Article

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Dehydrative Thioglycosylation of 1-Hydroxyl Glycosides Catalyzed by In Situ-Generated AlI_3

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Thioglycosylation of 1-hydroxyl glycosides catalyzed by in situ-generated AlI_3 from elemental aluminium and molecular iodine has been developed. This method provides an alternative route to access anomeric thioglycosides without the use of hazard Lewis acidic activators or per-modified activated thiol sources. The major advantages of this dehydrative procedure are environmental friendly, ease of operation, high anomeric diastereoselectivity, and mild reaction conditions.

Keywords: Dehydrative thioglycosylation; In situ-generated AlI_3; 1-Hydroxyl glycosides; Thioglycosides.

INTRODUCTION

Sulfur-containing glycoconjugates, glycolipids, and glycopeptides play essential roles in many biological transformations.[1] Because thioglycosidic linkages exhibit high stability toward chemical or enzymatic hydrolysis and anomerization compared to their *O*-glycosidic counterparts,[2] *S*-glycans are commonly used as *O*-glycan mimics to study therapeutics, protein interactions, and signal transactions.[3] In addition, by taking advantage of the tunable reactivity of different anomeric thiol substituents toward the activator, thioglycosides have been widely utilized as universal building blocks in the sequential, programmable one-pot synthesis of oligosaccharides.[4] As such, the development of sustainable and more efficient methods for the preparation of thioglycosides is of great interest. One of the most conventional methods to produce thioglycosides is the direct thiolysis of peracetylated sugar derivatives in the presence of Lewis acids or acidic activators including $TiCl_4$,[5] BF_3-Et_2O,[6] $ZrCl_4$,[7] $SnCl_4$,[8] MoO_2Cl_2,[9] TMSOTf-Me_3SiSMe,[10] ZnI_2,[11] $AlCl_3$,[12] In(OTf)$_3$,[13] Fe/I_2,[14] Al/I_2,[15] Et_3SiH/I_2,[16] $Me_3SiSiMe_3/I_2$,[17] *p*-TSA,[18] Amberlyst resin,[19] and silica-supported perchloric acid.[20] The sequential multistep S_N2 substitution of glycosyl halide with the basic H_2S equivalent or Na_2S in the presence of a suitable promoter also serves as a complementary approach for the synthesis of glycosyl thiol derivatives.[21,22] However, this nucleophilic reaction requires additional procedures for the preparation of glycosyl halides in advance, thus limiting its application.

On the contrary, the direct dehydrative thioglycosylation of 1-hydroxy glycosides is more fascinating because it allows for the synthesis of diversified sulfur-containing core units for the construction of complex glycans.[23] However, the traditional approach of appending thioglycoside units to 1-hydroxy sugars with thiols requires the use of stoichiometric dehydration reagents such as disulfide/phosphine,[24] $(CF_3SO_2)_2O$,[25] chlorothiophosphonic esters,[26] CBr_4/PPh_3,[27] thionyl halides/Ag(I),[28] DCC/Cu(I),[29] and TMSCl/Zn(OTf)$_2$,[30] which do not meet the requirements of green chemistry because a significant amount of toxic and undesired waste is produced during the reaction. Alternatively, employing moisture-sensitive or precious reagents such as $SnCl_4$,[31] BF_3,[32] ytterbrium(OTf)$_3$/2-methoxyacetic acid,[33] *p*-TSA,[34] and In(OTf)$_3$[19] is a greener method to achieve high conversion and avoid the production of waste; nevertheless, these protocols are also hazardous and toxic, and premodified, expensive activated thiol derivatives are sometimes required, thus making these methods harsher and restricting their utility.

Notable methods using safer hexamethyldisilane or triethyl silane reagents coupled with molecular iodine as a Lewis acid have improved the inherently inert thioglycosylation process through their operational simplicity and efficiency. Because α-glycosyl iodide is involved in the reaction, high stereoselectivities are also achieved

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in these thiolysis manipulations. We have previously developed thioglycosylation reactions of peracetylated sugars by employing nontoxic and environmentally benign, in situ-generated FeI_3 and AlI_3 catalyst systems. In this study, we further expand the utility of this inexpensive, nontoxic, and useful catalytic system using Al metal and molecular I_2 in the dehydrative thioglycosylation of 1-hydroxy sugars.

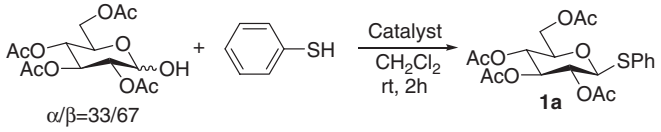
RESULTS AND DISCUSSION

Screening of catalyst and optimized condition

To investigate this promising catalytic system, a series of in situ-generated metal iodides were screened for a model thioglycosylation reaction between 1.5 equiv of benzenethiol and an anomeric mixture of 1-hydroxyl-2,3,4,6-tetraacetyl glucoside (α/β = 36/64) in CH_2Cl_2 at room temperature under N_2 atmosphere for 2 h. The reaction of 20 mol% in situ-generated TMSI with both $(Me_3Si)_2$ and Et_3SiH showed incomplete catalytic reactivity (Table 1, entries 1 and 2), providing the thioglucoside **1a** in 43 and 41% yields, respectively. ZnI_2 and alkali MgI_2 performed sluggishly with low productivities,[35] and the product **1a** was obtained in only 24 and 11% yields, respectively (Table 1, entries 3 and 4). In situ-generated CeI_3[36] from $CeCl_3$ and NaI showed inactive efficiency (Table 1, entry 5).

Next, the studies were continued by screening other metal iodides. The yield significantly improved in the presence of 20 mol% FeI_3,[14] and the product **1a** was obtained in 58% yield (Table 1, entry 6). With the exception of InI_3[35] (Table 1, entry 7), the group IIIa species provided the best reactivity. BI_3 generated from $NaBH_4$ and I_2[37] afforded **1a** in 67% yield, although this procedure is toxic (Table 1, entry 8). Nontoxic AlI_3 showed the best reactivity,[15] providing **1a** in 71% yield with exclusive β-diastereoselectivity (Table 1, entry 9). The best yield was obtained by employing 30 mol% AlI_3 to afford **1a** in 82% yield (Table 1, entry 10). It is noteworthy that β-anomeric diastereoselectivity was observed in the reactions because α-geometrical intermediary glycosyl iodide and neighboring 2-acetate group might be involved in these transformations. In

