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Vinyl bis-sulfone methodology in thiosugars: selective access to chiral thiovinyl sulfones and PSE oxathianes

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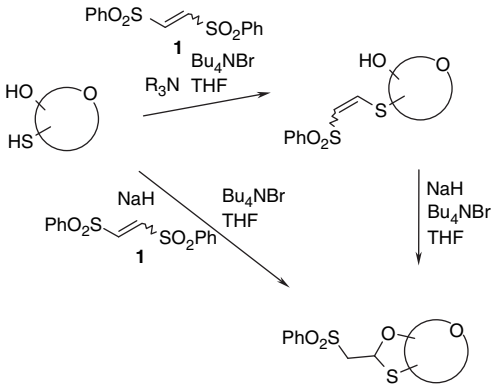
Abstract—Based on the vinyl bis-sulfone methodology previously developed to synthesize PSE acetals, an original approach to homochiral carbohydrate-derived PSE 1,3-oxathianes is described. The ready formation of intermediate phenylsulfonylvinyl sulfides, which have a synthetic potential of their own, emphasizes the versatility of the method.

1. Introduction

1,3-Oxathiane derivatives have found many applications in organic synthesis[1] but since the pioneering studies of Eliel and colleagues,[2] enantiopure 1,3-oxathianes have been mainly developed by several groups as efficient chiral auxiliaries in asymmetric syntheses.[3] Most of those auxiliaries were designed and prepared from terpenoid compounds—camphor, pulegone, myrtenal—with the notable exception of a tetralone-derived 1,3-oxathiane devised by Solladié-Cavallo and colleagues.[4] Carbohydrate-derived oxathianes were scarcely mentioned in the literature[5] and only recently, the use of a xylofuranose-based phosphinooxathiane was reported in asymmetric allylation.[6]

We have introduced in the carbohydrate field phenylsulfonylethylidene (PSE) acetals,[7] which display striking properties.[8] PSE acetals can readily be prepared through Michael type reaction of the corresponding diols with 1,2-bis(phenylsulfonyl)ethylene (BPSE, **1**). These atypical acetals often show properties opposite to those of classical acetals and in addition display uncommon synthetic features. An extension to PSE thioacetals has recently been outlined by us.[9] Developing synthetic pathways to sugar-based 2-(phenylsulfonylmethyl)-1,3-oxathianes (Scheme 1) appears profitable in several respects: (i) comparison of PSE thioacetals to PSE acetals with regard to unusual properties—reluctance to acid-catalyzed ring-opening, for example; (ii) introduction of a prochiral sulfur atom, ready to undergo tricoordination; and (iii) introduction of a stereogenic centre (the newly formed thioacetalic carbon) potentially exploitable in terms of chiral induction.



Scheme 1. Reactions of sugar-based mercaptans with BPSE.

2. Results and discussion

2.1. PSE oxathiane formation

1,3-Oxathiane derivatives are usually prepared according to a limited register of methods, mainly involving as follows: (i) acid-catalyzed thioacetalation of carbonyl functions; (ii) transthioacetalation of 1,3-dioxanes; and (iii) intramolecular Pummerer rearrangement of γ,δ-unsaturated sulfoxides.[1]

De Lucchi et al. have reported an efficient synthesis of isobornane-derived chiral 1,3-oxathianes through reaction of terpenoid hydroxythiols on electron poor acetylenes.[10] With

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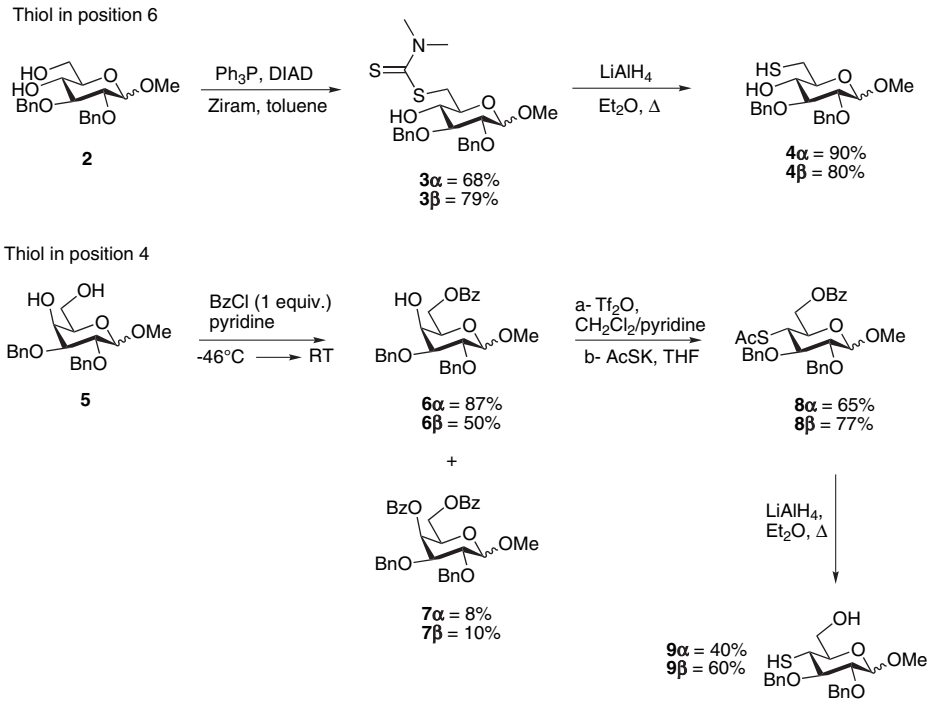


Scheme 2. Synthesis of the carbohydrate-derived hydroxythiols.

a view to applying a similar Michael addition approach to carbohydrate-derived hydroxythiols, we have prepared thiols derived from standard α- and β-D-glucopyranoside models.

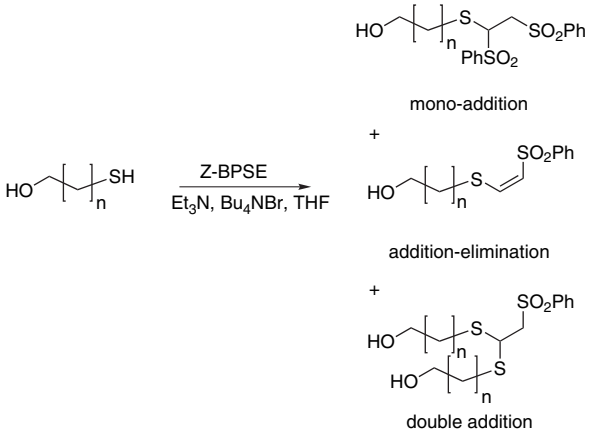
Our objective was to prepare both regioisomeric oxathianes, bearing the sulfur atom in either 6- or 4-position, and two different pathways were thus devised (Scheme 2). A direct approach involved methyl 2,3-di-*O*-benzyl-α- or β-D-glucopyranosides **2**, the primary position of which could be regioselectively thiofunctionalized through a Mitsunobu reaction with Ziram® under previously established conditions.[11] Reductive cleavage of the *N*,*N*-dimethyldithiocarbamates **3** was effected using lithium aluminohydride to deliver the thiols **4α** and **4β** in 61% and 63% yield, respectively, over the two-step sequence.

The Mitsunobu methodology having proven to be much less efficient on a secondary position, the introduction of sulfur at C-4 required stereoselective epimerization in the D-galactopyrano series. The primary position of methyl 2,3-di-*O*-benzyl-α- and β-D-galactopyranosides **5** was selectively *O*-benzoylated using 1 equiv of benzoyl chloride at low temperature, to give **6α** in 87% yield and **6β** in 50% yield only. 4,6-Dibenzoates **7α** and **7β** were also isolated in 8% and 10% yield, respectively. Sulfur introduction was effected through triflate activation followed by stereoselective nucleophilic displacement by potassium thioacetate to afford D-*gluco* configurated **8α** and **8β** in 65% and 77% yield, respectively. Final LAH reduction of both thioesters furnished both hydroxythiols **9α** and **9β** in 23% overall yield from **5**.

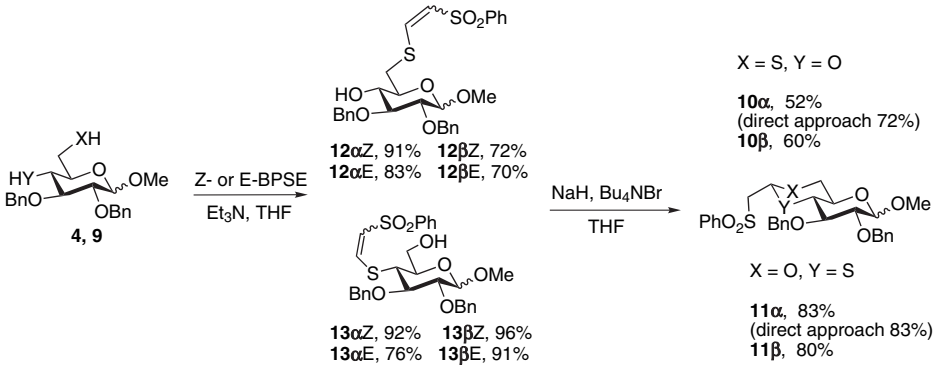
To prepare the corresponding PSE thioacetals, the four hydroxythiols **4α**,**β** and **9α**,**β** were then reacted with *Z*- or *E*-BPSE **1** under the conditions previously settled for 1,3-diols,[7] which proved equally efficient for synthesizing 1,3-oxathianes: for example, **10α** and **11α** (Scheme 4) were obtained in yields—72% and 83% yield, respectively—which compare with our preliminary results on 3-mercaptopropanol.[9]

Relying on the nucleophilicity ratio in favour of the thiol function as compared with the alcohol function, we have explored the possibility of a sequential pathway to the thioacetal: tertiary amine-catalyzed Michael addition–elimination should selectively lead to the formation of a thiovinyl sulfone intermediate, whereas stronger bases—NaH or LiHMDS—would directly afford the oxathiane.

However, earlier studies performed with aliphatic simple models—2-mercaptoethanol, 3-mercaptopropanol and 4-mercaptobutanol—have shown that side-reactions such as simple or double thiol conjugate additions (Scheme 3) can severely hamper the formation of the thiovinyl sulfone and lead to moderate yields.[9]



Scheme 3. Thiol conjugate additions on BPSE.



Scheme 4. Sequential synthesis of PSE oxathianes on glucopyranosides.

We were pleased to observe that applying the same conditions to the carbohydrate-derived thiols **4** and **9** led to the corresponding thiovinyl sulfones **12** and **13** with more rewarding 70–96% yields (Scheme 4). In addition, whatever the *Z*- or *E*-BPSE used, the reactions proceeded on α- or β-pyranosides with complete retention of the configuration of the double bond.[12] As compared with simple hydroxythiols, this improved selectivity towards thiovinyl sulfone formation might be attributed to the presence of the bulky glucopyranoside moiety.

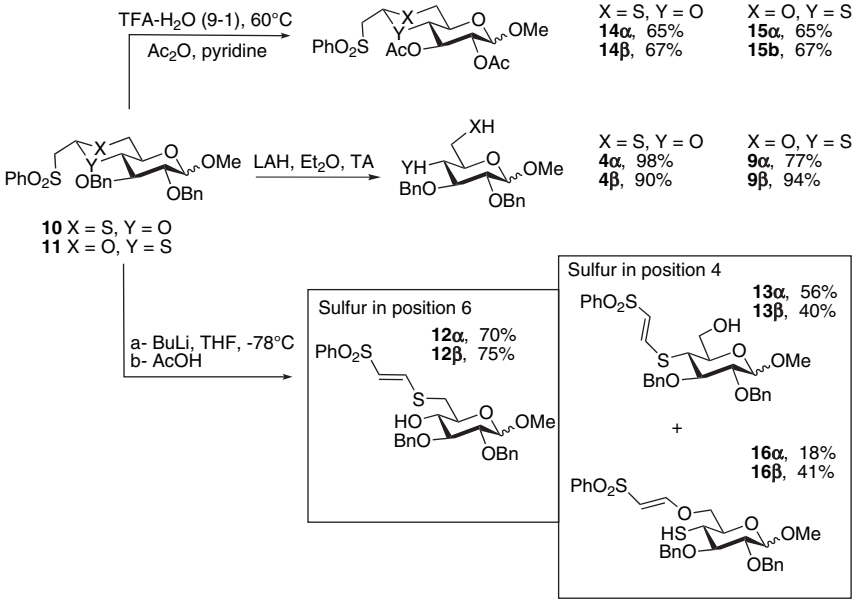
The thiovinyl sulfones could be converted into oxathianes through strong base-catalyzed cyclization, to give moderate to good yields of **10α** and **10β**—52% and 60%, respectively—as well as **11α** and **11β**—83% and 80%, respectively. The one-step procedure from hydroxythiols thus appears more efficient for the preparation of oxathianes.

