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6-*S*-Phenyl-glycopyranosides as ready precursors to the synthesis of glycuronides

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Abstract—6-*S*-Phenyl-gluco/galactopyranosides, readily prepared from the corresponding 6-hydroxy-glycosides, were demonstrated to be effective glycosyl donors or acceptors. The resulting coupling products were then easily converted into the corresponding glycuronide-containing compounds under mild conditions. © 2001 Elsevier Science Ltd. All rights reserved.

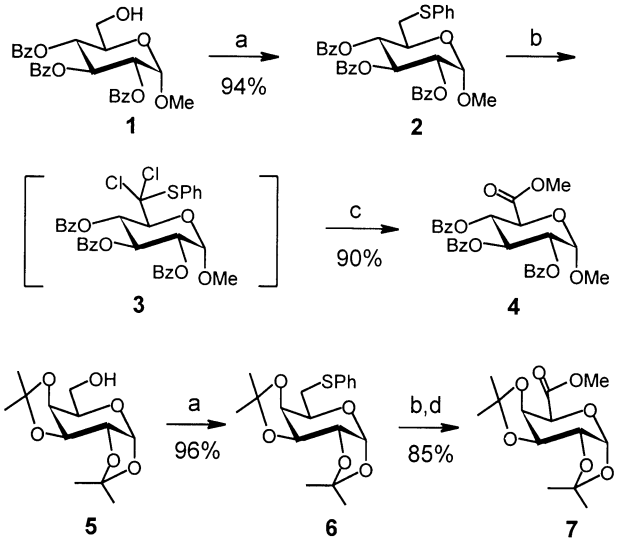
1. Introduction

Glycuronic acids, mainly glucuronic acid and galacturonic acid, are conspicuous integral components in proteoglycans of mammals,[1] capsular polysaccharides of bacteria,[2] and pectins and saponins of plants.[3,4] All these glycuronide-containing compounds are physiologically very important. Also important are glucuronides of drugs or xenobiotics which are frequently the final form eliminated from the body, performing a detoxification role.[5] To rationalize the function of these glycuronide-containing structures, which exist as complex macromolecules, in heterogeneous manner, or in tiny amounts, chemical synthesis becomes imperative for many investigators.[5–8] The presence of the electron-withdrawing 5-carboxyl group remarkably decreases the nucleophilicity of the hydroxy groups on glycuronide acceptors, or exerts a destabilizing effect on the incipient C-1 cation leading to low reactivity of glycuronide donors. Consequently, coupling with a glycuronide donor or acceptor is notably difficult compared with a neutral hexopyranoside counterpart.[5,6] Therefore, glycuronide donors armed with electron-donating protective groups have to be used in the synthesis.[9] Alternatively, glycuronide, glycuronide-containing oligosaccharides in particular, are conventionally synthesized by introduction of the carboxyl group at a later oxidation step after coupling with a neutral hexopyranoside moiety.[7,8] These requirements put remarkable restraints on the protective group manipulations in the synthesis of glycuronide-containing molecules.

To release the restraints in the glycuronide synthesis, we envisioned developing a glycuronide precursor with C-6 temporarily masked with a functional group, which could behave as a normal hexopyranoside donor or acceptor and could be readily transformed into the glycuronide residue after assembling the whole molecule. 6-Phenylthio ether of glucopyranosides were optimal.[10]

2. Results and discussion

The feasibility and efficiency of our new procedure for the glycuronide synthesis would depend on each of the three following transformations: (1) substitution of the 6-OH of a hexopyranoside with phenylthio group; (2) coupling with



Scheme 1. *Reagents and conditions*: (a) $(PhS)_2$, *n*-Bu_3P, pyridine, rt, 24 h; (b) SO_2Cl_2–pyridine (2.0 equiv.), CCl_4, 0°C; (c) $HgCl_2$ (10.0 equiv.), pyridine (2.0 equiv.), MeOH–H_2O–CH_2Cl_2 (2:1:1), rt; (d) Na_2CO_3, MeOH–H_2O (1:1), rt.

Keywords: thiosugars; glycosidation; carbohydrates; glycuronides.

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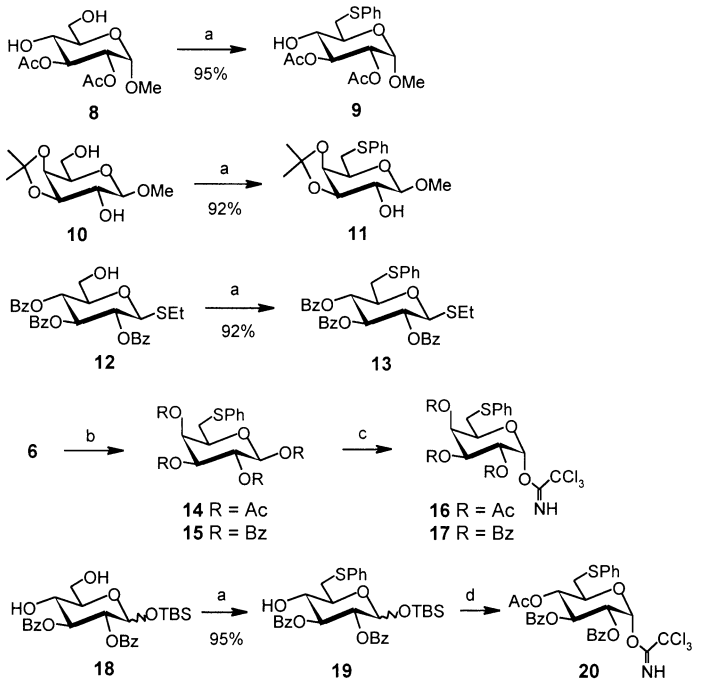