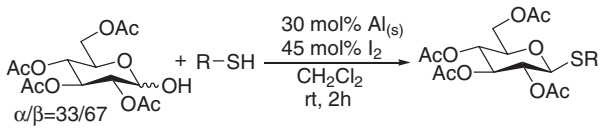
Table 1. Catalyst screening



Entry	Catalyst	Solvent	Yield[a]
1[b]	20 mol% $(Me_3Si)_2$/20 mol% I_2	CH_2Cl_2	43
2[b]	20 mol% Et_3SiH/20 mol% I_2	CH_2Cl_2	41
3[b]	20 mol% Zn/10 mol% I_2	CH_2Cl_2	24
4[b]	20 mol% Mg/60 mol% I_2	CH_2Cl_2	11
5[b]	20 mol% $CeCl_3$/60 mol% NaI	CH_2Cl_2	6
6[b]	20 mol% Fe/30 mol% I_2	CH_2Cl_2	58
7[b]	20 mol% In/30 mol% I_2	CH_2Cl_2	38
8[b]	20 mol% $NaBH_4$/80 mol% I_2	CH_2Cl_2	67
9[b]	20 mol% Al/30 mol% I_2	CH_2Cl_2	71
10[c]	30 mol% Al/45 mol% I_2	CH_2Cl_2	82
11[c]	30 mol% Al/45 mol% I_2	EtOAc	67
12[c]	30 mol% Al/45 mol% I_2	THF	55
13[c]	30 mol% Al/45 mol% I_2	DMF	38
14[c]	30 mol% Al/45 mol% I_2	Toluene	16

[a] Isolated yield.
[b] Reaction conditions: 1-hydroxyl-2,3,4,6-tetraacetate (0.5 mmol), silane or metal powder (20–30 mol%), I_2 or NaI (10–60 mol %), *para*-thiocresol (0.75 mmol), 2.5 mL of solvent, room temperature, N_2 atmosphere, 2 h.
[c] Reaction conditions: 1-hydroxyl-2,3,4,6-tetraacetate (0.5 mmol), Al powder (30 mol%), I_2 (45 mol%), 2.5 mL of solvent, room temperature, N_2 atmosphere, 2 h.

Table 2. The scope of thiol nucleophile



Entry	R	Product	Yield[a]
1[b]	4-Me-C_6H_4-	**1b**	81
2[b]	2-Me-C_6H_4-	**1c**	77
3[b]	4-MeO-C_6H_4-	**1d**	62
4[b]	4-Cl-C_6H_4-	**1e**	79
5[b]	2-Naphthyl-	**1f**	80
6[c]	$PhCH_2$-	**1g**	85
7[c]	CH_3CH_2-	**1h**	84
8[c]	$(CH_3)_2CH$-	**1i**	79
9[c]	Cyclohexyl-	**1j**	82
10[c]	*tert*-Butyl-	**1k**	45
11[c]	AcSH	**1l**	73
12[c]	AcSK	**1l**	13

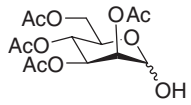
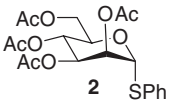
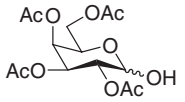
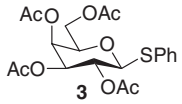
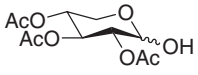
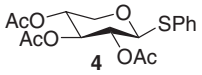
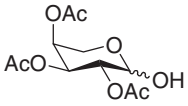
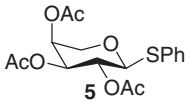
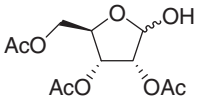
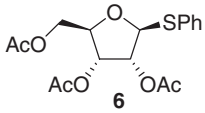
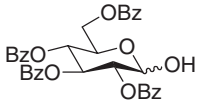
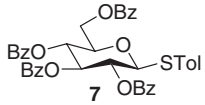
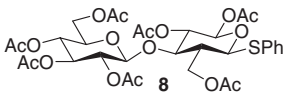
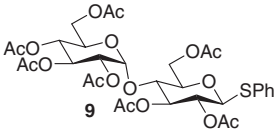
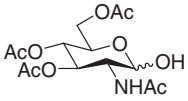
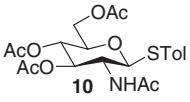
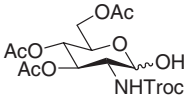
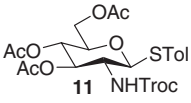
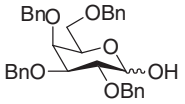
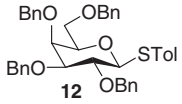
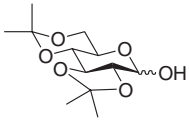
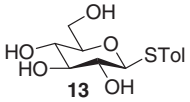
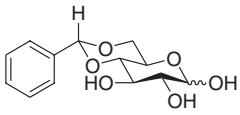
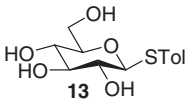
[a] Isolated yield.
[b] Reaction conditions: 1-hydroxyl-2,3,4,6-tetraacetate (0.5 mmol), Al powder (30 mol%), I_2 (45 mol%), 2.5 mL of solvent, room temperature, N_2 atmosphere, 2 h.
[c] 2.5 equiv of thiol was used.

addition, the formation of metal oxides (e.g., ZnO, In_2O_3, Al_2O_3, and Fe_2O_3) was also observed after the basic and aqueous termination of the reactions. These results implied that the dehydrative process might proceed through an interaction between the 1-hydroxyl group and the metal iodide. Furthermore, the metal iodide might also serve as a Lewis acid catalyst because the use of catalytic amounts of metal iodide could achieve moderate yields. The solvent effect strongly influences the yield in the dehydrative thiolysis process. It was found that oxygenated solvents such as EtOAc, THF, and DMF deactivated the reactions (Table 1, entries 11–13). The less polar toluene solvent showed the worst reactivity, probably due to the incomplete formation of AlI_3 and the poor solubility of 1-hydroxyl glucoside (Table 1, entry 14).