2.2. Chemical behaviour of PSE oxathianes

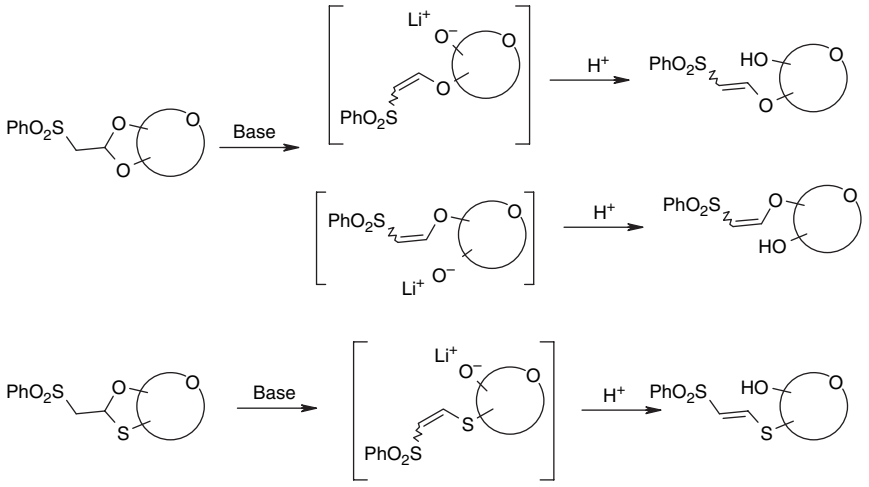
Our previous studies have disclosed that PSE acetals currently show inverse properties as compared to standard acetal protective groups.[8] We were, therefore, interested in estimating the influence of the sulfur atom on the reactivity of a PSE thioacetal. Under standard deprotection conditions in acidic media—80% aqueous acetic acid at 80 °C or 90% trifluoroacetic acid at room temperature—PSE oxathianes were not affected. Applying more severe conditions—90% trifluoroacetic acid at 60 °C for 24 h—to **10** or **11** afforded de-*O*-benzylated compounds **14** and **15** in reasonable yields. The above results clearly demonstrate that the introduction of a sulfur atom does not interfere with the acid-stability of PSE acetals.

In connection with anterior study of the behaviour of PSE acetals under reductive conditions,[7] oxathianes **10** and **11** were treated by lithium aluminium hydride to produce as expected full deprotection of the thioacetal moiety to restore the starting γ-hydroxythiols **4** and **9** in high yields (Scheme 5).

We then turned our attention to the possible selective opening of PSE oxathianes induced by strong bases: under such conditions, hydrogen-extrusion in alpha to the sulfone can take place and induce a retro-Michael reaction leading to the decyclized structures.



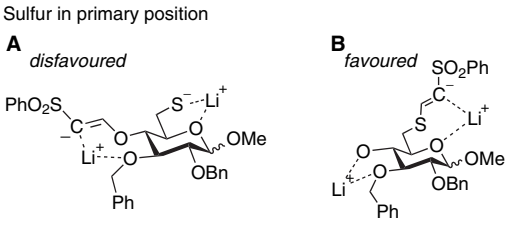
Scheme 5. Chemical behaviour of PSE oxathianes.



Scheme 6. Decyclization of PSE acetals and thioacetals.

When applied to PSE acetals, strongly basic conditions afforded equimolar mixtures of regioisomeric alkoxyvinyl sulfones, resulting from the lack of selectivity between intermediate lithium salts (Scheme 6).[13] In contrast, a better selectivity should be expected with PSE oxathianes considering the HSAB theory and preferred association of lithium with alcoholate rather than thiolate. Indeed, the results obtained with a couple of α,β-anomers have shown a good selectivity in favour of the formation of alkylthiovinylsulfones (Scheme 5). In the case of oxathianes **10α** and **10β** (sulfur in primary position), a good selective opening took place to afford **12α** and **12β** in 70% and 75% yield, respectively. In the case of oxathianes **11α** and **11β** (sulfur in secondary position), a more complex reaction occurred to produce alcohols **13** and thiols **16**: starting from **11α**, a 3:1 ratio in favour of the thiovinyl sulfone **13α** was attained, whereas no selectivity was observed with **11β**, which produced comparable amounts of alcohol **13β** and thiol **16β**. This latter case is indicative of a clear influence—due to implication of Li^+ complexation in transient structures—of the anomeric site on the formation of the vinyl sulfones.

Each anomer of either **10** or **11** might generate two possible fragmented intermediates complexed with lithium ions. The selectivity observed in the formation of **12α** and **12β** is consistent with the HSAB theory, predicting that complex **B** should be favoured over complex **A** (Scheme 7).

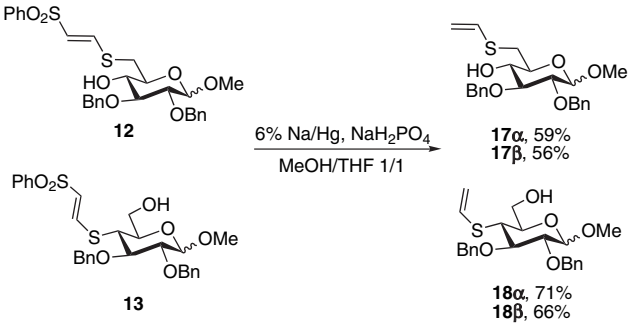


Scheme 7. Possible transient lithium salt complexes. Excess BuLi (3 equiv) being used, two deprotonation sites might be expected in the intermediates.

Thiovinyl sulfones **12** and **13** were finally subjected to monoelectronic reductive desulfonylation.

In previous works, we have shown that reductive desulfonylation is a powerful tool to generate highly reactive *O*- and *N*-vinyl derivatives.[14] In combination with chiral templates such as carbohydrates, these vinyl derivatives are much of interest in asymmetric reactions such as [3+2] cycloadditions or [4+2] reverse Diels–Alder reactions.[15] Extending the process to the formation of vinyl sulfides would open a number of new accesses to various derivatives—including useful vinyl sulfoxides and vinyl sulfones.

Standard amalgam methodology in phosphate-buffered protic solution[14] was therefore applied to thiovinyl sulfones **12** and **13**. The corresponding 4-*S*- and 6-*S*-vinyl sulfides **17** and **18** were isolated in reasonable (56–71%) yields, comparable to those obtained from parent nitrogen- and oxygen-derivatives (Scheme 8).



Scheme 8. Formation of sugar-derived vinyl sulfides.

3. Conclusion

We have investigated the first PSE oxathianes anchored on carbohydrate templates. Those chemical species, which can be prepared from the γ-hydroxythiols either in a single step or in a stepwise manner show a similar behaviour as compared to the parent PSE acetals: high reluctance to acid hydrolysis and removability under strongly basic conditions. PSE oxathianes can regioselectively be cleaved to afford thiovinyl sulfones, which can readily undergo monoelectronic reduction to promising *S*-vinyl sulfides. Further reactivity features of carbohydrate-based PSE oxathianes and *S*-vinyl sulfides are currently explored and will be published in due course.

4. Experimental

4.1. General methods

Solvents were dried and distilled by standard methods before use. All reagents were of commercial quality (Acros, Aldrich or Lancaster) and used without purification. Reactions were carried out under argon atmosphere and monitored by TLC analysis with silica gel plates (Kieselgel $60F_{254}$, Merck). Compounds were visualized with UV light and charring after a 10% H_2SO_4 ethanolic solution spray. Column chromatography was performed on silica gel 60 M (0.036–0.063 mm, Merck). ^{1}H NMR (250 MHz) and ^{13}C NMR (62.6 MHz) spectra ($CDCl_3$, internal TMS) were recorded on a Bruker AVANCE DPX 250 spectrometer. Chemical shifts (δ) are reported in parts per million downfield from TMS, coupling constants (J) are reported in Hertz and refer to apparent peak multiplicity. Assignments are based on H,H- and C,H-COSY experiments. Mass spectra were obtained using Ion Spray® (IS) method with an API 300 Perkin Elmer SCIEX spectrometer. HR-ESI-TOF-MS was performed on a Micromass LC TOF spectrometer. Optical rotations were measured at 20 °C with a Perkin Elmer 410 polarimeter.

4.2. Thiofunctionalization at the C-6 position: Mitsunobu dithiocarbamoylation[11]

To an ice-cold solution of the 4,6-diol **2α** [17791-36-5][16] or **2β** [31873-34-4][17] (1 g, 2.67 mmol) in toluene (10 mL) were successively added triphenylphosphine (1.05 g, 1.5 equiv), diethyl azodicarboxylate (0.63 mL, 1.5 equiv) and Ziram® (1.22 g, 1.5 equiv). The mixture was stirred overnight at room temperature. After filtration and concentration of the solution in vacuo, the residue was purified by column chromatography.

4.2.1. Methyl 2,3-di-*O*-benzyl-6-*S*-(*N*,*N*-dimethyldithiocarbamoyl)-6-thio-α-D-glucopyranoside (3α). Obtained from methyl 2,3-di-*O*-benzyl-α-D-glucopyranoside **2α**; silica gel column chromatography (toluene/AcOEt 95:5, then 9:1) afforded **3α** with 68% yield as a colourless gum, $[\alpha]_D$ −23 (*c* 2.2, $CHCl_3$). ^{1}H NMR δ 3.39 (s, 3H, OMe), 3.40 (s, 3H, NMe), 3.45 (dd, 1H, H-2), 3.49–3.54 (m, 1H, H-4), 3.57 (s, 3H, NMe), 3.64 (dd, 1H, J_{5-6b}=3.2, H-6b), 3.85 (t, 1H, J_{2-3}=J_{3-4}=9.5, H-3), 3.87–3.93 (m, 1H, H-5), 4.13 (dd, 1H, J_{5-6a}=4.1, J_{6a-6b}=14.7, H-6a), 4.59 (d, 1H, J_{1-2}=3.6, H-1), 4.67 and 4.80 (2d, AB system, 2H, J_{gem}=12.1, PhCH_2O), 4.89 (s, 2H, PhCH_2O), 7.28–7.42 (m, 10H, H–Ar). ^{13}C NMR δ 40.2 (C-6), 42.2 and 46.7 (2*NMe), 55.7 (OMe), 70.4 (C-5), 72.1 (C-4), 73.7 and 76.2 (2*PhCH_2O), 79.5 (C-2), 81.1 (C-3), 98.8 (C-1), 126.3–128.8 (10*CH–Ar), 138.3 and 138.8 (2*C_{IV}–Ar), 197.6 (C═S). IR (film): 3478 cm^{-1} (OH), 1515 and 1555 cm^{-1} (C═S). MS IS *m*/*z*=446.5 [M−OMe]$^+$, 478.5 [M+H]$^+$, 495.5 [M+NH_4]$^+$, 500.5 [M+Na]$^+$. HRMS: $C_{24}H_{31}NO_5S_2$: calcd 477.1643; found 477.1628.