Scheme 2. *Reagents and conditions*: (a) $(PhS)_2$, *n*-Bu_3P, pyridine, rt, 24 h; (b) (1) 80% HOAc, 50°C, 5 h; (2) Ac_2O, pyridine, rt, 6 h for **14** (81%); or BzCl, pyridine, rt, overnight for **15** (73%); (c) (1) NH_3–THF–MeOH; (2) CCl_3CN, DBU, CH_2Cl_2, rt, 1 h, 60% for **16**, 65% for **17**; (d) (1) Ac_2O, pyridine, rt, overnight; (2) TBAF, HOAc, THF, rt, 10 h; (3) CCl_3CN, DBU, CH_2Cl_2, rt, 1 h, 81% (for three steps).

6-phenylthio sugar donors or acceptors; (3) conversion of 6-phenylthio group to a carboxyl function. The transformations from 6-OH to 6-phenyl sulfide, and then to the corresponding methyl ester were examined first (Scheme 1). Treatment of methyl 2,3,4-tri-*O*-benzoyl-α-D-glucopyranoside (**1**)[11] with phenyl disulfide (2.0 equiv.) and tri-*n*-butylphosphine (2.0 equiv.) in pyridine at room temperature provided 6-phenyl sulfide **2** in 94% yield. These conditions have previously been successfully applied to the preparation of 5′-alkylthio-5′-deoxy-ribonucleosides.[12] Analogous conditions applied to 1,2;3,4-di-*O*-isopropylidene-α-D-galactopyranoside (**5**) afforded the corresponding 6-phenyl sulfide **6** in 96% yield. The transformation of 6-phenyl sulfides to the corresponding methyl esters was tried employing the unique procedure developed by Fortes et al.[13] Thus **2** was subjected to sulphuryl chloride (2.0 equiv.) and pyridine (2.0 equiv.) in carbon tetrachloride at 0°C to produce the α,α-di-chloro-phenylsulfide **3**. Although this reaction was very clean as shown by TLC, compound **3** was isolated in only low yield after silica gel column chromatography; the majority of **3** was believed to decompose on silica gel. Therefore, crude **3**, after the usual work-up, was directly charged with sodium carbonate in a solvent mixture of MeOH–H_2O–CH_2Cl_2 (2:1:1) at room temperature, as reported by Fortes. A complex mixture of products was detected on TLC, conceivably due to cleavage of the benzoyl groups under the basic conditions. An alternative hydrolysis protocol using $HgCl_2$, suggested by Fortes, worked very well on glycoside **3**. Thus treatment of crude **3** with $HgCl_2$ (10.0 equiv.) in the presence of pyridine (2.0 equiv.) in MeOH–H_2O–CH_2Cl_2 (2:1:1) at room temperature afforded the expected methyl uronate **4**[14] in 90% yield (over two steps). Similar conditions applied to phenyl sulfide **6** afforded methyl uronate **7** in lower yield

Table 1. Coupling with 6-phenylthio-glycopyranoside donors and acceptors

Entry	Donor	Acceptor	Conditions	Product	Yield (%)
1	**13**	**1**	A	**26**	60
2	**13**	**24**	A	**27**	56
3	**20**	**24**	B	**28**	82
4	**20**	**25**	B	**29**	85
5	**16**	**5**	B	**30**	92
6	**16**	**1**	B	**31**	63
7	**17**	**1**	B	**32**	96
8	**17**	**24**	B	**33**	94
9	**21**	**9**	C	**34**	70
10	**22**	**9**	C	**35**	81
11	**23**	**9**	C	**36**	92
12	**21**	**11**	C	**37**	99
13	**23**	**11**	C	**38**	99
14	**17**	**11**	C	**39**	99
15	**17**	**9**	C	**40**	83

Conditions A: donor (2.0 equiv.), acceptor (1.0 equiv.), 4 Å MS, CH_2Cl_2, MeOTf (5.0 equiv.). Conditions B: donor (1.0 equiv.), acceptor (1.5–2.0 equiv.), 4 Å MS, CH_2Cl_2, TMSOTf (0.2 equiv.). Conditions C: donor (2.0 equiv.), acceptor (1.0 equiv.), 4 Å MS, CH_2Cl_2, TMSOTf (0.2 equiv.). Isolated yields.

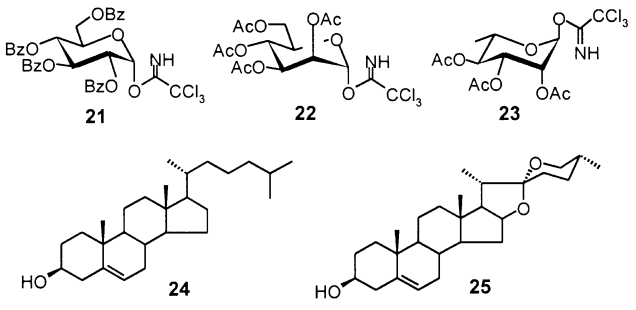

Figure 1. Other selected donors and acceptors.