The scope of thiol nucleophile

The application of this methodology to other mercaptans was also done (Table 2). Aromatic thiols with different electronic and steric properties were properly reacted with 1-hydroxyl-2,3,4,6-percatylated glucose using the AlI_3 catalyst to afford the thioglycosides **2–6** in excellent yields. Electron-rich *para*-thiocresol showed similar reactivity to benzenethiol (Table 2, entry 1). The more sterically hindered *ortho*-substituted methyl group slightly influenced the reaction (Table 2, entry 2). The reaction of 4-methoxyphenyl mercaptan was sluggish, and only 62% of the desired product **1d** was obtained (Table 2, entry 3), as the deprotection of the methoxy group was observed during the reaction. Both 4-chloro- and 2-naphthyl thiols were suitable substrates for this manipulation, affording **1e** and **1f** in excellent yields (Table 2, entries 4 and 5). We next screened the reactions of more nucleophilic aliphatic thiols. It was found that the aliphatic thiols were indeed more efficient than the aromatic ones, providing the thioglycosides **1g–1j** in excellent yields (Table 2, entries 6–9). However, 2.5 equiv of aliphatic thiol is needed to achieve high yields because of the fast disulfide formation that occurred under the reaction conditions. The sterically encumbered *tert*-butyl mercaptan was a poor substrate for this transformation (Table 2, entry 10), and the desired product **1k** was obtained in only 45% yield due to steric hindrance. The less nucleophilic thioacetic acid could also be applied to this dehydrative reaction, although with decreased conversion (Table 2, entry 11). In

Table 3. The scope of 1-hydroxyl glycosides[a]

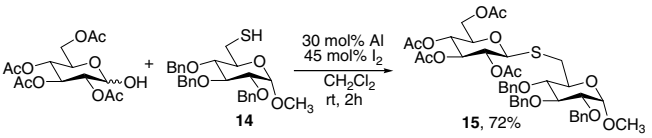
Entry	1-Hydroxyl glycosides	Product	Yield (%)[b]
1		 **2**	71
2		 **3**	81
3		 **4**	84
4		 **5**	82
5		 **6**	79
6		 **7**	83
7	1-Hydroxyl-D-lactose peracetate	 **8**	77
8	1-Hydroxyl-D-maltose peracetate	 **9**	81
9		 **10**	66
10		 **11**	78
11		 **12**	64
12		 **13**	76
13		 **13**	71

[a] Reaction conditions: 1-hydroxyl sugar (0.5 mmol), benzenethiol or *p*-thiocresol (1.5 mmol), Al powder (30 mol%), I_2 (45 mol %), 2.5 mL of solvent, room temperature, N_2 atmosphere, 2 h.
[b] Isolated yield.

contrast, the potassium salt of thioacetic acid was inefficiently substituted onto the anomeric center, affording thioglycoside **1l** in low yield (Table 2, entry 12). This result implies that the S_N2 substitution of glycosyl iodide might not be involved in the reaction and that the β-anomeric diastereoselectivities of thioglucosides **1a–1l** might be dominated by the anchimeric assistance of the 2-acetyl group.

The scope of 1-hydroxyl glycosides

To extend the scope and generality of the current dehydrative thioglycosylation protocol, reactions of other glycosyl donors were also performed (Table 3). 1-Hydroxyl peracetyl mannose exhibited anchimeric assistance with 2-axial acetate, affording the α-thioglycoside **2** in 71% yield (Table 3, entry 1). Galactosyl, xylosyl, and arabinosyl donors were smoothly reacted with benzenethiol to afford the β-thioglycosides **3–5** in 81–84% yields (Table 3, entries 2–4). Furanosyl D-ribose and 1-hydroyl perbenzoyl glucose were tolerated under the reaction conditions, providing products **6** and **7** in excellent yields (Table 3, entries 5 and 6). Disaccharides with α or β 1 → 4′ glycosidic linkages remained intact under the reaction conditions and exclusively formed the β-thioglycosides **8** and **9** in high yields (Table 3, entries 7 and 8). The current protocols tolerated *N*-acetyl (Ac-) and *N*-2,2,2-trichloroethyl carbonate (Troc-) protecting groups, and the corresponding 2-deoxy-2-*N*-acetyl and 2-deoxy-2-*N*-Troc-β-D-glucosides **10** and **11** were obtained in 66 and 78% yield, respectively (Table 3, entries 9 and 10). The low conversion of **10** might result from the strongly coordinated acetamide group and undesired oxazoline by-product formation. It should be noted that β-thioglycoside **12** was obtained almost exclusively in moderate yield when perbenzylated 1-hydroxyl galactose was applied under optimized conditions (Table 3, entry 11). In this case, we observed that the benzyl groups were randomly cleaved during the course of the reaction, thus decreasing the conversion of the desired product. The anomeric geometry of **12** might result from the 2-equatorial benzyl group and the α-geometry of the glucosyl iodide intermediate. The acetonide protection of 1-hydroxyl-2,3,4,6-*O*-isopropylidene glucoside and 4,6-*O*-benzylidene glucoside was also applicable, although deprotection of the acetal occurred after the aqueous workup, and both provided the corresponding product **13** in high yield (Table 3, entries 12 and 13).



Scheme 1. Synthesis of *S*-linked-thiodisaccharide.

We further applied the current dehydrative protocol to the direct thioglycosylation of 1-hydroxyl peracetylated glucose with methyl 2,3,4-tri-*O*-benzyl-6-thio-α-D-glucose **14** (Scheme 1). It was found that residual 6-sulfhydryl group of **14** was smoothly reacted with anomeric carbon of **14** and afforded the desired β-(1 → 6)-*S*-linked-thiodisaccharide **15** in 72% yield.

CONCLUSIONS

In conclusion, we have presented a new and handy method of dehydrative thioglycosylation of 1-hydroxyl sugars catalyzed by in situ-generated AlI_3. This operationally simple dehydrative thiolysis reaction gives rapid access to anomeric thioglycosides using nontoxic aluminium metal and I_2 which meet the recent standards of green chemistry. The current dehydrative processes occur with good to excellent diastereoselectivity, and afford product yields which provide practical alternative to access valuable *S*-glycosides.

EXPERIMENTAL

General

^1H NMR and ^{13}C NMR spectra were recorded on Jeol JVM-EX400: JEOL Ltd., Tokyo, JAPAN: or Varian Unity INOVA-500 Varian Inc., California USA spectrometers in deuterochloroform with chloroform as an internal reference unless otherwise stated. Chemical shifts are reported in ppm (δ). Coupling constants, *J*, are reported in Hz. Electrospray (ESI) mass spectra are reported with data in the form *m/e* (intensity relative to base peak). Analytical TLC was visualized with UV light or with phosphomolybdic acid (PMA) and $KMnO_4$ staining agents. Column (flash) chromatography was performed using 32–63 m silica gel. Solvents such as CH_2Cl_2, THF, EtOAc, and DMF were dried over CaH_2 before use. All reactions were run under nitrogen or Argon atmosphere and the end products were isolated as spectroscopically pure materials. The aluminum (20 μm, spherical powder, 99+%) was obtained from commercial suppliers, and was used

without further treatment. The 1-hydroxyl peracylglycosides were prepared by the transamidation of 1-acyl group of peracylated glycosides with hydrazinium acetate or primary amine[38–40] or purchased from a commercial supplier.