4.2.2. Methyl 2,3-di-*O*-benzyl-6-*S*-(*N*,*N*-dimethyldithiocarbamoyl)-6-thio-β-D-glucopyranoside (3β). Obtained from methyl 2,3-di-*O*-benzyl-β-D-glucopyranoside **2β**; silica gel column chromatography (toluene/AcOEt 95:5, then 9:1) afforded **3β** with 79% yield as a colourless gum, $[\alpha]_D$ −57 (*c* 3.5, $CHCl_3$). ^{1}H NMR δ 2.34 (s, OH), 3.33 (t, 1H, J_{2-3}=J_{1-2}=7.7, H-2), 3.39 (s, 3H, NMe), 3.51–3.59 (m, 9H, H-3, H-4, H-5, NMe, OMe), 3.75 (d, 1H, J_{5-6b}< 0.5, H-6b), 4.13 (dd, 1H, J_{5-6a}=2.8, J_{6a-6b}=14.7, H-6a), 4.32 (d, 1H, J_{1-2}=7.7, H-1), 4.71 and 4.87 (2d, AB system, 2H, J_{gem}=11.1, PhCH_2O), 4.85 (s, 2H, PhCH_2O), 7.17–7.36 (m, 10H, H–Ar). ^{13}C NMR δ 40.1 (C-6), 42.3 and 46.7 (2*NMe), 57.6 (OMe), 72.0 (C-5), 74.7 (C-4), 75.2 and 76.0 (2*PhCH_2O), 81.9 (C-2), 83.7 (C-3), 105.0 (C-1), 125.7–129.5 (10*CH–Ar), 138.9 and 139.1 (2*C_{IV}–Ar), 198.3 (C═S). MS IS *m*/*z*=446.5 [M−OMe]$^+$, 478.5 [M+H]$^+$, 500.5 [M+Na]$^+$, 516.5 [M+K]$^+$. HRMS: $C_{24}H_{31}NO_5S_2$: calcd 477.1643; found 477.1634.

4.3. Thiofunctionalization at the C-6 position: dithiocarbamate reduction[11b]

To an ice-cold solution of the dithiocarbamate in dry ether (1 mmol/10 mL), LAH (2.5 equiv) was added and the reaction mixture was stirred for 4 h under reflux. AcOEt (10 mL) and then 10% aqueous HCl was carefully added to the cooled suspension; the organic phase was decanted and the aqueous phase washed with AcOEt (2×10 mL). The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo and the residue was purified by column chromatography.

4.3.1. Methyl 2,3-di-*O*-benzyl-6-thio-α-D-glucopyranoside (4α). Obtained from **3α**; silica gel column chromatography (petroleum ether/AcOEt 85:15, then 8:2) afforded thiol **4α** with 90% yield as a colourless gum, $[\alpha]_D$ +27 (*c* 2, $CHCl_3$). ^{1}H NMR δ 1.59 (dd, 1H, J_{SH-6a}=9.4, J_{SH-6b}=7.2, SH), 2.23 (br s, OH), 2.65 (ddd, 1H, J_{5-6b}=7.3, H-6b), 2.90 (ddd, 1H, J_{5-6a}=2.8, J_{6a-6b}=14.1, H-6a), 3.37–3.45 (m, 1H, H-4), 3.42 (s, 3H, OMe), 3.52 (dd, 1H, J_{2-3}=9.6, H-2), 3.64 (ddd, 1H, H-5), 3.77 (t, 1H, J_{3-4}=9.6, H-3), 4.62 (d, 1H, J_{1-2}=3.4, H-1), 4.67 and 4.77 (2d, AB system, 2H, J_{gem}=12.1, PhCH_2O), 4.69 and 5.04 (2d, AB system, 2H, J_{gem}=11.5, PhCH_2O), 7.30–7.41 (m, 10H, H–Ar). ^{13}C NMR δ 26.3 (C-6), 55.2 (OMe), 71.2 (C-5), 71.9 (C-4), 72.9 and 75.3 (2*PhCH_2O), 79.8 (C-2), 81.1 (C-3), 97.6 (C-1), 125.8–128.6 (10*CH–Ar), 137.8 and 138.4 (2*C_{IV}–Ar). MS IS *m*/*z*=359.5 [M−OMe]$^+$, 408.5 [M+NH_4]$^+$, 413.5 [M+Na]$^+$. HRMS: $C_{21}H_{26}O_5S$: calcd 390.1501; found 390.1492.

4.3.2. Methyl 2,3-di-*O*-benzyl-6-thio-β-D-glucopyranoside (4β). Obtained from **3β**; silica gel column chromatography (petroleum ether/AcOEt 85:15, then 8:2) afforded thiol **4β** with 80% yield as a colourless gum, $[\alpha]_D$ −16 (*c* 1, $CHCl_3$). ^{1}H NMR δ 1.70 (dd, 1H, J_{SH-6a}=9.8, J_{SH-6b}=7.9, SH), 2.29 (br s, OH), 2.69 (ddd, 1H, J_{5-6b}=7.9, H-6b), 2.92 (ddd, 1H, J_{5-6a}=2.8, J_{6a-6b}=14.5, H-6a), 3.30 (ddd, 1H, J_{4-5}=7.9, H-5), 3.38–3.46 (m, 3H, H-2, H-3, H-4), 3.58 (s, 3H, OMe), 4.34 (d, 1H, J_{1-2}=7.2, H-1), 4.64 and 4.96 (2d, AB system, 2H, J_{gem}=11.5, PhCH_2O), 4.69 and 4.93 (2d, AB system, 2H, J_{gem}=11.1, PhCH_2O), 7.23–7.37 (m, 10H, H–Ar). ^{13}C NMR δ 26.6 (C-6), 57.3 (OMe), 72.1 (C-4), 74.7 and 75.3 (2*PhCH_2O), 75.7 (C-5), 82.1 (C-2), 83.8 (C-3), 104.8 (C-1), 127.8–128.8 (10*CH–Ar), 138.4 and 138.5 (2*C_{IV}–Ar). MS IS *m*/*z*=408.5 [M+NH_4]$^+$, 413.5 [M+Na]$^+$, 429.5 [M+K]$^+$. HRMS: $C_{21}H_{26}O_5S$: calcd 390.1501; found 390.1500.

4.4. Thiofunctionalization at the C-4 position: regioselective benzoylation at O-6[18]

A pyridine solution of the 4,6-diol **5α** [29388-46-3][19] or **5β** [6988-40-5][20] (4 g, 10.7 mmol/20 mL) was cooled to −46 °C, then benzoyl chloride (1.24 mL, 1 equiv) was added dropwise under argon atmosphere and the mixture was stirred overnight while slowly reaching room temperature. The mixture was diluted with CH_2Cl_2 and then poured on ice; the organic layer was decanted and washed successively with saturated aqueous $NaHCO_3$ and brine. After drying the combined organic extracts over $MgSO_4$ and concentration in vacuo, the residue was purified by column chromatography.

4.4.1. Methyl 6-*O*-benzoyl-2,3-di-*O*-benzyl-α-D-galactopyranoside (6α) [125884-36-8].[21] Obtained from methyl 2,3-di-*O*-benzyl-α-D-galactopyranoside;[19] silica gel column chromatography (petroleum ether/AcOEt 7:3) afforded the 6-*O*-benzoate **6α** with 87% yield as a white amorphous solid, $[\alpha]_D$ +80 (*c* 1, $CHCl_3$); [lit.[21] $[\alpha]_D$ +83 ($CHCl_3$)]; ^{1}H NMR δ 2.78 (br s, OH), 3.35 (s, 3H, OMe), 3.89 (br s, 2H, H-2, H-3), 3.99–4.10 (m, 2H, H-4, H-5), 4.51–4.56 (m, 2H, H-6a and H-6b), 4.66 and 4,81 (2d, AB system, 2H, J_{gem}=11.9, Ph*CH*$_2$O), 4.67 (d, 1H, J_{1-2}=3.6, H-1), 4.68 and 4.81 (2d, AB system, 2H, J_{gem}=11.9, Ph*CH*$_2$O), 7.22–7.43 (m, 12H, H–Ar), 7.53 (t, 1H, J_{vic}=7.5, *para*-H–Bz), 8.02 (d, 2H, J_{vic}=7.5, *ortho*-H–Bz). ^{13}C NMR δ 55.2 (OMe), 64.1 (C-6), 67.6, 67.8 (C-4, C-5), 73.0 and 73.5 (2*Ph*CH*$_2$O), 75.6, 76.6 (C-2, C-3), 98.4 (C-1), 126.3–128.9 (CH–Ar), 129.5 (CH–*ortho*-Bz), 129.7 (C_{IV}–Bz), 133.0 (CH–*para*-Bz), 138.0 and 138.2 (2*C_{IV}–Ar), 166.2 (C═O). MS IS *m*/*z*=447.5 [M−OMe]$^+$, 479.5 [M+H]$^+$, 496.5 [M+NH_4]$^+$, 501.5 [M+Na]$^+$. HRMS: $C_{28}H_{30}O_7$: calcd 478.1991; found 478.1987.

4.4.2. Methyl 6-*O*-benzoyl-2,3-di-*O*-benzyl-β-D-galactopyranoside (6β) [20786-72-5].[22] Obtained from methyl 2,3-di-*O*-benzyl-β-D-galactopyranoside;[19] silica gel column chromatography (petroleum ether/AcOEt 7:3) afforded the 6-*O*-benzoate **6β** with 50% yield as a white amorphous solid, $[\alpha]_D$ +3 (*c* 1.4, $CHCl_3$); [lit.[22] $[\alpha]_D$ −1.63 (*c* 0.45, $CHCl_3$)]. ^{1}H NMR δ 2.84 (br s, OH), 3.51 (dd, 1H, J_{3-4}= 3.2, H-3), 3.53 (s, 3H, OMe), 3.59–3.73 (m, 2H, H-2, H-5), 3.96 (br s, 1H, H-4), 4.28 (d, 1H, J_{1-2}=7.7, H-1), 4.54–4.64 (m, 2H, H-6a, H-6b), 4.69 (s, 2H, Ph*CH*$_2$O), 4.71 and 4.89 (2d, AB system, 2H, J_{gem}=11.3, Ph*CH*$_2$O), 7.17–7.42 (m, 12H, H–Ar), 7.51 (t, 1H, J_{vic}=7.7, *para*-H–Bz), 8.03 (d, 2H, J_{vic}=7.5, *ortho*-H–Bz). ^{13}C NMR δ 56.8 (OMe), 63.5 (C-6), 66.6 (C-4), 71.9 (C-5), 72.8 and 74.9 (2*Ph*CH*$_2$O), 78.8 (C-2), 80.4 (C-3), 104.6 (C-1), 127.8–128.3 (CH–Ar), 129.8 (C_{IV}–Bz), 129.6 (CH–*ortho*-Bz), 133.0 (CH–*para*-Bz), 138.0 and 138.6 (2*C_{IV}–Ar), 166.2 (C═O). MS IS *m*/*z*=447.5 [M−OMe]$^+$, 479.5 [M+H]$^+$, 496.5 [M+NH_4]$^+$, 501.5 [M+Na]$^+$, 517.5 [M+K]$^+$. HRMS: $C_{28}H_{30}O_7$: calcd 478.1991; found 478.1979.

Di-*O*-benzoylated α- and β-galactopyranosides were also isolated in minor amounts.

4.4.2.1. Methyl 4,6-di-*O*-benzoyl-2,3-di-*O*-benzyl-α-D-galactopyranoside (7α). Silica gel column chromatography (petroleum ether/AcOEt 8:2) afforded **7α** with 8% yield as a colourless gum, $[\alpha]_D$ +47 (*c* 4.2, $CHCl_3$). ^{1}H NMR δ 3.41 (s, 3H, OMe), 3.97 (dd, 1H, H-2), 4.13 (dd, 1H, J_{2-3}=10.0, H-3), 4.28–4.37 (m, 2H, H-5, H-6b), 4.49 (dd, 1H, J_{5-6a}= 3.8, J_{6a-6b}=8.8, H-6a), 4.62 and 4,84 (2d, AB system, 2H, J_{gem}=11.7, Ph*CH*$_2$O), 4.68 and 4.84 (2d, AB system, 2H, J_{gem}=11.7, Ph*CH*$_2$O), 4.80 (d, 1H, J_{1-2}=3.6, H-1), 5.89 (d, 1H, H-4), 7.20–7.54 (m, 16H, H–Ar), 8.03 (2d, 4H, *J*=7.5, *ortho*-H–Bz). ^{13}C NMR δ 55.4 (OMe), 63.1 (C-6), 66.9 (C-5), 68.7 (C-4), 72.0 and 73.7 (2*Ph*CH*$_2$O), 74.9 (C-2), 76.2 (C-3), 99.0 (C-1), 127.5–128.4 (CH–Ar), 129.6 and 129.9 (CH–*ortho*-Bz), 129.7 (2*C_{IV}–Bz), 133.1 and 133.2 (2*CH–*para*-Bz), 138.0 and 138.2 (2*C_{IV}–Ar), 165.7 and 166.0 (2*C═O). MS IS *m*/*z*=551.5 [M−OMe]$^+$, 583.5 [M+H]$^+$, 600.5 [M+NH_4]$^+$, 605.5 [M+Na]$^+$. HRMS: $C_{35}H_{34}O_8$: calcd 582.2253; found 582.2248.