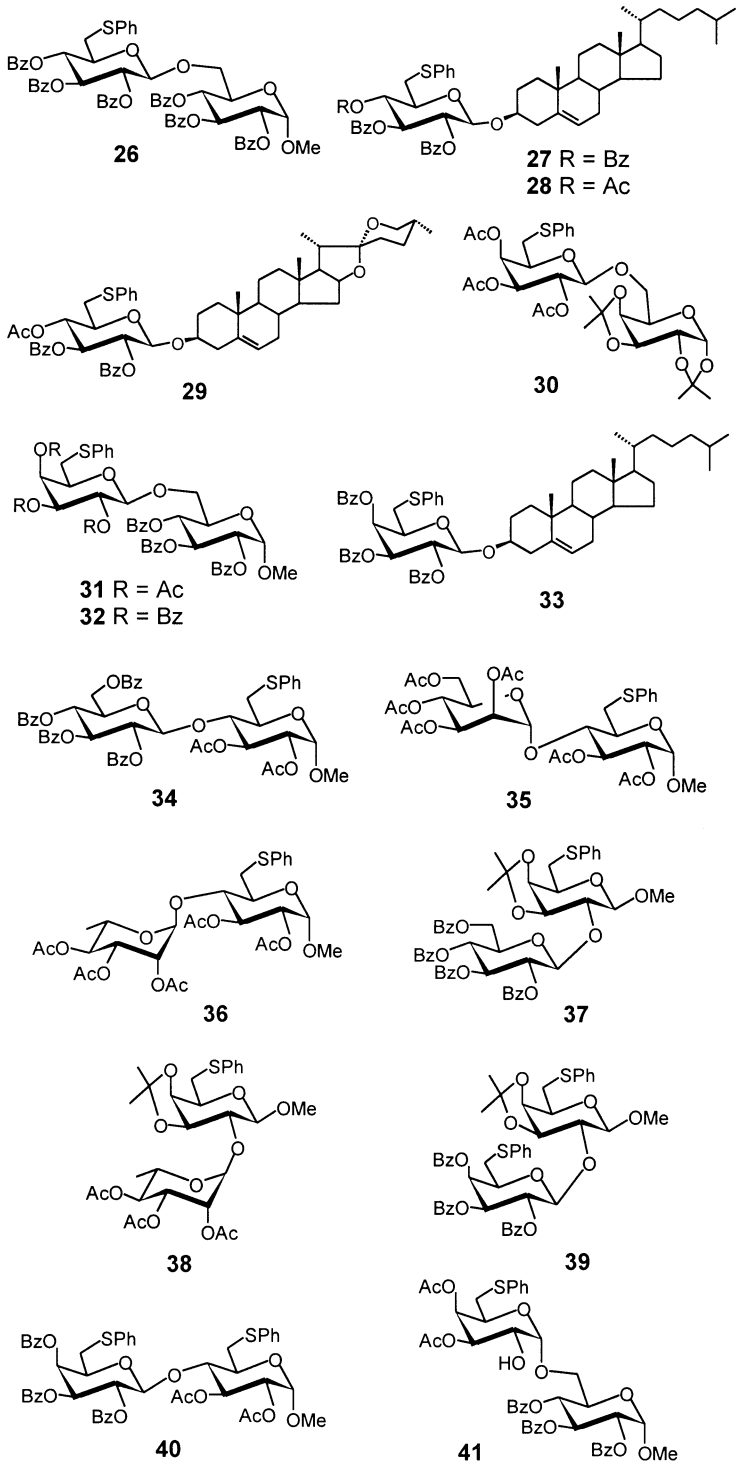

Figure 2. Glycosidation products.

(66%), conceivably due to the partial cleavage of the isopropylidene groups under acidic conditions in the presence of phenyl thiol eliminated from the starting **6**.[15] Alternatively, hydrolysis of **6** with sodium carbonate in MeOH–H_2O (1:1) afforded **7** in high yield (85%). Indeed, the Fortes protocol for transformation of phenyl sulfide to carboxyl function under direct and mild conditions was the impetus for us to try 6-phenyl sulfides as uronide precursors.

To be useful uronide precursors, 6-phenyl sulfides must behave as effective glycoside donors or acceptors. It was anticipated that 6-phenyl sulfide donors or acceptors would be much more active than the corresponding uronide counterparts due to replacement of the electron-withdrawing 5-carboxyl function with the phenyl thioether function. Problems might arise by the interference of the 6-phenyl thioether in the coupling reaction, although 2-phenylthio-2-deoxy-sugars are known to be good donors or acceptors in several glycosylation protocols.[16] To address the above rationale, several 6-phenyl sulfide donors and

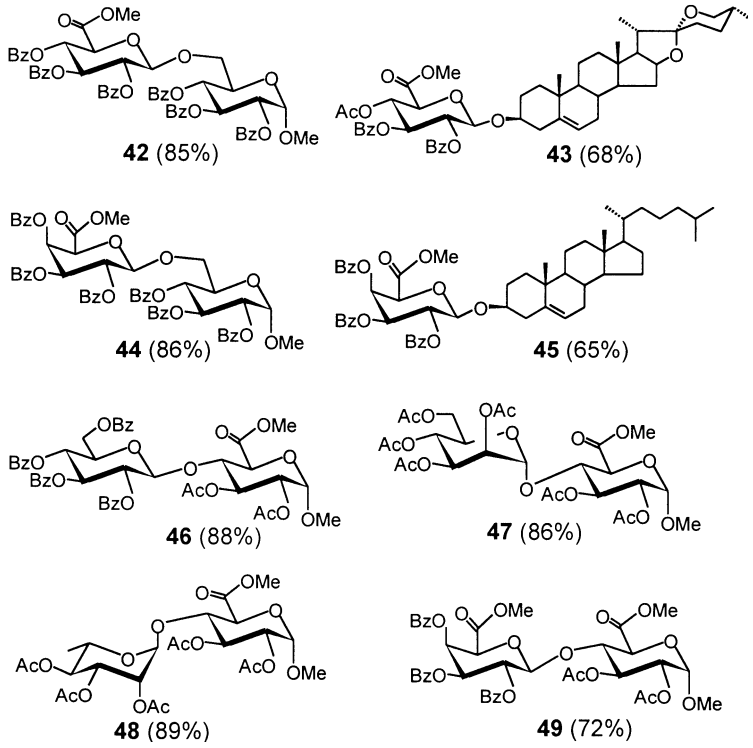

Figure 3. Methyl uronates prepared from 6-phenylthio substituted precursors. The numbers in parentheses are isolated yields.

acceptors were prepared (Scheme 2) and tried in the coupling reactions (Table 1).