General procedure for synthesis of thioglycoside from 1-hydroxyl sugars

To a solution of aluminum powder (20 μm, spherical powder, 0.15 mmol, 4.5 mg) in anhydrous CH_2Cl_2 solution (2 mL) was added I_2 (0.225 mmol, 57 mg) at room temperature under nitrogen atmosphere. After being stirred for 1 h, the solution became brown purple and the aluminum powder completely disappeared. To a solution of 1-hydroxyl-2,3,4,6-pentaacetyl glucose (0.5 mmol, 174 mg) and (0.75 mmol, 83 mg, 77 μL) benzenethiol in 2 mL CH_2Cl_2 was added. The resulting dark brown mixture was stirred at ambient temperature for 2 h. The reaction was quenched by adding 3 mL saturated $NaHCO_3$(aq) solution. The organic layer was separated and dried over $MgSO_4$ and filtered. The crude product was concentrated under reduced pressure and loaded directly on top of an eluent-filled silica gel column and purified by flash column chromatography, to provide **15** in 82% yield (181 mg).

Phenyl-2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-glucopyranoside (1a). ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.51–7.50 (m, 2H), 7.32–7.26 (m, 3H), 5.22 (t, 1H, J = 9.2 Hz), 5.02 (dd,1H, J = 9.8; 9.7 Hz), 4.97 (dd, 1H, J = 10.1; 6.1Hz), 4.70 (d, 1H, J = 10.4 Hz), 4.21–4.19 (m, 2H), 3.72 (m, 1H), 2.09 (s, 3H), 2.07 (s, 3H), 2.01 (s, 3H), 1.98 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.5 170.1, 169.3, 169.2, 133.1, 131.6, 128.9, 128.4, 85.7, 75.8, 73.9, 69.9, 68.2, 62.1, 20.7, 20.7, 20.5, 20.5; ESI MS ($C_{20}H_{24}O_9S$, m/z 440.46): 463, (M + Na^+); white solid; mp 118–120°C; TLC: R_f = 0.35 (ethyl acetate/hexane, 1/2).[14]

***p*-Tolyl-2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-glucopyranoside (1b).** ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.39 (d, 2H, J = 8.1 Hz), 7.39 (d, 2H, J = 7.9 Hz), 5.21 (dd, 1H, J = 10.0, 9.4 Hz), 5.03 (dd, 1H, J = 9.4; 9.3 Hz), 4.94 (t, 1H, J = 10.1 Hz), 4.63 (d, 1H, J = 10.0 Hz), 4.21–4.18 (m, 2H), 3.70 (ddd, 1H, J = 10.1, 4.7, 2.7 Hz), 2.35 (s, 3H), 2.09 (s, 3H), 2.08 (s, 3H), 2.01 (s, 3H), 1.98 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.6, 170.2, 169.4, 169.2, 138.8, 129.7, 127.6, 85.8, 75.8, 74.0, 69.9, 68.2, 62.1, 21.2, 20.7, 20.7, 20.6, 20.6; ESI MS ($C_{21}H_{26}O_9S$, m/z 454): 477 (M + Na^+); white crystalline; mp 114–116°C; TLC: R_f = 0.32 (ethyl acetate/hexane, 1/2).[14]

***o*-Tolyl-2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-glucopyranoside (1c).** ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.49 (d, 1H, J = 7.7 Hz), 7.21–7.13 (m, 3H), 5.20 (t, 1H, J = 12.0 Hz), 5.10–5.01 (m, 2H), 4.66 (dd, 1H, J = 10.2 Hz), 4.21 (dd, 1H, J = 12.3 Hz), 4.12 (dd, 1H, J = 12.3; 2.2 Hz), 3.67 (m, 2H), 2.38 (s, 3H), 2.07 (s, 3H), 2.05 (s, 3H), 2.00 (s, 3H), 1.98 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.42, 170.1, 169.3, 169.2, 140.4, 131.8, 130.3, 128.4, 126.53, 86.3, 75.7, 73.9, 70.1, 68.3, 62.2, 20.8, 20.6, 20.6, 20.5, 20.5; ESI MS ($C_{21}H_{26}O_9S$, m/z 454): 477 (M + Na^+); white crystalline; mp 114–116°C; TLC: R_f = 0.33 (ethyl acetate/hexane, 1/2).

4-Methoxy-phenyl-2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-glucopyranoside (1d). ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.49 (d, 2H, J = 10.8 Hz), 6.84 (d, 2H, J = 10.8 Hz), 5.17 (t, 1H, J = 9.2 Hz), 4.97 (t, 1H, J = 10.0 Hz), 4.87 (t, 1H, J = 9.6 Hz), 4.53 (d, 1H, J = 10.0 Hz), 4.19 (dd, 1H, J = 12.0; 4.4 Hz), 4.15 (dd, 1H, J = 12.3, 2.2 Hz), 3.80 (s, 3H), 3.66 (ddd, 1H, J = 7.2, 4.0, 3.2 Hz), 2.08 (s, 3H), 2.05 (s, 3H), 1.99 (s, 3H), 1.96 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.5, 170.1, 169.3, 169.2, 160.4, 136.5, 120.8, 114.4, 85.6, 75.7, 74.0, 69.9, 68.2, 62.0, 55.3, 20.7, 20.7, 20.5, 20.5; ESI MS ($C_{21}H_{26}O_{10}S$, m/z 470): 493(M + Na^+); white crystalline; mp 92–93°C; TLC: R_f = 0.31 (ethyl acetate/hexane, 1/2).[14]

4-Chloro-phenyl-2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-glucopyranoside (1e). ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.44 (d, 2H, J = 6.4 Hz), 7.27 (d, 2H, J = 6.4 Hz), 5.21 (t, 1H, J = 9.2 Hz), 5.01 (t, 1H, J = 9.6 Hz), 4.93 (t, 1H, J = 10 Hz), 4.64 (d, 1H, J = 10.0 Hz), 4.25–4.11 (m, 2H), 3.71 (ddd, 1H, J = 10.0, 4.8, 2.8 Hz), 2.07 (s, 3H), 2.06 (s, 3H), 2.00 (s, 3H), 1.97 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.4, 170.1, 169.3, 169.1, 134.9, 129.4, 85.2, 75.8, 73.8, 69.8, 68.1, 62.0, 20.7, 20.6; ESI MS ($C_{20}H_{23}ClO_9S$, m/z 474): 497 (M + Na^+); white crystalline; mp 112–113°C; TLC: R_f = 0.36 (ethyl acetate/hexane, 1/2).[14]

2-Naphthyl-2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-glucopyranoside (1f). ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.99 (s, 1H), 7.83–7.77 (m, 3H), 7.57–7.46 (m, 3H), 5.26 (t, 1H, J = 9.7 Hz), 5.11–5.04 (m, 2H), 4.78 (d, 1H,