4.4.2.2. Methyl 4,6-di-*O*-benzoyl-2,3-di-*O*-benzyl-β-D-galactopyranoside (7β) [79698-16-1].[22] Silica gel column chromatography (petroleum ether/AcOEt 8:2) afforded **7β** with 10% yield as a white amorphous solid, $[\alpha]_D$ +13 (*c* 1.8, $CHCl_3$); [lit.[23] $[\alpha]_D$ +20.12 (*c* 0.83, $CHCl_3$)]. ^{1}H NMR δ 3.69 (s, 3H, OMe), 3.73–3.85 (m, 2H, H-2, H-3), 4.07 (br t, 1H, H-5), 4.46 (dd, 1H, J_{5-6b}=6.4, J_{6a-6b}=11.3, H-6b), 4.48 (d, 1H, J_{1-2}=7.6, H-1), 4.66 (dd, 1H, J_{5-6a}= 6.6, H-6a), 4.66 and 4,92 (2d, AB system, 2H, J_{gem}=11.5, Ph*CH*$_2$O), 4.82 and 4.96 (2d, AB system, 2H, J_{gem}=11.1, Ph*CH*$_2$O), 5.94 (br s, 1H, H-4), 7.26–7.52 (m, 14H, H–Ar), 7.55–7.65 (m, 2H, *para*-H–Bz), 8.12 and 8.21 (2d, 4H, *J*=7.2, *ortho*-H–Bz). ^{13}C NMR δ 57.4 (OMe), 62.6 (C-6), 66.7 (C-4), 70.7 (C-5), 72.6 and 75.3 (2*Ph*CH*$_2$O), 79.0 and 79.2 (C-2, C-3), 104.9 (C-1), 127.6–128.5 (CH–Ar), 129.6 and 129.7 (CH–*ortho*-Bz), 129.6 (2*C_{IV}–Bz), 133.2 and 133.3 (2*CH–*para*-Bz), 137.8 and 138.6 (2*C_{IV}–Ar), 165.8 and 166.1 (2*C═O). MS IS *m*/*z*=551.5 [M−OMe]$^+$, 583.5 [M+H]$^+$, 600.5 [M+NH_4]$^+$, 605.5 [M+Na]$^+$, 621.5 [M+K]$^+$. HRMS: $C_{35}H_{34}O_8$: calcd 582.2253; found 582.2241.

4.5. Thiofunctionalization at the C-4 position: nucleophilic inversion[23]

To an ice-cold solution of the monobenzoates **6** (2 g, 4.18 mmol/30 mL) in CH_2Cl_2/pyridine (14:1 v/v) trifluoromethanesulfonic anhydride (3 equiv) was added dropwise. The mixture was stirred for 30 min at 0 °C, then for 1 h at room temperature. The orange solution was poured into an ice-cold 10% $KHSO_4$ solution; the organic phase was decanted and washed successively with ice-cold aqueous saturated $NaHCO_3$ and iced water. After drying the combined organic extracts over $MgSO_4$ and concentration in vacuo, the residue was engaged in the next step without further purification. To a solution of the crude triflate in freshly distilled THF (1 g, ca. 1.6 mmol/20 mL), solid potassium thioacetate (3 equiv) was added and the resulting brown solution was stirred for 12 h at room temperature. The mixture was diluted with 10 mL AcOEt and then poured into iced water; the organic layer was washed with water and the aqueous phases re-extracted with AcOEt (10 mL). After drying the combined organic extracts over $MgSO_4$ and concentration in vacuo, the residue was purified by column chromatography.

4.5.1. Methyl 4-*S*-acetyl-6-*O*-benzoyl-2,3-di-*O*-benzyl-4-thio-α-D-glucopyranoside (8α). Obtained from monobenzoate **6α**; silica gel column chromatography (petroleum

ether/AcOEt 9:1, then 8:2) afforded the *S*-acetylated compound **8α** with 65% yield as a beige gum, $[\alpha]_D$ +67 (*c* 2, $CHCl_3$). ^1H NMR δ 2.28 (s, 3H, SAc), 3.37 (s, 3H, OMe), 3.63 (dd, 1H, J_{1-2}=3.5, H-2), 3.78 (t, 1H, $J_{3-4}=J_{4-5}$=10.4, H-4), 3.86 (t, 1H, H-3), 4.04 (ddd, 1H, H-5), 4.40 (dd, 1H, J_{5-6b}=5.5, H-6b), 4.57 (dd, 1H, J_{5-6a}=2.3, J_{6a-6b}=11.9, H-6a), 4.65 and 4.79 (2d, AB system, 2H, J_{gem}=11.9, PhCH_2O), 4.67 (d, 1H, H-1), 4.72 and 4.93 (2d, AB system, 2H, J_{gem}=11.0, PhCH_2O), 7.24–7.38 (m, 10H, H–Ar), 7.42 (t, 2H, J_{vic}=7.6, *meta*-H–Bz), 7.54 (t, 1H, J_{vic}=7.3, *para*-H–Bz), 8.06 (d, 2H, J_{vic}=7.4, *ortho*-H–Bz). ^{13}C NMR δ 30.7 (SAc), 45.7 (C-4), 55.5 (OMe), 64.2 (C-6), 68.8 (C-5), 73.2 and 76.2 (2*PhCH_2O), 78.3 (C-3), 81.1 (C-2), 98.4 (C-1), 127.6–128.5 (CH–Ar), 129.8 (CH–*ortho*-Bz), 129.9 (C_{IV}–Bz), 133.1 (CH–*para*-Bz), 138.4 and 138.5 (2*C_{IV}–Ar), 166.2 (C=O Bz), 193.1 (C=O SAc). MS IS *m*/*z*=505.5 $[M-OMe]^+$, 537.5 $[M+H]^+$, 554.5 $[M+NH_4]^+$, 575.5 $[M+K]^+$. HRMS: $C_{30}H_{32}O_7S$: calcd 536.1869; found 536.1861.

4.5.2. Methyl 4-*S*-acetyl-6-*O*-benzoyl-2,3-di-*O*-benzyl-4-thio-β-D-glucopyranoside (8β). Obtained from monobenzoate **6β**; silica gel column chromatography (petroleum ether/AcOEt 9:1, then 8:2) afforded the *S*-acetylated compound **8β** with 77% yield as a beige gum, $[\alpha]_D$ +35 (*c* 1.5, $CHCl_3$). ^1H NMR δ 2.27 (s, 3H, SAc), 3.50 (m, 1H, H-2), 3.55 (s, 3H, OMe), 3.65 (m, 1H, H-3), 3.69 (t, 1H, H-4, $J_{3-4}=J_{4-5}$=10.4), 3.88 (ddd, 1H, H-5), 4.35 (d, 1H, J_{1-2}=7.9, H-1), 4.43 (dd, 1H, J_{5-6b}=5.7, H-6b), 4.65 (dd, 1H, J_{5-6a}=3.0, J_{6a-6b}=12.1, H-6a), 4.68 and 4.88 (2d, AB system, 2H, J_{gem}=11.1, PhCH_2O), 4.71 and 4.93 (2d, AB system, 2H, J_{gem}=11.1, PhCH_2O), 7.22–7.38 (m, 10H, H–Ar), 7.43 (t, 2H, J_{vic}=7.6, *meta*-H–Bz), 7.55 (t, 1H, J_{vic}=7.3, *para*-H–Bz), 8.07 (d, 2H, J_{vic}=7.5, *ortho*-H–Bz). ^{13}C NMR δ 30.9 (SAc), 46.2 (C-4), 57.2 (OMe), 64.4 (C-6), 72.7 (C-5), 75.0 and 76.1 (2*PhCH_2O), 80.8 (C-3), 83.4 (C-2), 104.7 (C-1), 127.7–128.5 (CH–Ar), 129.9 (CH–*ortho*-Bz), 130.0 (C_{IV}–Bz), 133.2 (CH–*para*-Bz), 138.3 and 138.5 (2*C_{IV}–Ar), 166.4 (C=O Bz), 193.5 (C=O SAc). MS IS *m*/*z*=505.5 $[M-OMe]^+$, 537.5 $[M+H]^+$, 554.5 $[M+NH_4]^+$, 559.5 $[M+Na]^+$. HRMS: $C_{30}H_{32}O_7S$: calcd 536.1869; found 536.1854.

4.6. Thiofunctionalization at the C-4 position: reductive cleavage[24]

To an ice-cold solution of **8** in dry ether (1 mmol/10 mL), LAH (4 equiv) was added and the reaction mixture was stirred for 4 h under reflux. AcOEt (10 mL) and then 10% aqueous HCl was carefully added to the cooled suspension; the organic phase was decanted and the aqueous phase washed with AcOEt (2×10 mL). The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo and the residue was purified by column chromatography.

4.6.1. Methyl 2,3-di-*O*-benzyl-4-thio-α-D-glucopyranoside (9α). Obtained from thioacetate **8α**; silica gel column chromatography (petroleum ether/AcOEt 7:3, 65:35, then 6:4) afforded the thiol **9α** with 40% yield as a beige gum, $[\alpha]_D$ +11 (*c* 1, $CHCl_3$). ^1H NMR δ 1.71 (d, 1H, J_{vic}=7.2, SH), 1.90 (br s, 1H, OH), 2.90 (dt, 1H, J_{4-5}=10.4, H-4), 3.39 (s, 3H, OMe), 3.47 (dd, 1H, J_{1-2}=3.4, H-2), 3.65 (ddd, 1H, H-5), 3.71 (t, 1H, $J_{2-3}=J_{3-4}$=10.4, H-3), 3.79 (dd, 1H, J_{5-6b}=4.7, H-6b), 3.88 (dd, 1H, J_{5-6a}=2.6, J_{6a-6b}=11.9, H-6a), 4.64 (d, 1H, H-1), 4.65 and 4.79 (2d, AB system, 2H, J_{gem}=12.1, PhCH_2O), 4.84 and 4.97 (2d, AB system, 2H, J_{gem}=10.4, PhCH_2O), 7.25–7.43 (m, 10H, H–Ar). ^{13}C NMR δ 42.0 (C-4), 55.5 (OMe), 63.0 (C-6), 72.9 (C-5), 73.4 and 76.5 (PhCH_2O), 80.9 (C-2), 81.9 (C-3), 98.6 (C-1), 127.9–128.6 (CH–Ar), 138.1 and 138.5 (2*C_{IV}–Ar). MS IS *m*/*z*=359.5 $[M-OMe]^+$, 408.5 $[M+NH_4]^+$, 413.5 $[M+Na]^+$. HRMS: $C_{21}H_{26}O_5S$: calcd 390.1501; found 390.1488.

4.6.2. Methyl 2,3-di-*O*-benzyl-4-thio-β-D-glucopyranoside (9β). Obtained from thioacetate **8β**; silica gel column chromatography (petroleum ether/AcOEt 7:3, 65:35, then 6:4) afforded the thiol **9β** with 60% yield as a beige gum, $[\alpha]_D$ −28 (*c* 2.3, $CHCl_3$). ^1H NMR δ 1.73 (d, 1H, J_{vic}=6.6, SH), 2.10 (br s, 1H, OH), 2.86–2.99 (m, 1H, H-4), 3.31–3.42 (m, 3H, H-2, H-3, H-5), 3.58 (s, 3H, OMe), 3.80 (dd, 1H, J_{5-6b}=5.3, H-6b), 3.98 (dd, 1H, J_{5-6a}=2.8, J_{6a-6b}=12.0, H-6a), 4.36 (br d, 1H, J_{1-2}=7.4, H-1), 4.70 and 4.91 (2d, AB system, 2H, J_{gem}=11.1, PhCH_2O), 4.79 and 4.93 (2d, AB system, 2H, J=10.6, PhCH_2O), 7.28–7.45 (m, 10H, H–Ar). ^{13}C NMR δ 41.7 (C-4), 57.4 (OMe), 63.1 (C-6), 74.9 and 76.2 (PhCH_2O), 77.7 (C-5), 83.2 (C-2), 85.0 (C-3), 105.0 (C-1), 127.9–128.5 (CH–Ar), 138.2 and 138.4 (2*C_{IV}–Ar). MS IS *m*/*z*=359.5 $[M-OMe]^+$, 408.5 $[M+NH_4]^+$, 413.5 $[M+Na]^+$. HRMS: $C_{21}H_{26}O_5S$: calcd 390.1501; found 390.1483.