The first step of the transformation of 6-OH gluco/galactopyranosides (**8**,[17] **10**,[18] **12**,[19] and **18**) to the corresponding 6-phenyl sulfides (**9**, **11**, **13**, and **19**) was again very successful in the presence of PhSSPh (2.0 equiv.) and *n*-Bu_3P (2.0 equiv.) in pyridine at room temperature. Not only the yields were excellent (92–95%), but also the regioselectivity was ideal. For diols **8**, **10**, and **18**, only 6-phenyl sulfides were produced under excess amounts of the reagents.

Glycosylation using thioglycoside donors bearing a 6-phenylthio ether function, e.g. **13**, might be problematic due to the necessity of using thiophilic promoters.[20] Trichloroacetimidates, another widely used donors,[21] should be unaffected by the introduction of the 6-phenyl thioether function. Therefore, 6-*S*-phenyl-gluco/galactopyranosyl trichloroacetimidates (**16**, **17**, and **20**) were prepared, using routine transformations (Scheme 2).

As anticipated, glycosylation of sugar alcohol **1** and cholesterol (**24**) with thioglycoside **13** bearing a 6-phenyl thioether function under the promotion of NIS/AgOTf generated a complicated mixture of the products. Under the action of a milder thiophilic promoter MeOTf,[22] the desired coupling products **26** and **27** were produced in 60 and 56% yields, respectively (Table 1, entries 1 and 2). As expected, glycosylation with 6-*S*-phenyl-gluco/galactopyranosyl trichloroacetimidates (**16**, **17**, and **20**) catalyzed by TMSOTf produced the corresponding products (**28**–**33**) cleanly (82–96% yields, except 63% yield for **31**) (Table 1, entries 3–8). The lower yield for coupling between sugar alcohol **1** and imidate **16** to produce **31** is not unusual, since **41** was also produced in 32% yield; the 1,2-*cis*-coupling product with the absence of the 2-*O*-acetyl group (e.g. **41**) has long been known to be produced through a 1,2-*ortho* ester pathway,[23] which is common when using glycosyl donors bearing an acetyl group at the 2-position.[24] Replacing the 2-*O*-acetyl group with a benzoyl group normally hampered the formation of 1,2-*ortho* ester, therefore producing the expected coupling products in higher yields.[25] Evidently, glycosylation of **1** with imidate **17** produced **32** in 96% yield.

6-*S*-Phenyl-gluco/galactopyranosides **9** and **11**, bearing a free 4-OH and 2-OH, respectively, were demonstrated to be good acceptors when coupling with common trichloroacetimidate donors **21**,[26] **22** (Fig. 1),[27] and **23**[28] under the action of TMSOTf (0.2 equiv.), producing the corresponding products (**34**–**38**) in satisfactory yields (70–99%). (Table 1, entries 9–13) Moreover, coupling between 6-*S*-phenyl-glycosyl donor and 6-*S*-phenyl-glycoside acceptor was also proven effective (entries 14 and 15). Thus glycosylation of **9** and **11** with imidate **17** under common conditions catalyzed by TMSOTf produced disaccharides **39** and **40** in 83 and 99% yields, respectively. It should be mentioned that glycosyl donors bearing a neighboring participating group (acetyl or benzoyl groups) were employed in the above glycosylation reactions which led therefore only to the corresponding 1,2-*trans*-glycoside products.

Finally, the crucial transformation from 6-phenyl sulfides to the corresponding methyl uronates were examined again on some of the above coupling products using analogous conditions for converting 6-phenyl sulfide **1** to glucuronide **4** mentioned earlier. Thus, all the 6-phenyl sulfides tested (**26**, **29**, **32**–**36**, **40**) (Fig. 2) were first converted into the

corresponding α,α-dichloro-phenyl sulfides upon treatment with sulfuryl chloride in the presence of pyridine in carbon tetrachloride, TLC showed that all the reactions proceeded cleanly. After usual work-up, the crude α,α-dichloro-phenyl sulfides were subjected to hydrolysis in the presence of mercury chloride and pyridine in a solvent mixture of MeOH–H_2O–CH_2Cl_2 (2:1:1). Steroidal glycosides derived from **29** and **33** were hydrolyzed in MeOH–H_2O–$CHCl_3$ (2:1:1) instead where they showed better solubility. Since all the substrates bear acyl protecting groups, basic hydrolysis conditions (Na_2CO_3) were avoided. All the expected methyl uronates (**42**–**49**) (Fig. 3) were produced in satisfactory yields (65–88% yields for two steps). Especially, [(methyl β-D-galactopyranosyl)uronate]-(1→4)-(methyl α-D-glucopyranoside)uronate (**49**) was also obtained in 72% yield.