J = 10.0 Hz), 4.23 (dd, 1H, J = 12.3; 5.1 Hz), 4.18 (dd, 1H, J = 12.3, 2.4 Hz), 3.72 (ddd, 1H, J = 7.4, 4.9, 2.4 Hz), 2.11 (s, 3H), 2.02 (s, 3H), 2.00 (s, 3H), 1.98 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.5, 170.1, 169.3, 169.21, 133.4, 132.9, 132.9, 132.7, 130.2, 128.7, 128.4, 127.7, 126.7, 126.6, 85.8, 75.9, 73.9, 70.0, 68.2, 62.1, 20.7, 20.6, 20.5, 20.5; ESI MS ($C_{24}H_{26}O_9S$, m/z 490): 513 (M + Na^+); white crystalline; mp 108–109°C; TLC: R_f = 0.36 (ethyl acetate/hexane, 1/2).[14]

Benzyl-2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-glucopyranoside (1g). ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.33–7.27 (m, 5H), 5.15–5.03 (m, 3H), 4.28 (d, 1H, J = 9.7 Hz), 4.25 (dd, 1H, J = 12.4; 5.1 Hz), 4.13 (dd, 1H, J = 12.4, 2.3 Hz), 3.94 (d, 1H, J = 12.9 Hz), 3.83 (d, 1H, J = 12.9 Hz), 3.59 (ddd, 1H, J = 9.7, 5.0, 2.3 Hz), 2.11 (s, 3H), 2.06 (s, 6H), 1.99 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.6, 170.1, 169.4, 169.3, 136.8, 129.0, 128.6, 127.4, 81.9, 75.8, 73.8, 69.6, 62.2, 33.7, 20.7, 20.6, 20.5, 20.5; ESI MS ($C_{21}H_{26}O_9S$, m/z 454): 477 (M + Na^+); white crystalline; mp 98–99°C; TLC: R_f = 0.38 (ethyl acetate/hexane, 1/2).[14]

Ethyl-2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-glucopyranoside (1h). ^{1}H NMR ($CDCl_3$, 400 MHz): δ 5.22 (t, 1H, J = 9.2 Hz), 5.06 (t, 1H, J = 10.0 Hz), 5.01 (t, 1H, J = 10 Hz), 4.48 (d, 1H, J = 10.0 Hz), 4.24 (dd, 1H, J = 12.0, 3.2 Hz), 4.11 (dd, 1H, J = 12.4, 2.0 Hz), 3.69 (ddd, 1H, J = 10.0, 4.8, 2.4 Hz), 2.74–2.63 (m, 2H), 2.05 (s, 3H), 2.03 (s, 3H), 1.99 (s, 3H), 1.97 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.6, 170.1, 169.3, 169.3, 83.5, 75.8, 73.9, 69.8, 68.3, 62.1, 24.1, 20.7, 20.5, 20.5, 14.8; ESI MS ($C_{16}H_{24}O_9S$, m/z 392): 415 (M + Na^+); white crystalline; mp 82–83°C TLC: R_f = 0.36 (ethyl acetate/hexane, 1/2).[14]

***Iso*-propyl-2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-glucopyranoside (1i).** ^{1}H NMR ($CDCl_3$, 400 MHz): δ 5.20 (t, 1H, J = 9.3 Hz), 5.04 (t, 1H, J = 9.8 Hz), 4.97 (t, 1H, J = 9.8 Hz), 4.56 (d, 1H, J = 10.1 Hz), 4.20 (dd, 1H, J = 12.3, 5.3 Hz), 4.10 (m, 1H), 3.68 (ddd, 1H, J = 9.9, 5.2, 2.2 Hz), 3.14 (septet, 1H), 2.04 (s, 3H), 2.02 (s, 3H), 2.01 (s, 3H), 1.99 (s, 3H), 1.98 (s, 3H), 1.27 (dd, 6H, J = 6.6, 4.1 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.5, 170.1, 169.3, 169.3, 83.3, 75.9, 73.8, 70.2, 68.4, 62.2, 35.6, 24.0, 23.7, 20.7, 20.6, 20.53, 20.5; ESI MS ($C_{17}H_{26}O_9S$, m/z 406): 429 (M + Na^+); white solid; mp 108–111°C; TLC: R_f = 0.39 (ethyl acetate/hexane, 1/2).[14]

Cyclohexyl-2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-glucopyranoside (1j). ^{1}H NMR ($CDCl_3$, 400 MHz): δ 5.21 (t, 1H, J = 9.4 Hz), 5.06 (t, 1H, J = 9.9 Hz), 4.98 (t, 1H, J = 10.1 Hz), 4.59 (d, 1H, J = 10.1 Hz), 4.21 (dd, 1H, J = 12.3, 5.3 Hz), 4.12 (dd, 1H, J = 12.4, 2.5 Hz), 3.69 (ddd, 1H, J = 10.0, 5.4, 2.5 Hz), 2.89 (m, 2H), 2.06 (s, 3H), 2.03 (s, 3H), 2.02 (s, 3H), 1.99 (s, 3H), 1.98 (m, 2H), 1.75 (m, 2H), 1.43–1.21 (m, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.6, 170.2, 169.4, 169.3, 83.2, 75.7, 74.0, 70.3, 68.5, 62.3, 43.9, 34.2, 33.9, 26.0, 25.9, 25.6, 20.7, 20.7, 20.58, 20.56; ESI MS ($C_{20}H_{30}O_9S$, m/z 446): 469 (M + Na^+); white solid; mp 120–122°C; TLC: R_f = 0.40 (ethyl acetate/hexane, 1/2).[14]

***Tert*-butyl-2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-glucopyranoside (1k).** ^{1}H NMR ($CDCl_3$, 400 MHz): δ 5.25 (t, 1H, J = 9.3 Hz), 5.03 (t, 1H, J = 9.7 Hz), 4.94 (t, 1H, J = 9.8 Hz), 4.63 (d, 1H, J = 10.0 Hz), 4.19 (dd, 1H, J = 12.2, 6.0 Hz), 4.10 (dd, 1H, J = 12.2, 2.2 Hz), 3.71 (ddd, 1H, J = 6.4, 6.0, 2.3 Hz), 2.04 (s, 3H), 2.03 (s, 3H), 2.02 (s, 3H), 2.0 (s, 3H), 1.36 (s, 9H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.6, 170.2, 169.4, 169.3, 82.3, 75.6, 74.0, 70.2, 68.6, 62.6, 44.3, 31.4, 20.7, 20.7, 20.58, 20.56; ESI MS ($C_{18}H_{28}O_9S$, m/z 420): 443 (M + Na^+); white solid; mp 140–142°C; TLC: R_f = 0.23 (ethyl acetate/hexane, 1/2).[14]