4.7. Chemoselective thiol addition: synthesis of phenylsulfonylvinyl sulfides

To an ice-cold solution of the thiols **4**, **9** (390 mg, 1 mmol/15 mL) in dry THF were successively added Et_3N (1 equiv), *Z*- or *E*-BPSE (1 equiv) and a few crystals of Bu_4NBr. The mixture was stirred for 12 h at room temperature, then diluted with AcOEt and poured into iced water; the aqueous phases were extracted with AcOEt (10 mL) and the combined organic extracts dried over $MgSO_4$. After concentration in vacuo, the residue was purified by column chromatography.

4.7.1. Methyl 2,3-di-*O*-benzyl-6-*S*-[(*E*)-2′-(phenylsulfonyl)-vinyl]-6-thio-α-D-glucopyranoside (12α*E*). Obtained from **4α** and *E*-BPSE; silica gel column chromatography (petroleum ether/AcOEt 7:3, then 6:4) afforded compound **12α*E*** with 83% yield as a colourless gum, $[\alpha]_D$ +36 (*c* 3.7, $CHCl_3$). ^1H NMR δ 2.88 (dd, 1H, J_{5-6b}=8.1, J_{6a-6b}=13.8, H-6b), 3.21 (dd, 1H, J_{5-6a}=2.4, H-6a), 3.30 (s, 3H, OMe), 3.35 (m, 1H, H-4), 3.49 (dd, 1H, J_{1-2}=3.6, J_{2-3}=9.6, H-2), 3.68–3.76 (m, 2H, H-3, H-5), 4.56 (d, 1H, H-1), 4.65 and 4.75 (2d, AB system, 2H, J_{gem}=12.1, PhCH_2O), 4.66 and 5.03 (2d, AB system, 2H, J_{gem}=11.5, PhCH_2O), 6.28 (d, 1H, J_{vic}=14.7, H-2′), 7.32–7.39 (m, H–Ar), 7.46–7.61 (m, 3H, *Ph*SO_2), 7.78 (d, 1H, H-1′), 7.82–7.86 (m, 2H, *ortho*-H–*Ph*SO_2). ^{13}C NMR δ 34.4 (C-6), 55.4 (OMe), 70.2 (C-5), 72.5 (C-4), 73.2 and 75.5 (PhCH_2O), 79.8 (C-2), 81.0 (C-3), 98.1 (C-1), 122.1 (C-2′), 126.0–129.3 (CH–Ar), 133.1 (CH–*para*-*Ph*SO_2), 137.9 and 138.6 (2*C_{IV}–Ar), 141.4 (C_{IV}–*Ph*SO_2), 146.4 (C-1′). MS IS *m*/*z*=574.5 $[M+NH_4]^+$, 579.5 $[M+Na]^+$, 595.5 $[M+K]^+$. HRMS: $C_{29}H_{32}O_7S_2$: calcd 556.1589; found 556.1578.

4.7.2. Methyl 2,3-di-*O*-benzyl-6-*S*-[(*Z*)-2′-(phenylsulfonyl)-vinyl]-6-thio-α-D-glucopyranoside (12α*Z*). Obtained from **4α** and *Z*-BPSE; silica gel column chromatography (petroleum ether/AcOEt 7:3, 65:35, then 6:4) afforded compound **12α*Z*** with 91% yield as a colourless gum, $[\alpha]_D$ +26 (*c* 2.0, $CHCl_3$). ^{1}H NMR δ 2.77 (dd, 1H, J_{5-6b}=8.3, J_{6a-6b}=14.7, H-6b), 2.91 (br s, 1H, OH), 3.12 (br d, 1H, J_{5-6a}<0.5, H-6a), 3.14 (s, 3H, OMe), 3.26–3.37 (m, 1H, H-4), 3.43 (dd, 1H, J_{2-3}=9.6, H-2), 3.64 (br t, 1H, J_{4-5}=9.6, H-5), 3.72 (t, 1H, J_{3-4}=9.6, H-3), 4.53 (d, 1H, J_{1-2}=3.6, H-1), 4.60 and 4.69 (2d, AB system, 2H, J_{gem}=12.1, Ph*CH*$_2$O), 4.71 and 4.96 (2d, AB system, 2H, J_{gem}=11.5, Ph*CH*$_2$O), 6.16 (d, 1H, J_{vic}=10.2, H-2′), 7.21 (d, 1H, H-1′), 7.28–7.35 (m, H–Ar), 7.48 (m, 2H, *meta*-H–*Ph*SO$_2$), 7.86 (m, 1H, *para*-H–*Ph*SO$_2$), 7.95 (d, 2H, J_{vic}=7.7, *ortho*-H–*Ph*SO$_2$). ^{13}C NMR δ 37.2 (C-6), 56.5 (OMe), 72.4 (C-5), 73.5 (C-4), 74.0 and 76.3 (Ph*CH*$_2$O), 80.5 (C-2), 82.1 (C-3), 98.8 (C-1), 122.8 (C-2′), 128.1–130.8 (CH–Ar), 139.0 and 139.8 (2*C$_{IV}$–Ar), 142.4 (C$_{IV}$–*Ph*SO$_2$), 149.9 (C-1′). MS IS *m*/*z*=579.5 [M+Na]$^+$, 595.5 [M+K]$^+$. HRMS: $C_{29}H_{32}O_7S_2$: calcd 556.1589; found 556.1583.

4.7.3. Methyl 2,3-di-*O*-benzyl-6-*S*-[(*E*)-2′-(phenylsulfonyl)-vinyl]-6-thio-β-D-glucopyranoside (12β*E*). Obtained from **4β** and *E*-BPSE; silica gel column chromatography (petroleum ether/AcOEt 7:3, then 6:4) afforded compound **12β*E*** with 70% yield as a colourless gum, $[\alpha]_D$ −13 (*c* 4.1, $CHCl_3$). ^{1}H NMR δ 2.66 (br s, 1H, OH), 2.91 (dd, 1H, J_{5-6b}=6.8, J_{6a-6b}=14.1, H-6b), 3.23 (br d, 1H, J_{5-6a}<0.5, H-6a), 3.34–3.40 (m, 4H, H-2, H-3, H-4, H-5), 3.48 (s, 3H, OMe), 4.28 (br d, 1H, J_{1-2}=6.8, H-1), 4.64 and 4.91 (2d, AB system, 2H, J_{gem}=11.1, Ph*CH*$_2$O), 4.67 and 4.93 (2d, AB system, 2H, J_{gem}=11.3, Ph*CH*$_2$O), 6.29 (d, 1H, H-2′, J_{vic}=14.7), 7.23–7.36 (m, H–Ar), 7.47 (t, 2H, *meta*-H–Ar *Ph*SO$_2$), 7.56 (t, 1H, *para*-H–*Ph*SO$_2$), 7.80 (d, 1H, H-1′), 7.84 (d, 2H, *ortho*-H–*Ph*SO$_2$, J_{vic}=7.5). ^{13}C NMR δ 34.4 (C-6), 57.1 (OMe), 72.6 (C-4), 74.6 and 75.2 (Ph*CH*$_2$O), 74.7 (C-5), 82.2 (C-2), 83.8 (C-3), 104.7 (C-1), 121.8 (C-2′), 127.3–129.2 (CH–Ar), 133.1 (CH–*para*-*Ph*SO$_2$), 138.3 (2*C$_{IV}$–Ar), 141.2 (C$_{IV}$–*Ph*SO$_2$), 146.5 (C-1′). MS IS *m*/*z*=525.5 [M−OMe]$^+$, 574.5 [M+NH$_4$]$^+$, 579.5 [M+Na]$^+$, 595.5 [M+K]$^+$. HRMS: $C_{29}H_{32}O_7S_2$: calcd 556.1589; found 556.1580.

4.7.4. Methyl 2,3-di-*O*-benzyl-6-*S*-[(*Z*)-2′-(phenylsulfonyl)-vinyl]-6-thio-β-D-glucopyranoside (12β*Z*). Obtained from **4β** and *Z*-BPSE; silica gel column chromatography (petroleum ether/AcOEt 7:3, 6:4, then 1:1) afforded compound **12β*Z*** with 72% yield as a colourless gum, $[\alpha]_D$ +43 (*c* 3.6, $CHCl_3$). ^{1}H NMR δ 2.63 (br s, 1H, OH), 2.80 (dd, 1H, J_{5-6b}=7.7, J_{6a-6b}=14.7, H-6b), 3.21 (br d, 1H, J_{5-6a}< 0.5, H-6a), 3.29–3.53 (m, 4H, H-2, H-3, H-4, H-5), 3.56 (s, 3H, OMe), 4.22 (d, 1H, J_{1-2}=7.2, H-1), 4.63 and 4.88 (2d, AB system, 2H, J_{gem}=11.5, Ph*CH*$_2$O), 4.69 and 4.93 (2d, AB system, 2H, J_{gem}=11.7, Ph*CH*$_2$O), 6.16 (d, 1H, J_{vic} *J*= 10.4, H-2′), 7.23–7.36 (m, H–Ar, H-1′), 7.48 (m, 2H, *meta*-H–Ar *Ph*SO$_2$), 7.88 (m, 1H, *para*-H–*Ph*SO$_2$), 7.96 (d, 2H, J_{vic}=7.7, *ortho*-H–*Ph*SO$_2$). ^{13}C NMR δ 37.4 (C-6), 57.3 (OMe), 72.3 (C-4), 75.1 and 75.2 (Ph*CH*$_2$O), 75.8 (C-5), 81.7 (C-2), 83.4 (C-3), 104.7 (C-1), 121.7 (C-2′), 127.1–129.5 (CH–Ar), 133.4 (CH–*para*-*Ph*SO$_2$), 138.3 (2*C$_{IV}$–Ar), 141.4 (C$_{IV}$–*Ph*SO$_2$), 149.0 (C-1′). MS IS *m*/*z*=525.5 [M−OMe]$^+$, 574.5 [M+NH$_4$]$^+$, 579.5 [M+Na]$^+$, 595.5 [M+K]$^+$. HRMS: $C_{29}H_{32}O_7S_2$: calcd 556.1589; found 556.1594.

4.7.5. Methyl 2,3-di-*O*-benzyl-4-*S*-[(*E*)-2′-(phenylsulfonyl)-vinyl]-4-thio-α-D-glucopyranoside (13α*E*). Obtained from **9α** and *E*-BPSE; silica gel column chromatography (petroleum ether/AcOEt 7:3, 65:35, then 6:4) afforded **13α*E*** with 76% yield as a colourless gum, $[\alpha]_D$ +38 (*c* 1.5, $CHCl_3$). ^{1}H NMR δ 2.45 (br s, 1H, OH), 3.25 (t, 1H, J_{3-4}= J_{4-5}=10.8, H-4), 3.36 (s, 3H, OMe), 3.52 (dd, 1H, J_{1-2}= 3.4, J_{2-3}=9.2, H-2), 3.64–3.79 (m, 3H, H-5, H-6a, H-6b), 3.84 (t, 1H, H-3), 4.60 and 4.74 (2d, AB system, 2H, J_{gem}=12.2, Ph*CH*$_2$O), 4.63 (d, 1H, H-1), 4.71 and 4.87 (2d, AB system, 2H, J_{gem}=10.9, Ph*CH*$_2$O), 6.45 (d, 1H, J_{vic}=14.7, H-2′), 7.25–7.34 (m, H–Ar), 7.45 (br t, 2H, *meta*-H–*Ph*SO$_2$), 7.55 (br t, 1H, J_{vic}=7.3, *para*-H–*Ph*SO$_2$), 7.80 (d, 2H, J_{vic}=7.3, *ortho*-H–*Ph*SO$_2$), 7.83 (d, 1H, H-1′). ^{13}C NMR δ 50.1 (C-4), 56.1 (OMe), 62.2 (C-6), 71.2 (C-5), 73.8 and 76.6 (Ph*CH*$_2$O), 79.1 (C-3), 81.2 (C-2), 98.8 (C-1), 123.9 (C-2′), 127.8–129.7 (CH–Ar), 133.6 (CH–*para*-*Ph*SO$_2$), 138.3 and 138.5 (2*C$_{IV}$–Ar), 141.5 (C$_{IV}$–*Ph*SO$_2$), 145.5 (C-1′). MS IS *m*/*z*=525.5 [M−OMe]$^+$, 557.5 [M+H]$^+$, 574.5 [M+NH$_4$]$^+$. HRMS: $C_{29}H_{32}O_7S_2$: calcd 556.1589; found 556.1591.