3. Conclusion

A novel and effective procedure for the preparation of glycuronides has been developed which employs 6-*S*-phenyl-hexopyranosides as precursors. The success of the present procedure takes advantage of the ease of the three following transformations: (1) the substitution of 6-OH of a hexopyranoside with phenylthio group (PhSSPh, *n*-Bu_3P) provides high yields and regioselectivity; (2) coupling with 6-phenylthio sugar donors or acceptors under Schmidt trichloroacetimidate glycosylation conditions proceeds normally; (3) conversion of 6-phenylthio group to a methyl ester function using Fortes protocol (SO_2Cl_2, pyridine, CCl_4, and then $HgCl_2$, pyridine, MeOH–H_2O–CH_2Cl_2) works well regardless of the multi-functions presented in the substrates (acetyl groups, benzoyl groups, glycosidic bonds, and carbon–carbon double bonds). The present procedure has avoided the difficulties in the previous synthesis of glycuronides, which needs to use the sluggish glycuronide donors and acceptors or perform an oxidation step in a later stage of the synthesis.

4. Experimental

4.1. General remarks

Solvents were distilled from the appropriate drying agents before use. All reactions were carried out under a positive pressure of argon and were monitored by TLC on silica gel HF_{254} (0.5 mm, Qingdao, China). Spots were detected under UV light or by charging with 10% H_2SO_4 in MeOH. Flash column chromatography was carried out on silica gel H (400 mesh, Qingdao, China). Optical rotations were measured on a Perkin–Elmer 241 MC polarimeter. ^1H NMR spectra were recorded on a Bruker AM-300 spectrometer using $CDCl_3$ as solvent and tetramethylsilane as a internal reference. Mass spectra were recorded on a HP5989A mass spectrometer. IR spectra were recorded with a FTS-185 spectrometer.

4.2. Typical procedure for the preparation of 6-phenylsulfides (2, 6, 9, 11, 13, 19)

To a solution of the 6-OH glycopyranoside (2.0 mmol) in dry pyridine (10 mL) was added $(PhS)_2$ (2.0 equiv.) and *n*-Bu_3P (2.0 equiv.). After being stirred at room temperature for 24 h, the mixture was diluted with EtOAc. The organic layer was washed with brine, and then dried over $MgSO_4$, and concentrated in vacuo. The residue was purified by flash column chromatography.

4.2.1. Methyl 2,3,4-tri-*O*-benzoyl-6-*S*-phenyl-6-thio-α-D-glucopyranoside (2). Chromatography with petroleum ether–EtOAc (8:1–4:1) gave **2** as a colorless syrup (96%): $[\alpha]_D^{25}=+49.8$ (*c* 1.33, $CHCl_3$); ν_{max}(neat) 3063, 2937, 1728, 1602, 1584, 1452, 1316, 1281, 1266, 1179, 1108, 1094, 1070, 1046, 1026 cm^{-1}; δ_H (300 MHz $CDCl_3$) 8.01–7.20 (m, 20H), 6.11 (t, 1H, *J*=9.9 Hz), 5.50 (t, 1H, *J*=9.9 Hz), 5.28 (dd, 1H, *J*=9.9, 3.6 Hz, H-2), 5.22 (d, 1H, *J*=3.6 Hz, H-1), 4.25 (dt, 1H, *J*=9.9, 2.5 Hz, H-5), 3.47 (s, 3H), 3.26 (dd, 1H, *J*=13.9, 2.6 Hz, H-6), 3.15 (dd, 1H, *J*=13.9, 8.8 Hz, H-6′); EIMS *m/z*: 599, 598, 567, 489, 105. Anal. Calcd for $C_{34}H_{30}O_8S$: C, 68.21; H, 5.05; S, 5.36. Found: C, 67.96; H, 5.10; S, 5.59.

4.2.2. 1,2;3,4-Di-*O*-isopropylidene-6-*S*-phenyl-6-thio-α-D-galactopyranoside (6). Chromatography with petroleum ether–EtOAc (10:1–8:1) gave **6** as a colorless syrup (96%): $[\alpha]_D^{25}=-105.4$ (*c* 1.21, $CHCl_3$); ν_{max}(neat) 3059, 2989, 2936, 1585, 1482, 1440, 1382, 1373, 1307, 1256, 1212 cm^{-1}; δ_H NMR (300 MHz, $CDCl_3$) 7.41–7.15 (m, 5H), 5.54 (d, 1H, *J*=5.0 Hz, H-1), 4.61 (dd, 1H, *J*=8.0, 2.5 Hz, H-3), 4.39 (dd, 1H, *J*=8.0, 1.8 Hz, H-4), 4.29 (dd, 1H, *J*=5.0, 2.5 Hz, H-2), 3.85 (td, 1H, *J*=6.9, 1.8 Hz, H-5), 3.18 (d, 2H, *J*=6.9 Hz, H-6), 1.47, 1.36, 1.29, and 1.25 (each s, each 3H); EIMS *m/z*: 352, 337, 295, 279, 237, 219; HRMS *m/z*: Calcd for $C_{18}H_{24}O_5S$: 352.08952. Found: 352.13866. Anal. Calcd for $C_{18}H_{24}O_5S$: C, 61.34; H, 6.86; S, 9.10. Found: C, 60.90; H, 7.01; S, 9.39.