2,3,4,6-Tetra-*O*-acetyl-1-*S*-acetyl-1-thio-β-D-glucopyranoside (1l). ^{1}H NMR ($CDCl_3$, 400 MHz): δ 5.24 (d, 1H, J = 10.0 Hz), 5.14–5.08 (m, 2H), 4.25 (dd, 1H, J = 12.5; 4.4 Hz), 4.08 (dd, 1H, J = 12.4; 1.6 Hz), 3.83 (dt, 1H, J = 10.0 Hz, J = 1.8 Hz), 2.38 (s, 3H), 2.07 (s, 3H), 2.03 (s, 3H), 2.02 (s, 3H), 1.99 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 192.0, 170.6, 169.9, 169.33, 169.28, 80.1, 76.3, 73.9, 68.9, 67.8, 61.6, 30.8, 20.66, 20.51, 20.3, 20.2; ESI MS ($C_{17}H_{25}O_{10}S$, m/z 421): 445 - (M + Na + H^+); TLC: R_f = 0.33 (ethyl acetate/hexane, 1/2).[14]

Phenyl-2,3,4,6-tetra-*O*-acetyl-1-thio-α-D-mannopyranoside (2). ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.50–7.48 (m, 2H), 7.33–7.29 (m, 3H), 5.59 (brs, 1H), 5.36–5.29 (m, 2H), 4,55 (m, 1H), 4.30 (dd, 1H, J = 12.4; 6.0 Hz), 4.10 (dd, 1H, J = 12.4 Hz, J = 2.4 Hz), 2.15 (s, 3H), 2.08 (s, 3H), 2.05 (s, 3H), 2.02 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.5, 169.9, 169.8, 169.1, 132.6, 132.0, 129.2, 128.1, 85.7, 70.9, 69.5, 69.4, 66.4, 62.4, 20.9, 20.7, 20.7, 20.6; ESI MS ($C_{20}H_{24}O_9S$, m/z 440): 463 (M + Na^+); TLC: R_f = 0.27 (ethyl acetate/hexane, 1/3).[14]

Phenyl-2,3,4,6-tetra-*O*-acetyl-1-thio-β-D-galactopyranoside (3). ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.47–7.45 (m, 2H), 7.26–7.24 (m, 3H, aromatic H), 5.36 (d, 1H, J = 3.2 Hz), 5.18 (t, 1H, J = 10.0 Hz), 5.01 (dd, 1H, J = 10.0; 3.2 Hz), 4.69 (d, 1H, J = 10.0 Hz), 4.13 (dd, 1H, J = 11.6 Hz, J = 7.2 Hz), 4.06 (dd, 1H, J = 11.6 Hz, J = 6 Hz), 3.91 (t, 1H, J = 6.8 Hz), 2.05 (s, 3H), 2.03 (s, 3H), 1.97 (s, 3H), 1.91 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.0, 169.8, 169.6, 169.1, 132.2, 128.6, 127.8, 86.1, 74.1, 71.7, 67.0, 61.4, 20.5, 20.3, 20.3, 20.2; ESIMS ($C_{20}H_{24}O_9S$, m/z 440): 463 (M + Na^+); TLC: R_f = 0.33 (ethyl acetate/hexane, 1/2).[14]

Phenyl-2,3,4-tri-*O*-acetyl-1-thio-β-D-xylopyranoside (4). ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.50–7.47 (m, 2H), 7.33–7.31 (m, 3H), 5.19 (t, 1H, J = 8.2 Hz), 4.90 (t, 1H, J = 8.2 Hz), 4.88 (m, 1H). 4.78 (dd, 1H, J = 8.3 Hz), 4.28 (dd, 1H, J = 11.8; 4.9 Hz), 3.42 (dd, 1H, J = 12.0, 8.8 Hz), 2.11 (s, 3H), 2.04 (S, 6H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 169.9, 169.7, 169.3, 132.7, 132.2, 129.0, 128.2, 86.2, 72.0, 69.8, 68.4, 65.2, 20.8, 20.7; ESIMS ($C_{17}H_{20}O_7S$, m/z 368): 391 (M + Na^+); white crystalline; mp 76–77°C; TLC: R_f = 0.26 (ethyl acetate/hexane, 1/3).[14]

Phenyl-2,3,4-tri-*O*-acetyl-1-thio-β-L-arabinopyranoside (5). ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.49–7.46 (m, 2H), 7.28–7.27 (m, 3H), 5.26–5.20 (m, 1H), 5.23 (t, 1H, J = 8.2 Hz), 5.09 (dd, 1H, J = 8.44, 3.4 Hz), 4.80 (d, 1H, J = 7.8 Hz), 4.12 (dd, 1H, J = 12.7, 4.2 Hz), 3.65 (dd, 1H, J = 12.7, 2.0 Hz), 2.06 (S, 6H), 2.01 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 169.9, 169.7, 169.2, 133.1, 132.1, 128.8, 127.7, 86.5, 70.3, 68.3, 67.4, 65.1, 20.6, 30.6, 20.5; ESIMS ($C_{17}H_{20}O_7S$, m/z 368): 391 (M + Na^+); TLC: R_f = 0.28 (ethyl acetate/hexane, 1/3).[14]

Phenyl-2,3,5-tetra-*O*-acetyl-β-D-ribofuranoside (6). ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.53–7.51 (m, 2H), 7.34–7.32 (m, 3H), 5.31 (d, 1H, J = 4.8 Hz), 5.26–5.19 (m, 2H), 4.27 (m, 1H). 4.26 (dd, 1H, J = 12.8, 2.8 Hz), 4.09 (dd, 1H, J = 12.8, 5.2 Hz), 2.09 (s, 3H), 2.07 (s, 3H), 2.06 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.5, 169.6, 133.4, 131.7, 129.0, 128.4, 87.9, 80.1, 73.9, 71.4, 63.4, 20.8, 20.5; ESI MS ($C_{17}H_{20}O_7S$, m/z 368): 391 (M + Na^+); TLC: R_f = 0.31 (ethyl acetate/hexane, 1/3).[14]