4.7.6. Methyl 2,3-di-*O*-benzyl-4-*S*-[(*Z*)-2′-(phenylsulfonyl)-vinyl]-4-thio-α-D-glucopyranoside (13α*Z*). Obtained from **9α** and *Z*-BPSE; silica gel column chromatography (petroleum ether/AcOEt 6:4, 55:45, then 1:1) afforded **13α*Z*** with 92% yield as a colourless gum, $[\alpha]_D$ +9 (*c* 1.9, $CHCl_3$). ^{1}H NMR δ 1.95 (br s, 1H, OH), 3.08 (t, 1H, J_{3-4}=J_{4-5}= 10.7, H-4), 3.38 (s, 3H, OMe), 3.48 (dd, 1H, J_{1-2}=3.4, J_{2-3}=9.4, H-2), 3.72 (dt, 1H, J_{5-6a}=J_{5-6b}=2.3, H-5), 3.79–3.85 (m, 2H, H-6a, H-6b), 3.87 (br t, 1H, H-3), 4.56 and 4.84 (2d, AB system, 2H, J_{gem}=10.2, Ph*CH*$_2$O), 4.62 (d, 1H, H-1), 4.63 and 4.77 (2d, AB system, 2H, J_{gem}=12.0, Ph*CH*$_2$O), 6.14 (d, 1H, J_{vic}=10.2, H-2′), 7.13–7.37 (m, H-1′, H–Ar), 7.45 (br t, 2H, *meta*-H–*Ph*SO$_2$), 7.57 (br t, 1H, J_{vic}=7.4, *para*-H–*Ph*SO$_2$), 7.95 (d, 2H, J_{vic}=7.6, *ortho*-H–*Ph*SO$_2$). ^{13}C NMR δ 52.3 (C-4), 55.7 (OMe), 61.9 (C-6), 70.6 (C-5), 73.4 and 76.4 (Ph*CH*$_2$O), 79.3 (C-3), 80.7 (C-2), 98.5 (C-1), 122.7 (C-2′), 127.2–129.2 (CH–Ar), 133.6 (CH–*para*-*Ph*SO$_2$), 137.9 (2*C$_{IV}$–Ar), 141.4 (C$_{IV}$–*Ph*SO$_2$), 145.8 (C-1′). MS IS *m*/*z*=525.5 [M−OMe]$^+$, 557.5 [M+H]$^+$, 574.5 [M+NH$_4$]$^+$. HRMS: $C_{29}H_{32}O_7S_2$: calcd 556.1589; found 556.1575.

4.7.7. Methyl 2,3-di-*O*-benzyl-4-*S*-[(*E*)-2′-(phenylsulfonyl)-vinyl]-4-thio-β-D-glucopyranoside (13β*E*). Obtained from **9β** and *E*-BPSE; silica gel column chromatography (petroleum ether/AcOEt 7:3, 65:35, then 6:4) afforded **13β*E*** with 96% yield as a colourless gum, $[\alpha]_D$ +62 (*c* 1, $CHCl_3$). ^{1}H NMR δ 2.55 (br s, 1H, OH), 3.28 (t, 1H, J_{3-4}=J_{4-5}= 10.4, H-4), 3.35–3.55 (m, 3H, H-2, H-3, H-5), 3.54 (s, 3H, OMe), 3.74 (d, 1H, J_{5-6b}<0.5, H-6b), 3.91 (br d, 1H, J_{5-6a}< 0.5, J_{6a-6b}=12.0, H-6a), 4.33 (d, 1H, J_{1-2}=7.7, H-1), 4.66 and 4.89 (2d, AB system, 2H, J_{gem}=11.1, Ph*CH*$_2$O), 4.69 and 4.83 (2d, AB system, 2H, J_{gem}=10.9, Ph*CH*$_2$O), 6.43 (d, 1H, J_{vic}=14.7, H-2′), 7.19–7.32 (m, H–Ar), 7.41 (br t, 2H, *meta*-H–*Ph*SO$_2$), 7.52 (br t, 1H, J_{vic}=7.2, *para*-H–*Ph*SO$_2$), 7.78 (d, 2H, J_{vic}=7.1, *ortho*-H–*Ph*SO$_2$), 7.82 (d, 1H, H-1′). ^{13}C NMR δ 49.5 (C-4), 57.3 (OMe), 61.8 (C-6), 74.8 and 75.9 (Ph*CH*$_2$O), 75.1 (C-5), 81.7 (C-3), 83.0 (C-2), 104.5 (C-1), 123.7 (C-2′), 127.3–129.5 (CH–Ar), 133.1 (CH–*para*-*Ph*SO$_2$), 137.7 and 138.1 (2*C$_{IV}$–Ar), 140.9 (C$_{IV}$–*Ph*SO$_2$), 144.8 (C-1′). MS IS *m*/*z*=525.5 [M−OMe]$^+$, 557.5 [M+H]$^+$,

574.5 [M+NH_4]$^+$, 579.5 [M+Na]$^+$. HRMS: $C_{29}H_{32}O_7S_2$: calcd 556.1589; found 556.1573.

4.7.8. Methyl 2,3-di-*O*-benzyl-4-*S*-[(*Z*)-2′-(phenylsulfonyl)-vinyl]-4-thio-β-D-glucopyranoside (13β*Z*). Obtained from **9β** and *Z*-BPSE; silica gel column chromatography (petroleum ether/AcOEt 7:3, 55:45, then 1:1) afforded **13β*Z*** with 91% yield as a colourless gum, $[\alpha]_D$ −23 (*c* 3.5, $CHCl_3$). ^{1}H NMR δ 2.10 (br s, 1H, OH), 3.12 (t, 1H, J_{3-4}=J_{4-5}=10.8, H-4), 3.37 (t, 1H, H-3), 3.40–3.55 (m, H-2, H-5), 3.56 (s, 3H, OMe), 3.81 (dd, 1H, J_{5-6b}=3.4, H-6b), 3.94 (dd, 1H, J_{5-6a}=2.0, J_{6a-6b}=12.3, H-6a), 4.34 (d, 1H, J_{1-2}=7.9, H-1), 4.58 and 4.83 (2d, AB system, 2H, J_{gem}=10.2, Ph*CH*$_2$O), 4.69 and 4.90 (2d, AB system, 2H, J_{gem}=11.1, Ph*CH*$_2$O), 6.14 (d, 1H, J_{vic}=10.2, H-2′), 7.10–7.35 (m, H-1′, H–Ar), 7.45 (br t, 2H, *meta*-H–*Ph*SO_2), 7.56 (br t, 1H, J_{vic}=7.3, *para*-H–*Ph*SO_2), 7.94 (d, 2H, J_{vic}=7.1, *ortho*-H–*Ph*SO_2). ^{13}C NMR δ 50.0 (C-4), 57.4 (OMe), 61.9 (C-6), 75.0 and 76.5 (Ph*CH*$_2$O), 75.1 (C-5), 82.5 (C-3), 83.0 (C-2), 104.7 (C-1), 122.7 (C-2′), 127.7–129.4 (CH–Ar), 133.6 (CH–*para*-*Ph*SO_2), 137.7 and 138.2 (2*C_{IV}–Ar), 141.3 (C_{IV}–*Ph*SO_2), 145.8 (C-1′). MS IS *m*/*z*=525.5 [M−OMe]$^+$, 557.5 [M+H]$^+$, 574.5 [M+NH_4]$^+$, 579.5 [M+Na]$^+$. HRMS: $C_{29}H_{32}O_7S_2$: calcd 556.1589; found 556.1596.

4.8. Oxathiane synthesis: base-catalyzed cyclization

To an ice-cold solution of the phenylsulfonylvinyl sulfides **12**, **13** (556 mg, 1 mmol/10 mL) in dry THF were successively added NaH (1 equiv) and a few crystals of Bu_4NBr. The mixture was stirred for 12 h at room temperature, then diluted with AcOEt and poured into iced water; the aqueous phases were extracted with AcOEt (10 mL) and the combined organic extracts dried over $MgSO_4$. After concentration in vacuo, the residue was purified by column chromatography.

4.8.1. Methyl 2,3-di-*O*-benzyl-4-*O*, 6-*S*-[(1*S*)-2-(phenylsulfonyl)-ethylidene]-6-thio-α-D-glucopyranoside (10α). Obtained from either **12α*E*** or **12α*Z***; silica gel column chromatography (petroleum ether/AcOEt 7:3, then 6:4) afforded **10α** with 52% yield as a white amorphous solid, $[\alpha]_D$ +70 (*c* 2.5, $CHCl_3$). ^{1}H NMR δ 2.75 (dd, 1H, J_{5-6b}=4.3, J_{6a-6b}=12.7, H-6b), 2.88 (d, 1H, J_{5-6a}=10.6, H-6a), 3.26 (t, 1H, J_{3-4}=J_{4-5}=9.3, H-4), 3.34 (dd, 1H, J_{7-8b}=4.1, H-8b), 3.38 (s, 3H, OMe), 3.46 (dd, 1H, J_{2-3}=9.3, H-2), 3.62 (dd, 1H, J_{7-8a}=7.2, J_{8a-8b}=14.5, H-8a), 3.74 (dt, 1H, H-5), 3.88 (t, 1H, J_{3-4}=9.3, H-3), 4.50 (d, 1H, J_{1-2}=3.7, H-1), 4.64 and 4.83 (2d, AB system, 2H, J_{gem}=12.1, Ph*CH*$_2$O), 4.73 and 4.98 (2d, AB system, 2H, J_{gem}=10.8, Ph*CH*$_2$O), 5.17 (dd, 1H, H-7), 7.20–7.55 (m, H–Ar), 7.64 (br t, 1H, J_{vic}=7.3, *para*-H–*Ph*SO_2), 7.95 (br d, 2H, J_{vic}=7.2, *ortho*-H–*Ph*SO_2). ^{13}C NMR δ 31.6 (C-6), 55.6 (OMe), 60.3 (C-8), 64.2 (C-5), 73.9 and 75.7 (Ph*CH*$_2$O), 76.1 (C-7), 78.7 and 78.9 (C-2, C-3), 84.3 (C-4), 98.9 (C-1), 127.6–129.4 (CH–Ar), 134.2 (CH–*para*-*Ph*SO_2), 138.2, 138.9, 139.3 (3*C_{IV}–Ar). MS IS *m*/*z*=525.5 [M−OMe]$^+$, 557.5 [M+H]$^+$, 574.5 [M+NH_4]$^+$, 579.5 [M+Na]$^+$, 595.5 [M+K]$^+$. HRMS: $C_{29}H_{32}O_7S_2$: calcd 556.1589; found 556.1587.

4.8.2. Methyl 2,3-di-*O*-benzyl-4-*O*, 6-S-[(1*S*)-2-(phenylsulfonyl)-ethylidene]-6-thio-β-D-glucopyranoside (10β). Obtained from either **12β*E*** or **12β*Z***; silica gel column chromatography (petroleum ether/AcOEt 7:3, then 6:4) afforded **10β** with 60% yield as a white amorphous solid, $[\alpha]_D$ +64 (*c* 1.7, $CHCl_3$). ^{1}H NMR δ 2.87 (dd, 1H, J_{5-6b}=4.7, J_{6a-6b}=13.8, H-6b), 2.95 (d, 1H, J_{5-6a}=9.1, H-6a), 3.27–3.40 (m, 4H, H-2, H-4, H-5, H-8b), 3.55 (s, 3H, OMe), 3.58 (t, 1H, J_{2-3}=J_{3-4}=9.1, H-3), 3.61 (dd, 1H, J_{7-8a}=7.4, J_{8a-8b}=14.5, H-8a), 4.32 (d, 1H, J_{1-2}=7.8, H-1), 4.70 and 4.84 (2d, AB system, 2H, J_{gem}=10.9, Ph*CH*$_2$O), 4.72 and 4.98 (2d, AB system, 2H, J_{gem}=10.8, Ph*CH*$_2$O), 5.14 (dd, 1H, J_{7-8b}=4.0, H-7), 7.24–7.42 (m, H–Ar), 7.52 (br t, 2H, *meta*-H–*Ph*SO_2), 7.63 (br t, 1H, *para*-H–*Ph*SO_2), 7.94 (d, 2H, J_{vic}=7.7, *ortho*-H–*Ph*SO_2). ^{13}C NMR δ 31.4 (C-6), 57.5 (OMe), 60.3 (C-8), 68.1 (C-5), 75.3 and 75.5 (Ph*CH*$_2$O), 76.2 (C-7), 81.2 (C-3), 82.0 (C-4), 83.7 (C-2), 104.7 (C-1), 127.7–129.5 (CH–Ar), 134.2 (CH–*para*-*Ph*SO_2), 138.4, 138.7, 139.2 (3*C_{IV}–Ar). MS IS *m*/*z*=525.5 [M−OMe]$^+$, 557.5 [M+H]$^+$, 574.5 [M+NH_4]$^+$, 579.5 [M+Na]$^+$. HRMS: $C_{29}H_{32}O_7S_2$: calcd 556.1589; found 556.1579.