4.2.3. Methyl 2,3-di-*O*-acetyl-6-*S*-phenyl-6-thio-α-D-glucopyranoside (9). Chromatography with petroleum ether–EtOAc (2:1–1:1) afforded **9** as a colorless syrup (95%): $[\alpha]_D^{13}=+117.1$ (*c* 1.19, $CHCl_3$); ν_{max}(neat) 3472, 2935, 1747, 1584, 1482, 1440, 1372, 1243 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.68–7.25 (m, 5H), 5.24 (tt, 1H, *J*=9.5, 1.9 Hz, H-2), 4.88 (m, 2H, H-1, H-3), 3.86 (dt, 1H, *J*=9.6, 2.5 Hz, H-5), 3.59 (t, 1H, *J*=9.6 Hz, H-4), 3.54 (dd, 1H, *J*=13.6, 2.5 Hz, H-6), 3.38 (s, 3H, OMe), 3.08 (dd, 1H, *J*=13.6, 8.2 Hz, H-6′), 2.10 and 2.08 (each s, each 3H, Ac); EIMS *m/z*: 370, 339, 310, 43; HRMS *m/z* Calcd for $C_{17}H_{22}O_7S$: 370.06366. Found: 370.10795.

4.2.4. Methyl 3,4-*O*-isopropylidene-6-*S*-phenyl-6-thio-β-D-galactopyranoside (11). Chromatography with petroleum ether–EtOAc (3:1) gave **11** as a colorless syrup (92%): $[\alpha]_D^{29}=-6.6$ (*c* 1.47, $CHCl_3$); ν_{max}(neat) 3451, 2993, 2848, 1581, 1480, 1383, 1220, 1203 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.43–7.21 (m, 5H), 4.24 (dd, 1H, *J*=5.5, 2.2 Hz), 4.04 (m, 2H), 3.83 (dt, 1H, *J*=6.9, 2.2 Hz, H-5), 3.54 (m, 1H), 3.45 (s, 3H), 3.33 (dd, 2H, *J*=6.9, 4.4 Hz), 1.52 and 1.30 (each s, each 3H); EIMS *m/z*: 326, 311, 295, 268, 251, 123; HRMS *m/z* Calcd for $C_{16}H_{22}O_5S$: 326.07386. Found: 326.12151. Anal. Calcd for $C_{16}H_{22}O_5S$: C, 58.88; H, 6.79. Found: C, 58.79; H, 6.96.

4.2.5. Ethyl 2,3,4-tri-*O*-benzoyl-6-*S*-phenyl-6-thio-1-thio-β-D-glucopyranoside (13). Chromatography with petroleum

ether–EtOAc (10:1–5:1) gave **13** as a colorless syrup (92%): $[\alpha]_D^{19}$=+37.2 (*c* 1.49, $CHCl_3$); ν_{max}(neat) 3063, 2974, 2930, 1729, 1602, 1584, 1451, 1316, 1282, 1261, 1178, 1110, 1087, 1069, 1025 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.96–7.21 (m, 20H), 5.86 (t, 1H, *J*=9.6 Hz), 5.53 (t, 2H, *J*=9.6 Hz), 4.81 (d, 1H, *J*=9.6 Hz, H-1), 3.95 (m, 1H, H-5), 3.30–3.15 (m, 2H, H-6), 2.73 (m, 2H, SCH_2), 1.28 (t, 3H, *J*=7.4 Hz, CH_3); EIMS *m/z*: 628, 567, 415, 105. Anal. Calcd for $C_{35}H_{32}O_7S_2$: C, 66.86; H, 5.13. Found: C, 66.62; H, 5.30.

4.2.6. *tert*-Butyldimethylsilyl 2,3-di-*O*-benzoyl-6-*S*-phenyl-6-thio-α/β-D-glucopyranoside (19). Compounds **19** were inseparable α/β anomers (95%). Their acetylation products (Ac_2O, pyridine, 100%) were separated (α/β=2/1) and characterized. *tert-Butyldimethylsilyl 4-O-acetyl-2,3-di-O-benzoyl-6-S-phenyl-6-thio-α-D-gluco-pyranoside*: $[\alpha]_D^{25}$=+101.0 (*c* 1.02, $CHCl_3$); ν_{max}(neat) 3065, 2930, 2859, 1755, 1729, 1603, 1585, 1482, 1452, 1374, 1222 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.97–7.21 (m, 15H), 5.97 (t, 1H, *J*=9.9 Hz, H-3), 5.58 (d, 1H, *J*=3.0 Hz, H-1), 5.29 (t, 1H, *J*=9.9 Hz, H-4), 5.17 (dd, 1H, *J*=9.9, 3.0 Hz, H-2), 4.33 (m, 1H, H-5), 3.21 (dd, 1H, *J*=13.7, 3.3 Hz, H-6), 3.10 (dd, 1H, *J*=13.7, 8.0 Hz, H-6′), 1.96 (s, 3H, Ac), 0.85 (s, 9H); EIMS *m/z*: 619, 579, 505, 105. *tert-Butyldimethylsilyl 4-O-acetyl-2,3-di-O-benzoyl-6-S-phenyl-6-thio-β-D-glucopyranoside*: $[\alpha]_D^{25}$=+67.1 (*c* 1.02, $CHCl_3$); ν_{max} (neat) 3064, 2931, 2859, 1733, 1603, 1585, 1482, 1452, 1374, 1282 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.91–7.23 (m, 15H), 5.62 (t, 1H, *J*=9.8 Hz, H-3), 5.41 (dd, 1H, *J*=9.8, 7.6 Hz, H-2), 5.25 (t, 1H, *J*=9.8 Hz, H-4), 4.95 (d, 1H, *J*=7.6 Hz, H-1), 3.80 (m, 1H, H-5), 3.13 (m, 2H, H-6), 1.96 (s, 3H, Ac), 0.78 (s, 9H); EIMS *m/z*: 637, 619, 579, 505, 105. Anal. Calcd for $C_{34}H_{40}O_8SiS$: C, 64.13; H, 6.33. Found: C, 64.06; H, 6.09.