***p*-Tolyl-2,3,4,6-tetra-*O*-benzoyl-1-thio-β-D-glucopyranoside (7).** ^{1}H NMR ($CDCl_3$, 500 MHz): δ 8.08 (d, 2H, J = 7.8 Hz), 8.00 (d, 2H, J = 7.8 Hz), 7.92 (d, 2H, J = 7.8 Hz), 7.82 (d, 2H, J = 7.8 Hz), 7.62 (t, 1H, J = 7.4 Hz), 7.57–7.40 (m, 9H), 7.36 (t, 2H, J = 7.7 Hz), 7.28 (t, 2H, J = 7.9 Hz), 6.96 (d, 2H, J = 7.9 Hz), 5.93 (t, 1H, J = 9.5 Hz), 5.62 (t, 1H, J = 9.8 Hz), 5.49 (t, 1H, J = 9.8 Hz), 5.01 (d, 1H, J = 9.9 Hz), 4.71 (dd, 1H, J = 12.2; 2.1 Hz), 4.50 (dd, 1H, J = 12.2; 5.7 Hz), 4.23–4.19 (m, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz): δ 166.0, 165.8, 165.1, 165.0, 138.6, 133.87, 133.43, 133.27, 133.17, 133.1, 129.82, 129.80, 129.69, 129.60, 129.2, 128.74, 128.67, 128.4, 128.2, 127.5, 86.28, 76.2, 74.2, 70.4, 69.3, 63.1, 21.1; ESIMS ($C_{41}H_{34}IO_9$, m/z 703): 726 (M + Na^+); TLC: R_f = 0.42 (ethyl acetate/hexane, 1/1).[14]

Phenyl-2,3,6-tri-*O*-acetyl-4-*O*-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-galactopyranosyl)-1-thio-β-D-glucopyranoside (8). ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.49–7.46 (m, 2H), 7.33–7.27 (m, 3H), 5.34 (dd, 1H, J = 3.4; 1.0 Hz), 5.23 (t, 1H, J = 9.2 Hz), 5.09 (dd, 1H, J = 10.4; 7.8 Hz), 4.94 (dd, 1H, J = 10.4, 3.4 Hz), 4.88 (dd, 1H, J = 10.0, 9.2 Hz), 4.66 (d, 1H, J = 10.1Hz), 4.52 (dd, 1H, J = 12.0, 2.0 Hz), 4.46 (d, 1H, J = 8.0 Hz), 4.10 (m, 1H), 4.14–4.04 (m, 2H), 3.85 (bt, 1H, J = 7.2 Hz), 3.63–3.62 (m, 2H), 2.15 (s, 3H), 2.10 (s, 3H), 2.09, (s, 3H), 2.04 (s, 6H), 2.03 (s, 3H), 1.95 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.2, 170.2, 170.0, 169.9, 169.6, 169.5, 169.05, 133.0, 131.7, 128.8, 128.2, 100.9, 85.4, 76.15, 73.8, 70.9, 70.7, 70.3, 69.1, 66.6, 62.1, 60.8, 20.72, 20.67, 20.5, 20.4; ESI MS ($C_{32}H_{40}O_{17}S$, m/z 728): 752 (M + Na^+); white crystalline; mp 170–171°C; TLC: R_f = 0.13 (ethyl acetate/hexane, 1/1).[14]

Phenyl-2,3,6-tri-*O*-acetyl-4-*O*-(2′,3′,4′,6′-tetra-*O*-acetyl-α-D-glucopyranosyl)-1-thio-β-D-glucopyranoside (9). ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.48–7.46 (m, 2H), 7.34–7.27 (m, 3H), 5.37 (d, 1H, J = 4 Hz), 5.33 (dd, 1H, J = 10.3, 9.7Hz,), 5.27 (t, 1H, J = 8.9Hz), 5.02 (dd, 1H, J = 10.0; 9.7 Hz), 4.89–4.79 (m, 2H), 4.52 (d, 1H, J = 10.0 Hz), 4.27–4.21 (m, 2H), 4.16 (dd, 1H, J = 12.4, 7.7 Hz), 4.03 (dd, 1H, J = 12.4, 2.1 Hz), 3.95–3.87 (m, 2H), 3.70 (ddd, 1H, J = 7.5, 4.8, 2.6 Hz), 2.11 (s, 3H), 2.09 (s, 3H), 2.05 (s, 3H), 2.02 (s, 3H), 2.01 (s, 3H), 1.98 (s, 3H), 1.97 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.49, 170.47, 170.3, 170.1, 169.9, 169.5, 169.4, 133.4, 131.3, 128.9, 128.4, 95.6, 85.1, 76.5, 76.1, 72.6, 70.7, 70.0, 69.3, 68.6, 68.1, 62.9, 61.6, 20.86, 20.83, 20.76, 20.67, 20.63; ESIMS

($C_{32}H_{40}O_{17}S$, *m/z* 728): 751 ($M + Na^+$); TLC: R_f = 0.12 (ethyl acetate/hexane, 1/1).[14]

***p*-Tolyl-2-acetamido-3,4,6-tetra-*O*-acetyl-2-deoxy-1-thio-β-D-glucopyranoside (10).** ^1H NMR ($CDCl_3$, 400 MHz): δ 7.39 (d, 2H, *J* = 8.0 Hz), 7.10 (d, 2H, *J* = 8.0 Hz), 5.61 (t, 1H, *J* = 8.7 Hz), 5.19 (t, 1H, *J* = 9.8 Hz), 5.02 (t, 1H, *J* = 9.7 Hz), 4.69 (d, 1H, *J* = 10.4 Hz), 4.19–4.16 (m, 2H), 3.97 (dd, 1H, *J* = 9.4 Hz, *J* = 3.2 Hz), 3.71–3.67 (m, 1H), 2.33 (s, 3H), 2.07 (s, 3H), 2.05 (s, 3H), 2.00 (s, 3H), 1.98 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.9, 170.6, 170.1, 169.3, 132.5, 132.3, 128.8, 127.9, 86.5, 75.6, 73.7, 68.5, 62.4, 53.2, 23.2, 20.7, 20.6, 20.5; ESIMS ($C_{21}H_{27}NO_8S$, *m/z* 453): 476 ($M + Na^+$); TLC: R_f = 0.39 (ethyl acetate/hexane, 1/1).[14]

***p*-Methylphenyl-3,4,6-tri-*O*-acetyl-2-deoxy-1-thio-2-(2,2,2-trichloroethyloxycarbonylamino)-β-D-glucopyranoside (11).** ^1H NMR ($CDCl_3$, 400 MHz): δ 7.41 (d, 2H, *J* = 8.0 Hz), 7.11 (d, 2H, *J* = 8.0 Hz), 5.25 (q, 2H, *J* = 10.0 Hz), 5.01 (t, 1H, *J* = 10.0 Hz), 4.79 (d, 2H, *J* = 10.4 Hz), 4.72 (d, 1H, *J* = 12.0 Hz), 4.22 (dd, 1H, *J* = 12.4, 5.2 Hz), 4.16 (dd, 1H, *J* = 12.4, 2.4 Hz), 3.07 (septet, 1H, *J* = 2.4 Hz), 2.35 (s, 3H), 2.08 (s, 3H), 2.005 (s, 3H), 2.002 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.59, 170.56, 169.4, 153.8, 138.7, 133.7, 129.7, 127.9, 86.7, 75.8, 74.5, 73.2, 68.5, 62.3, 55.0, 21.2, 20.7, 20.6, 20.56; ESIMS ($C_{22}H_{26}Cl_3NO_9S$, *m/z* 587): 610 ($M + Na^+$); TLC: R_f = 0.32 (ethyl acetate/hexane, 1/2).[41]

