); δ_C (600 MHz; $CDCl_3$, from HMQC) 132.3–128.5 (Bz), 99.4 (C-1′, $J_{C1,H1}$, 172.3), 97.0 (C-1″, $J_{C1'',H1''}$ 172.6), 82.7 (C-1, $J_{C1,H1}$ 150.5), 77.2 (C-5, C-6″), 72.4 (C-2), 69.3 (C-4, C-5′), 69.2 (C-2″), 69.0 (C-2′), 68.9 (C-4″), 68.2 (C-5″), 68.0 (C-3′), 67.4 (C-6), 65.7 (C-3″, C-4′), 62.4 (C-3, C-6′), 31.4–22.4 [$S(CH_2)_6$], 20.6–20.2 (8 × OAc), 13.8 (CH_3); *m*/*z* (HR ES-MS) 1185.3810. $C_{55}H_{70}O_{25}S{\cdot}Na^+$ requires *m*/*z*, 1185.3819.

Data for *compound* **24**: $[a]_D^{22}$ −12.1 (*c* 6.6, $CHCl_3$) (Found: C, 59.0; H, 3.6. $C_{41}H_{52}O_{16}S$ requires C, 59.1; H, 6.3%); δ_H (600 MHz; $CDCl_3$) 8.14–7.42 (m, 10H, Bz), 5.75 (d, 1H, *J* 3.5, H-2), 5.38 (t, 1H, *J* 9.7, H-4), 5.31–5.23 (m, 3H, H-2′, H-3′, H-4′), 4.88 (s, 1H, H-1), 4.81 (d, 1H, *J* 1.5, H-1′), 4.15 (dd, 1H, *J* 9.7, H-3), 4.13 (dd, 1H, *J* 4.8, 12.1, H^a-6′), 3.99–3.89 (m, 4H, H-5′, H^a-6, H^b-6 + H-5), 3.66 (dd, 1H, *J* 1.8 H, 10.6, H^b-6), 2.72 (m, 2H, SCH_2), 2.11 (s, 3H, OAc), 2.00 (s, 3H, OAc), 1.99 (s, 3H, OAc), 1.96 (s, 3H, OAc), 1.64–1.20 [m, 10H, $(CH_2)_5CH_3$], 0.85 (t, 3H, *J* 7.1, CH_3); δ_C (600 MHz; $CDCl_3$, from HMQC) 133.6–128.7 (Bz), 97.1 (C-1′, $J_{C1,H1}$, 170.2), 82.8 (C-1, $J_{C1,H1}$ 149.5), 76.8 (C-5), 73.7 (C-2), 73.0 (C-3), 70.5 C-4, 69.0 (C-2′, C-3′), 68.3 (C-5′), 67.0 (C-6), 65.8 (C-4′), 62.0 (C-6′), 31.4–22.4 [$S(CH_2)_6$], 20.8–20.4 (4 × OAc); 13.8 (CH_3); *m*/*z* (HR ES-MS) 855.2873. $C_{41}H_{52}O_{16}S{\cdot}Na^+$ requires *m*/*z*, 855.2868.

Heptyl 3,6-di-*O*-(α-D-mannopyranosyl)-1-thio-β-D-mannopyranoside 25

Compound **23** (110 mg, 95 μmol) was transesterified and the crude product was purified as described for **8** to yield compound **25** (53 mg, 91%); $[a]_D^{22}$ +18.4 (*c* 2.6, MeOH) (Found: C, 45.55; H, 7.5. $C_{25}H_{46}O_{15}S{\cdot}2H_2O$ requires C, 45.85; H, 7.7%); δ_H (600 MHz; D_2O) 5.11 (d, 1H, *J* 1.6, H-1′), 4.90 (d, 1H, *J* 1.7, H-1″), 4.85 (s, 1H, H-1), 4.19 (d, 1H, *J* 3.5, H-2), 4.07 (dd, 1H, *J* 3.5, H-2′), 3.99 (dd, 1H, *J* 3.5, H-2″), 3.95 (dd, 1H, *J* 5.1, 11.4, H^a-6), 3.92–3.87 (m, 3H, H-3′, H^a-6′, H^a6a″), 3.83 (dd, 1H, *J* 9.0, H-3″), 3.82 (t, 1H, *J* 9.7, H-4), 3.79–3.73 (m, 5H, H-3, H-4′, H^b-6, H^b-6′, H^b-6″), 3.72–3.65 (m, 3H, H-5″, H-5′, H-4″), 3.60 (ddd, 1H, *J* 1.8, H-5), 2.74 (m, 2H, SCH_2), 1.64 (m, 2H, SCH_2CH_2), 1.42–1.24 [m, 8H, $(CH_2)_4$], 0.87 (t, 3H, *J* 7.0, CH_3); δ_C (600 MHz; D_2O, from HMQC) 103.2 (C-1′, $J_{C1,H1}$, 172.4), 100.2 (C-1″, $J_{C1'',H1''}$ 171.6), 85.9 (C-1, $J_{C1,H1}$ 154.1), 82.7 (C-4′), 79.2 (C-5), 74.2 (C-3), 73.4 (C-5″), 72.8 (C-2), 71.6 (C-4), 71.2 (C-3′), 71.0 (C-2′), 70.9 (C-2″), 67.6 (C-4″, C-5′), 66.6 (C-3″), 66.4 (C-6), 61.9 (C-6′, C-6″), 31.8 (SCH_2), 30.2 (SCH_2CH_2), 32.2–23.0 [$(CH_2)_4$], 14.4 (CH_3); *m*/*z* (HR ES-MS) 641.2446. $C_{25}H_{46}O_{15}S{\cdot}Na^+$ requires *m*/*z*, 641.2450.

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