4.2.7. 1,2,3,4-Tetra-*O*-acetyl/benzoyl-6-*S*-phenyl-6-thio-β-D-galactopyranoside (14/15). A solution of **6** (2.0 g, 5.67 mmol) in 80% HOAc (40 mL) was stirred at 50°C for 5 h and then concentrated in vacuo. The trace of HOAc and water were removed by coevaporation with toluene several times. The residue was directly acylated with Ac_2O in pyridine at room temperature for 6 h or BzCl in pyridine at room temperature overnight to afford the crude **14** or **15** after usual workup. The crude **14** was purified by flash column chromatography (petroleum ether–EtOAc 6:1–3:1) to afford a white foam (2.0 g, 81% from **6**): $[\alpha]_D^{26}$=−5.9 (*c* 1.15, $CHCl_3$); ν_{max}(KBr) 3490, 3060, 2985, 2939, 1747, 1584, 1483, 1440, 1370, 1221 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.41–7.22 (m, 5H), 5.65 (d, 1H, *J*= 8.2 Hz), 5.55 (d, 1H, *J*=3.3 Hz), 5.31 (t, 1H, *J*=8.3 Hz), 5.03 (dd, 1H, *J*=10.2, 3.3 Hz), 3.81 (t, 1H, *J*=6.9 Hz), 3.17 (dd, 1H, *J*=14.0, 6.3 Hz), 2.93 (dd, 1H, *J*=14.0, 7.4 Hz), 2.14, 2.12, 2.02, and 1.99 (each s, each 3H); EIMS *m/z*: 441, 440, 381, 320, 249, 43; HRMS *m/z* Calcd for $C_{20}H_{24}O_9S$: 440.06912. Found: 440.11699. The crude **15** was purified by flash column chromatography (petroleum ether–EtOAc 10:1–4:1) to afford a white foam (2.85 g, 73% from **6**): $[\alpha]_D^{27}$=+96.5 (*c* 1.01, $CHCl_3$); ν_{max}(KBr) 3063, 1732, 1452, 1316, 1264 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 8.15–7.21 (m, 25H), 6.18 (d, 1H, *J*=8.2 Hz, H-1), 6.08 (d, 1H, *J*=3.3 Hz), 6.05 (t, 1H, *J*=8.2 Hz, H-2), 5.68 (dd, 1H, *J*=8.2, 3.3 Hz, H-3), 4.19 (t, 1H, *J*=7.0 Hz, H-5), 3.31 (dd, 1H, *J*=14.3, 7.0 Hz, H-6), 3.12 (dd, 1H, *J*=14.3, 7.0 Hz, H-6′); EIMS *m/z*: 689, 688, 567, 444, 105. Anal. Calcd for $C_{40}H_{32}O_9S{\cdot}0.5H_2O$: C, 68.86; H, 4.77. Found: C, 69.13; H, 4.79.

4.2.8. 2,3,4-Tri-*O*-acetyl/benzoyl-6-*S*-phenyl-6-thio-α-D-galactopyranosyl trichloroacetimidate (16/17). Compound **14** (2.4 g, 5.45 mmol) was dissolved in NH_3–THF–MeOH (60 mL) and stirred at 0°C for 50 min. The solvent was evaporated and the residue was purified by chromatography (petroleum ether–EtOAc 2:1) to give a colorless syrup (1.5 g), which was then dissolved in CH_2Cl_2 (15 mL). CCl_3CN (3.3 mL) and DBU (one drop) were added to the resulting solution. After being stirred at room temperature for 1 h, the solution was concentrated in vacuo. The residue was purified by flash column chromatography (petroleum ether–EtOAc with 1% of triethylamine 3:1–2:1) to afford **16** (1.77 g, 60% from **14**) as a white foam: $[\alpha]_D^{29}$=+60.6 (*c* 1.54, $CHCl_3$); ν_{max}(KBr) 3325, 2972, 1745, 1684, 1581, 1481, 1438, 1371, 1247, 1218 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 8.63 (s, 1H), 7.24 (m, 5H), 6.58 (d, 1H, *J*= 3.0 Hz), 5.72 (m, 1H), 5.36 (m, 2H), 4.23 (t, 1H, *J*= 6.9 Hz), 3.12 (dd, 1H, *J*=14.0, 6.3 Hz), 2.92 (dd, 1H, *J*= 14.0, 7.4 Hz), 2.15 and 2.02 (each s, total 9H); EIMS *m/z*: 544, 543, 381, 320, 291, 43; HRMS *m/z* Calcd for $C_{20}H_{22}O_8SNCl_3$: 540.96836. Found: 541.01420. Anal. Calcd for $C_{20}H_{22}O_8SNCl_3$: C, 44.26; H, 4.09; N, 2.58. Found: C, 44.13; H, 4.30; N, 2.41. A procedure similar to that for the preparation of **16** was employed to prepare **17** (1.37 g, 65% from **15**) as a white foam: $[\alpha]_D^{29}$=+101.8 (*c* 1.07, $CHCl_3$); ν_{max}(KBr) 3339, 3063, 1731, 1676, 1602, 1452, 1270 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 8.63 (s, 1H), 8.10–7.21 (m, 20H), 6.86 (d, 1H, *J*=3.6 Hz, H-1), 6.20 (m, 1H), 6.01 (dd, 1H, *J*=10.7, 3.0 Hz, H-3), 5.92 (dd, 1H, *J*=10.7, 3.6 Hz, H-2), 4.51 (t, 1H, *J*=6.9 Hz), 3.24 (dd, 1H, *J*=14.3, 6.6 Hz, H-6), 3.10 (dd, 1H, *J*=14.3, 7.1 Hz, H-6′); EIMS *m/z*: 729, 567, 444, 105. Anal. Calcd for $C_{35}H_{28}O_8NSCl_3$: C, 57.66; H, 3.87; N, 1.92. Found: C, 57.44; H, 3.89; N, 1.81.