***p*-Methylphenyl-2,3,4,6-tetra-*O*-benzyl-1-thio-β-D-galactopyranoside (12).** ^1H NMR ($CDCl_3$, 400 MHz): δ 7.46 (d, 1H, *J* = 1.6 Hz), 7.44 (t, 2H, *J* = 2.0 Hz), 7.41–7.23 (m, 21H), 7.05 (d, 2H, *J* = 7.6 Hz), 5.69 (d, 1H, *J* = 5.6 Hz), 5.01 (d, 1H, *J* = 11.2 Hz), 4.92 (d, 1H, *J* = 12.0 Hz), 4.82 (d, 1H, *J* = 11.6 Hz), 4.78 (d, 1H, *J* = 12.0 Hz), 4.74 (d, 1H, *J* = 11.6 Hz), 4.63 (d, 1H, *J* = 11.6 Hz), 4.54 (dd, 1H, *J* = 4.0 Hz), 4.43 (q, 2H, *J* = 6.8 Hz), 4.41–4.38 (m, 1H), 4.03 (q, 1H, *J* = 1.6 Hz), 3.87 (dd, 1H, *J* = 10.0, 2.8 Hz), 3.64–3.54 (m, 2H) , 2.32 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 138.7, 138.6, 138.1, 138.0, 137.1, 123.3, 130.6, 129.6, 128.4, 128.3, 128.27, 128.17, 128.10, 127.9, 127.64, 127.62, 127.56, 127.50, 127.46, 127.41, 87.9, 79.4, 76.5, 75.2, 74.8, 73.4, 73.3, 72.5, 70.2, 68.9, 29.7; ESIMS ($C_{41}H_{42}O_5S$, *m/z* 647): 670 ($M + Na^+$); TLC: R_f = 0.36 (ethyl acetate/hexane, 1/12).[42]

***p*-Methylphenyl-1-thio-β-D-glucopyranoside (13).** ^1H NMR ($CDCl_3$, 400 MHz): δ 7.46 (d, 2H, *J* = 8.0 Hz), 7.13 (d, 2H, *J* = 8.0 Hz), 4.58 (bs, 1H, OH), 4.52 (d, 1H, *J* = 7.4 Hz), 3.86 (dd, 1H, *J* = 11.0, 1.4 Hz), 3.68 (t, 1H, *J* = 2.6 Hz), 3.67 (dd, 1H, *J* = 11.1, 4.9 Hz), 3.36–3.26 (m, 2H), 3.20 (t, 1H, *J* = 9.6 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.9, 170.6, 170.1, 169.3, 132.5, 132.3, 138.9, 133.6, 131.2, 130.7, 89.7, 82.1, 79.7, 73.8, 71.5, 63.0, 21.2; ESIMS ($C_{13}H_{18}O_5S$, *m/z* 286): 309 ($M + Na^+$); TLC: R_f = 0.36 (ethyl acetate, 100%).[9]

Procedure for synthesis of β-(1 → 6)-*S*-linked-thiodisaccharide 15

To aluminum powder (20 μm, spherical powder, 0.18 mmol, 5.4 mg) in anhydrous CH_2Cl_2 solution (2 mL) was added I_2 (0.27 mmol, 68 mg) at room temperature under nitrogen atmosphere. After being stirred for 1 h, the solution became brown purple and the aluminum powder completely disappeared. To a solution of 1-hydroxyl-2,3,4,6-pentaacetyl glucose (0.6 mmol, 209 mg) and 0.5 mmol 2,3,4-tri-*O*-benzyl-6-thio-α-D-glucose **14** (0.5 mmol, 240 mg) in 2 mL CH_2Cl_2, the above solution was added. The resulting dark brown mixture was stirred at ambient temperature for 2 h. The reaction was quenched by adding 3 mL saturated $NaHCO_3$(aq) solution. The organic layer was separated and dried over $MgSO_4$ and filtered. The crude product was concentrated under reduced pressure and loaded directly on top of an eluent-filled silica gel column and purified by flash column chromatography to provide **15** in 72% yield (292 mg).

Methyl-2,3,4,-tri-*O*-benzyl-6-*S*-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyl)-6-thio-α-D-glucopyranoside (15).[9] ^1H NMR ($CDCl_3$, 400 MHz) δ 7.37–7.27 (m, 15H), 5.19 (t, *J* = 9.6, 1H), 5.05 (t, *J* = 9.6, 1H), 4.95 (t, *J* = 7.2, 1H), 4.98 (d, *J* = 11.0, 1H), 4.92 (d, 1H, *J* = 11.0), 4.81–4.77 (m, 2H), 4.66 (d, *J* = 13.2, 1H), 4.64 (d, *J* = 13.2, 1H), 4.60 (d, *J* = 7.2, 1H), 4.57 (d, *J* = 3.6, 1H), 4.18 (dd, *J* = 12.4, 4.8, 1H), 4.05 (dd, *J* = 12.4, 2.0, 1H), 3.96 (t, *J* = 9.2, 1H), 3.83 (td, *J* = 8.0, 2.0, 1H), 3.59 (ddd, *J* = 10.0, 4.4, 2.0, 1H), 3.49 (dd, *J* = 9.6, 3.2, 1H), 3.40 (s, 3H), 3.31 (t, *J* = 9.2, 1H), 3.00 (dd, *J* = 13.6, 2.0, 1H), 2.69 (dd, *J* = 13.6, 8.8, 1H), 2.04 (s, 3H), 2.02 (s, 3H), 2.01 (s, 3H), 2.00 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 170.6, 170.2, 169.3, 169.1, 138.6, 138.2, 138.1, 128.47, 128.45, 128.37,

128.0, 127.94, 127.86, 127.83, 127.6, 97.8, 83.9, 81.9, 80.7, 79.9, 75.71, 75.70, 75.0, 73.9, 73.3, 71.0, 70.2, 68.3, 62.0, 55.1, 31.6, 20.61, 20.58, 20.55, 20.51; 810.9; ESI-MS ($C_{42}H_{50}O_{14}S$, *m/z* 810): 833 ($M + Na^+$); TLC R_f = 0.38 (ethyl acetate/hexane, 1/2).[43,44]

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