4.8.3. Methyl 2,3-di-*O*-benzyl-6-*O*, 4-*S*-[(1*R*)-2-(phenylsulfonyl)-ethylidene]-4-thio-α-D-glucopyranoside (11α). Obtained from either **13α*E*** or **13α*Z***; silica gel column chromatography (petroleum ether/AcOEt 7:3, then 6:4) afforded **11α** with 83% yield as a white amorphous solid, $[\alpha]_D$ −2 (*c* 1.5, $CHCl_3$). ^{1}H NMR δ 3.03 (t, 1H, J_{3-4}=J_{4-5}=10.2, H-4), 3.21 (t, 1H, J_{5-6b}=J_{6a-6b}=10.7, H-6b), 3.32 (s, 3H, OMe), 3.35 (dd, 1H, J_{7-8b}=2.5, H-8b), 3.55 (dd, 1H, J_{2-3}=9.2, H-2), 3.60 (dd, 1H, J_{8a-8b}=14.3, H-8a), 3.69 (dt, 1H, H-5), 3.85 (dd, 1H, J_{5-6a}=4.2, H-6a), 4.58 and 4.84 (2d, AB system, 2H, J_{gem}=10.6, Ph*CH*$_2$O), 4.59 (d, 1H, J_{1-2}=3.4, H-1), 4.63 and 4.77 (2d, AB system, 2H, J_{gem}=11.9, Ph*CH*$_2$O), 5.20 (dd, 1H, J_{7-8a}=9.2, H-7) 7.25–7.38 (m, 10H, H–Ar), 7.49–7.66 (m, 3H, *Ph*SO_2), 7.88 (d, 2H, J_{vic}=7.4, *ortho*-H–*Ph*SO_2). ^{13}C NMR δ 50.1 (C-4), 55.8 (OMe), 60.5 (C-8), 64.8 (C-5), 71.1 (C-6), 73.7 and 76.2 (Ph*CH*$_2$O), 77.7 (C-3), 78.3 (C-7), 81.4 (C-2), 99.2 (C-1), 126.6–129.8 (CH–Ar), 134.6 (CH–*para*-*Ph*SO_2, 138.5 and 138.6 (2*C_{IV}–Ar), 140.6 (C_{IV}–*Ph*SO_2). MS IS *m*/*z*=557.5 [M+H]$^+$, 574.5 [M+NH_4]$^+$, 579.5 [M+Na]$^+$, 595.5 [M+K]$^+$. HRMS: $C_{29}H_{32}O_7S_2$: calcd 556.1589; found 556.1582.

4.8.4. Methyl 2,3-di-*O*-benzyl-6-*O*, 4-*S*-[(1*R*)-2-(phenylsulfonyl)-ethylidene]-4-thio-β-D-glucopyranoside (11α). Obtained from either **13α*E*** or **13α*Z***; silica gel column chromatography (petroleum ether/AcOEt 7:3, then 6:4) (petroleum ether/AcOEt 7:3 and 6:4) afforded **11α** with 80% yield as a white amorphous solid, $[\alpha]_D$ +17 (*c* 3.5, $CHCl_3$). ^{1}H NMR δ 3.07 (t, 1H, J_{3-4}=J_{4-5}=9.4, H-4), 3.21–3.35 (m, 2H, H-5, H-6b), 3.37–3.46 (m, 3H, H-2, H-3, H-8b), 3.51 (s, 3H, OMe), 3.60 (dd, 1H, J_{7-8a}=9.2, J_{8a-8b}=14.7, H-8a), 3.91–4.01 (m, 1H, H-6a), 4.31 (d, 1H, J_{1-2}=7.0, H-1), 4.56 and 4.78 (2d, AB system, 2H, J_{gem}=10.8, Ph*CH*$_2$O), 4.69 and 4.88 (2d, AB system, 2H, J_{gem}=11.1, Ph*CH*$_2$O), 5.19 (dd, 1H, J_{7-8b}=2.8, H-7), 7.23–7.36 (m, 10H, H–Ar), 7.49–7.65 (m, 3H, *Ph*SO_2), 7.88 (d, 2H, J_{vic}=7.4, *ortho*-H–*Ph*SO_2). ^{13}C NMR δ 49.3 (C-4), 57.7 (OMe), 60.5 (C-8), 68.6 (C-5), 70.8 (C-6), 75.4 and 75.9 (Ph*CH*$_2$O), 78.2 (C-7), 80.9 (C-3), 83.9 (C-2), 105.5 (C-1), 127.3–129.5 (14*CH–Ar), 134.3 (CH–*para*-*Ph*SO_2), 138.1 and 138.6 (2*C_{IV}–Ar), 140.2 (C_{IV}–*Ph*SO_2). MS IS *m*/*z*=557.5 [M+H]$^+$, 574.5 [M+NH_4]$^+$, 579.5 [M+Na]$^+$, 595.5 [M+K]$^+$. HRMS: $C_{29}H_{32}O_7S_2$: calcd 556.1589; found 556.1586.

4.9. Oxathianes behaviour under acidic conditions: benzyl deprotection

The oxathiane was dissolved in 9:1 TFA/H_2O (100 mg/5 mL) and the mixture was stirred at 60 °C until complete consumption of the starting material. After evaporation and coevaporation with toluene, the raw product was acetylated (4 equiv of Ac_2O in 5 mL pyridine, 12 h at rt). The solution was evaporated, coevaporated with toluene and the residue was purified by column chromatography.

4.9.1. Methyl 2,3-di-*O*-acetyl-4-*O*, 6-*S*-[(1*S*)-2-(phenylsulfonyl)-ethylidene]-6-thio-α-D-glucopyranoside (14α). Obtained from **10α**; silica gel column chromatography (petroleum ether/AcOEt 7:3, then 6:4) afforded **14α** with 65% yield as a white amorphous solid, $[\alpha]_D$ +128 (*c* 0.9, $CHCl_3$). ^{1}H NMR δ 2.04, 2.07 (2s, 6H, 2*O*Ac*), 2.80 (dd, 1H, J_{5-6b}=4.2, H-6b), 2.97 (dd, 1H, J_{5-6a}=10.6, J_{6a-6b}=13.0, H-6a), 3.21 (dd, 1H, J_{7-8b}=3.2, H-8b), 3.34 (t, 1H, J_{3-4}=J_{4-5}=9.8, H-4), 3.35 (s, 3H, OMe), 3.55 (dd, 1H, J_{7-8a}=8.5, J_{8a-8b}=14.3, H-8a), 3.81 (dt, 1H, H-5), 4.86 (d, 1H, J_{1-2}=3.6, H-1), 4.80 (dd, 1H, J_{2-3}=9.8, H-2), 5.27 (dd, 1H, H-7), 5.46 (t, 1H, H-3), 7.51–7.67 (m, 3H, *Ph*SO_2), 7.87 (d, 2H, J_{vic}=7.4, *ortho*-H–*Ph*SO_2). ^{13}C NMR δ 21.1 and 21.2 (OAc), 31.9 (C-6), 55.9 (OMe), 60.1 (C-8), 64.4 (C-5), 68.7 (C-3), 71.5 (C-2), 76.4 (C-7), 81.6 (C-4), 97.6 (C-1), 128.5 and 129.8 (4*CH *ortho* and *meta*-*Ph*SO_2), 134.4 (CH–*para*-*Ph*SO_2), 140.1 (C_{IV}–*Ph*SO_2), 170.6 and 170.7 (2*CO). MS IS *m*/*z*=401.5 [M−AcOH]$^+$, 429.5 [M−OMe]$^+$, 461.5 [M+H]$^+$, 478.5 [M+NH_4]$^+$, 483.5 [M+Na]$^+$. HRMS: $C_{19}H_{24}O_9S_2$: calcd 460.0862; found 460.0852.

4.9.2. Methyl 2,3-di-*O*-acetyl-4-*O*, 6-*S*-[(1*S*)-(2-phenylsulfonyl)-ethylidene]-6-thio-β-D-glucopyranoside (14β). Obtained from **10β**; silica gel column chromatography (petroleum ether/AcOEt 7:3, then 6:4) afforded **14β** with 65% yield as a white amorphous solid, $[\alpha]_D$ +13 (*c* 2.1, $CHCl_3$). ^{1}H NMR δ 2.06, 2.10 (2s, 6H, 2*O*Ac*), 2.94 (dd, 1H, J_{5-6b}=4.2, H-6b), 3.04 (dd, 1H, J_{5-6a}=9.6, J_{6a-6b}=12.8, H-6a), 3.27 (dd, 1H, J_{7-8b}=3.2, H-8b), 3.41 (t, 1H, J_{3-4}=J_{4-5}=9.6, H-4), 3.49 (s, 3H, OMe), 3.47–3.53 (m, 1H, H-5), 3.59 (dd, 1H, J_{7-8a}=8.6, J_{8a-8b}=14.3, H-8a), 4.43 (d, 1H, J_{1-2}=7.9, H-1), 4.95 (dd, 1H, J_{2-3}=9.6, H-2), 5.24 (t, 1H, H-3), 5.25 (dd, 1H, H-7), 7.58 (t, 2H, *meta*-H–*Ph*SO_2), 7.69 (t, 1H, *para*-H–*Ph*SO_2), 7.91 (d, 2H, J_{vic}=7.4, *ortho*-H–*Ph*SO_2). ^{13}C NMR δ 21.1 and 21.2 (OAc), 31.7 (C-6), 57.6 (OMe), 60.0 (C-8), 68.5 (C-5), 71.7 (C-3), 72.0 (C-2), 76.5 (C-7), 80.6 (C-4), 102.1 (C-1), 127.7 (2*CH *ortho*-*Ph*SO_2), 129.3 (2*CH *meta*-*Ph*SO_2), 133.9 (CH–*para*-*Ph*SO_2), 139.4 (C_{IV}–*Ph*SO_2), 169.4 and 170.7 (2*CO). MS IS *m*/*z*=401.5 [M−AcOH]$^+$, 429.5 [M−OMe]$^+$, 461.5 [M+H]$^+$, 478.5 [M+NH_4]$^+$, 483.5 [M+Na]$^+$. HRMS: $C_{19}H_{24}O_9S_2$: calcd 460.0862; found 460.0849.

4.9.3. Methyl 2,3-di-*O*-acetyl-6-*O*, 4-*S*-[(1*R*)-2-(phenylsulfonyl)-ethylidene]-4-thio-α-D-glucopyranoside (15α). Obtained from **11α**; silica gel column chromatography (petroleum ether/AcOEt 7:3, then 6:4) afforded **15α** with 67% yield as a white amorphous solid, $[\alpha]_D$ +155 (*c* 2.0, $CHCl_3$). ^{1}H NMR δ 2.05, 2.09 (2s, 6H, 2*O*Ac*), 3.15 (t, 1H, J_{3-4}=J_{4-5}=9.4, H-4), 3.27–3.35 (m, 2H, H-6b, H-8b), 3.34 (s, 3H, OMe), 3.60 (dd, 1H, J_{7-8a}=9.1, J_{8a-8b}=14.7, H-8a), 3.81 (dt, 1H, H-5), 3.91 (dd, 1H, J_{5-6a}=4.5 J_{6a-6b}=10.8, H-6a), 4.90 (dd, 1H, J_{7-8b}=3.4, H-7), 4.92 (d, 1H, J_{1-2}=3.4, H-1), 5.24 (dd, 1H, J_{2-3}=9.4, H-2), 5.26 (t, 1H, J_{2-3}=9.4, J_{3-4}=9.4, H-3), 7.56 (t, 2H, *meta*-H–*Ph*SO_2), 7.67 (t, 1H, *para*-H–*Ph*SO_2), 7.89 (d, 2H, J_{vic}=7.7, *ortho*-H–*Ph*SO_2). ^{13}C NMR δ 20.9 and 21.2 (OAc), 48.9 (C-4), 55.8 (OMe), 60.3 (C-8), 64.4 (C-5), 68.5 (C-3), 71.1 (C-6), 72.3 (C-7), 78.5 (C-2), 97.8 (C-1), 128.9 (2*CH *ortho*-*Ph*SO_2), 129.5 (2*CH *meta*-*Ph*SO_2), 134.4 (CH–*para*-*Ph*SO_2), 140.2 (C_{IV}–*Ph*SO_2), 170.5 and 170.6 (2*CO). MS IS *m*/*z*=429.5 [M−OMe]$^+$, 461.5 [M+H]$^+$, 478.5 [M+NH_4]$^+$, 483.5 [M+Na]$^+$. HRMS: $C_{19}H_{24}O_9S_2$: calcd 460.0862; found 460.0857.

4.9.4. Methyl 2,3-di-*O*-acetyl-6-*O*, 4-*S*-[(1*R*)-2-(phenylsulfonyl)-ethylidene]-4-thio-β-D-glucopyranoside (15β). Obtained from **11β**; silica gel column chromatography (petroleum ether/AcOEt 7:3, then 6:4) afforded **15β** with 65% yield as a white amorphous solid, $[\alpha]_D$ −23 (*c* 3.2, $CHCl_3$). ^{1}H NMR δ 2.03, 2.09 (2s, 6H, 2*O*Ac*), 3.15 (t, 1H, J_{3-4}=J_{4-5}=9.4, H-4), 3.32 (dd, 1H, H-8b), 3.34–3.44 (m, 2H, H-5, H-6b), 3.46 (s, 3H, OMe), 3.60 (dd, 1H, J_{7-8a}=8.9, J_{8a-8b}=14.7, H-8a), 4.00 (dd, 1H, J_{5-6a}=3.8, J_{6a-6b}=10.8, H-6a), 4.39 (d, 1H, J_{1-2}=7.7, H-1), 4.90–4.97 (m, 1H, H-2), 4.99 (t, 1H, J_{2-3}=9.4, J_{3-4}=9.4, H-3), 5.22 (dd, 1H, J_{7-8b}=2.6, H-7), 7.56 (t, 2H, *meta*-H–*Ph*SO_2), 7.67 (t, 1H, *para*-H–*Ph*SO_2), 7.89 (d, 2H, J_{vic}=7.4, *ortho*-H–*Ph*SO_2). ^{13}C NMR δ 20.8 and 21.1 (OAc), 48.1 (C-4), 57.5 (OMe), 60.3 (C-8), 68.6 (C-5), 70.7 (C-6), 71.9 (C-3), 72.9 (C-2), 78.3 (C-7), 102.3 (C-1), 128.7 (2*CH *ortho*-*Ph*SO_2), 129.5 (2*CH *meta*-*Ph*SO_2), 134.4 (CH–*para*-*Ph*SO_2), 140.1 (C_{IV}–*Ph*SO_2), 169.9 and 170.6 (2*CO). MS IS *m*/*z*=429.5 [M−OMe]$^+$, 461.5 [M+H]$^+$, 478.5 [M+NH_4]$^+$, 483.5 [M+Na]$^+$, 499.5 [M+K]$^+$. HRMS: $C_{19}H_{24}O_9S_2$: calcd 460.0862; found 460.0851.

4.10. Vinyl ether synthesis: reductive desulfonylation

Six percent of NaHg (6.5 g) and NaH_2PO_4 (4 g) were added to a solution of the phenylsulfonylvinyl sulfide (150 mg) in MeOH (5 mL) and freshly distilled THF (1 mL). The mixture was stirred at room temperature until complete consumption of the starting material, and then filtered over Celite; after concentration of the filtrate, the residue was purified by column chromatography.

4.10.1. Methyl 2,3-di-*O*-benzyl-6-*S*-vinyl-6-thio-α-D-glucopyranoside (17α). Obtained from **12α**; silica gel column chromatography (petroleum ether/AcOEt 9:1, then 85:15) afforded **17α** with 59% yield as a colourless gum, $[\alpha]_D$ +38 (*c* 1.6, $CHCl_3$). ^{1}H NMR δ 2.93 (dd, 1H, J_{5-6b}=2.1, J_{6a-6b}=13.8, H-6b), 3.17 (d, 1H, J_{5-6a}<0.5, H-6a), 3.34–3.42 (m, 1H, H-4), 3.39 (s, 3H, OMe), 3.53 (dd, 1H, H-2), 3.75 (m, 1H, J_{4-5}=8.3, H-5), 3.77 (t, 1H, J_{2-3}=9.6, H-3), 4.62 (d, 1H, J_{1-2}=3.4, H-1), 4.66 and 4.77 (2d, AB system, 2H, J_{gem}=11.9, Ph*CH*$_2$O), 4.69 and 5.04 (2d, AB system, 2H, J_{gem}=11.5, Ph*CH*$_2$O), 5.16 (d, 1H, H-2′*Z*), 5.17 (d, 1H, $J_{2'Z-2'E}$<0.5, H-2′*E*), 6.40 (dd, 1H, $J_{1'-2'E}$=16.6, $J_{1'-2'Z}$=10.1, H-1′ vinyl), 7.30–7.38 (m, 10H, H–Ar). ^{13}C NMR δ 33.6 (C-6), 55.6 (OMe), 70.4 (C-5), 73.1 (C-4), 73.5 and 75.8 (Ph*CH*$_2$O), 80.3 (C-2), 81.6 (C-3), 98.3 (C-1), 111.5 (C-2′), 128.4–129.1 (CH–Ar), 135.2 (C-1′), 140.4 and 141.1 (2*C_{IV}–Ar). MS IS *m*/*z*=439.5 [M+Na]$^+$, 455.5 [M+K]$^+$. HRMS: $C_{23}H_{28}O_5S$: calcd 416.1657; found 416.1641.

4.10.2. Methyl 2,3-di-*O*-benzyl-6-*S*-vinyl-6-thio-β-D-glucopyranoside (17β). Obtained from **12β**; silica gel column chromatography (petroleum ether/AcOEt 9:1, then 85:15) afforded **17β** with 56% yield as a white amorphous solid, $[\alpha]_D$ +4 (*c* 1.7, $CHCl_3$). ^{1}H NMR δ 2.77 (dd, 1H, J_{5-6b}=8.3, J_{6a-6b}=13.8, H-6b), 3.17 (dd, 1H, J_{5-6a}=2.5, H-6a), 3.40–3.50 (m, 4H, H-2, H-3, H-4, H-5,), 3.58 (s, 3H, OMe), 4.34 (d, 1H, J_{1-2}=6.8, H-1), 4.66 and 4.98 (2d, AB system, 2H, J_{gem}=11.5, PhCH_2O), 4.71 and 4.94 (2d, AB system, 2H, J_{gem}=11.1, PhCH_2O), 5.16 (d, 1H, H-2′*Z*), 5.21 (d, 1H, $J_{2'Z-2'E}$<0.5, H-2′*E*), 6.45 (dd, 1H, $J_{1'-2'E}$=16.8, $J_{1'-2'Z}$=10.0, H-1′), 7.26–7.39 (m, 10H, H–Ar). ^{13}C NMR δ 34.0 (C-6), 57.5 (OMe), 73.3 (C-4), 74.9 and 75.6 (PhCH_2O), 75.5 (C-5), 82.4 (C-2), 84.1 (C-3), 105.2 (C-1), 111.3 (C-2′), 128.1–129.1 (CH–Ar), 133.6 (C-1′), 138.7 and 138.8 (2*C_{IV}–Ar). MS IS *m*/*z*=385.5 $[M-OMe]^+$, 417.5 $[M+H]^+$, 434.5 $[M+NH_4]^+$. HRMS: $C_{23}H_{28}O_5S$: calcd 416.1657; found 416.1648.

4.10.3. Methyl 2,3-di-*O*-benzyl-4-*S*-vinyl-4-thio-α-D-glucopyranoside (18α). Obtained from **13α**; silica gel column chromatography (petroleum ether/AcOEt 7:3, then 6:4) afforded **18α** with 71% yield as an amorphous white solid, $[\alpha]_D$ +40 (*c* 1.8, $CHCl_3$). ^{1}H NMR δ 2.93 (t, 1H, J_{3-4}=9.2, H-4), 3.39 (s, 3H, OMe), 3.50 (dd, 1H, J_{2-3}=9.2, H-2), 3.71 (ddd, J_{5-6a}=3.0, J_{5-6b}=10.2, H-5), 3.82–3.93 (m, 3H, H-3, H-6a, H-6b), 4.63 (d, 1H, J_{1-2}=3.4, H-1), 4.65 and 4.82 (2d, AB system, 2H, J_{gem}=12.1, PhCH_2O), 4.88 (s, 2H, PhCH_2O), 5.26 (d, 1H, H-2′*Z*), 5.38 (d, 1H, $J_{2'Z-2'E}$< 0.5, H-2′*E*), 6.45 (dd, 1H, $J_{1'-2'E}$=16.6, $J_{1'-2'Z}$=9.8, H-1′), 7.26–7.43 (m, 10H, H–Ar). ^{13}C NMR δ 49.2 (C-4), 55.7 (OMe), 62.9 (C-6), 71.6 (C-5), 73.7 and 76.8 (PhCH_2O), 79.2 (C-3), 81.2 (C-2), 98.9 (C-1), 115.1 (C-2′), 126.3–128.9 (CH–Ar), 131.3 (C-1′), 139.1 and 139.4 (2*C_{IV}–Ar). MS IS *m*/*z*=385.5 $[M-OMe]^+$, 417.5 $[M+H]^+$, 434.5 $[M+NH_4]^+$, 439.5 $[M+Na]^+$. HRMS: $C_{23}H_{28}O_5S$: calcd 416.1657; found 416.1639.

4.10.4. Methyl 2,3-di-*O*-benzyl-4-*S*-vinyl-4-thio-β-D-glucopyranoside (18β). Obtained from **13β**; silica gel column chromatography (petroleum ether/AcOEt 7:3, then 6:4) afforded **18β** with 66% yield as an amorphous white solid, $[\alpha]_D$ +39 (*c* 2.5, $CHCl_3$). ^{1}H NMR δ 2.98 (t, 1H, $J_{3,4}$=J_{4-5}= 10.0, H-4), 3.31–3.52 (m, 3H, H-2, H-3, H-5), 3.59 (s, 3H, OMe), 3.82–4.07 (m, 2H, H-6a, H-6b), 4.35 (d, 1H, J_{1-2}= 7.9, H-1), 4.72 and 4.92 (2d, AB system, 2H, J_{gem}=11.1, PhCH_2O), 4.86 (s, 2H, PhCH_2O), 5.27 (d, 1H, H-2′*Z*), 5.39 (d, 1H, $J_{2'Z-2'E}$<0.5, H-2′*E*), 6.43 (dd, 1H, $J_{1'-2'E}$=16.6, $J_{1'-2'Z}$=9.8, H-1′), 7.28–7.35 (m, 10H, H–Ar). ^{13}C NMR δ 48.7 (C-4), 57.6 (OMe), 63.4 (C-6), 75.3 and 76.9 (PhCH_2O), 76.2 (C-5), 82.5 (C-2), 83.8 (C-3), 105.1 (C-1), 116.1 (C-2′), 126.8–129.3 (CH–Ar), 131.8 (C-1′), 139.3 and 139.4 (2*C_{IV}–Ar). MS IS *m*/*z*=385.5 $[M-OMe]^+$, 417.5 $[M+H]^+$, 434.5 $[M+NH_4]^+$. HRMS: $C_{23}H_{28}O_5S$: calcd 416.1657; found 416.1650.

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