4.2.9. 4-*O*-Acetyl-2,3-di-*O*-benzoyl-6-*S*-phenyl-6-thio-α-D-glucopyranosyl trichloroacetimidate (20). To a solution of **19** (637 mg, 1.0 mmol) in dry THF (8 mL), was added HOAc (0.08 mL) and TBAF (2.0 mL, 1 M solution in THF). After being stirred at room temperature for 10 h, the mixture was diluted with ether and washed with brine. The organic layer was dried over $MgSO_4$, and concentrated in vacuo. The residue was purified by flash column chromatography (petroleum ether–EtOAc 4:1) to afford a colorless syrup, which was then dissolved in CH_2Cl_2 (10 mL). CCl_3CN (0.6 mL) and DBU (one drop) were added to the resulting solution. After being stirred at room temperature for 1 h, the solution was concentrated in vacuo. The residue was purified by flash column chromatography (petroleum ether–EtOAc with 1% of triethylamine 6:1–4:1) to afford **20** (545 mg, 81% from **19**) as a white foam: $[\alpha]_D^{27}$=+92.8 (*c* 0.99, $CHCl_3$); ν_{max}(KBr) 3376, 1728, 1653, 1452, 1281, 1223 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 8.60 (s, 1H), 7.93–7.21 (m, 15H), 6.73 (s, br, 1H, H-1), 6.02 (t, 1H, *J*=9.9 Hz, H-3), 5.50 (dd, 1H, *J*=9.9, 3.6 Hz, H-2), 5.40 (t, 1H, *J*=9.9 Hz, H-4), 4.35 (m, 1H, H-5), 3.24 (dd, 1H, *J*=14.3, 3.6 Hz, H-6), 3.11 (dd, 1H, *J*=14.3, 7.4 Hz, H-6′), 1.99 (s, 3H); EIMS *m/z*: 668, 667, 522, 505, 311, 105. Anal. Calcd for

$C_{30}H_{26}O_8SNCl_3$: C, 54.03; H, 3.93; N, 2.10. Found: C, 54.21; H, 4.03; N, 2.09.

4.3. Procedure for preparation of 26 and 27

A suspension of the thioglycoside donor **13** (0.51 mmol), acceptor (**1** or **24**, 0.25 mmol), and 4 Å MS in dry CH_2Cl_2 (8 mL) was stirred at room temperature for 30 min. And MeOTf (0.29 mL) was then added to the reaction. After 10 h, the reaction was quenched with triethylamine (0.1 mL) and filtered. The filtrate was concentrated in vacuo to give a residue, which was purified by flash column chromatography.

4.3.1. Methyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4-tri-*O*-benzoyl-6-*S*-phenyl-6-thio-β-D-glucopyranosyl)-α-D-glucopyranoside (26). Chromatography with petroleum ether–EtOAc (4:1) afforded **26** as a colorless syrup (60%): $[\alpha]_D^{19}$=+32.8 (*c* 1.03, $CHCl_3$); ν_{max}(neat) 2939, 1730, 1452, 1316, 1282, 1264, 1110, 1095, 1070, 1027 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 8.00–7.20 (m, 35H), 6.09 (t, 1H, *J*=9.9 Hz), 5.84 (t, 1H, *J*=9.6 Hz), 5.52 (t, 1H, *J*=9.9 Hz), 5.48 (t, 1H, *J*=9.6 Hz), 5.34 (t, 1H, *J*=10.2 Hz), 5.13 (dd, 1H, *J*=10.2, 3.6 Hz), 5.00 (d, 1H, *J*=3.6 Hz), 4.88 (d, 1H, *J*=8.0 Hz), 4.24 (m, 1H), 4.01 (dd, 1H, *J*=11.5, 1.7 Hz), 3.92 (m, 1H), 3.72 (dd, 1H, *J*=11.3, 7.4 Hz), 3.64 (m, 1H), 3.20 (m, 4H); ESIMS *m/z*: 1097 (M+Na+1). Anal. Calcd for $C_{61}H_{52}O_{16}S\cdot H_2O$: C, 67.15; H, 4.99. Found: C, 67.39; H, 5.09.

4.3.2. Cholesterol-3-yl 2,3,4-tri-*O*-benzoyl-6-*S*-phenyl-6-thio-β-D-glucopyranoside (27). Chromatography with petroleum ether–EtOAc (10:1) afforded **27** as a white foam (56%): $[\alpha]_D^{26}$=+30.6 (*c* 1.18, $CHCl_3$); ν_{max}(KBr) 3071, 2944, 2867, 1733, 1602, 1584, 1451, 1378, 1315, 1286 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.98–7.18 (m, 20H), 5.82 (t, 1H, *J*=9.6 Hz), 5.48 (m, 2H), 5.28 (m, 1H), 4.88 (d, 1H, *J*=8.0 Hz), 3.93 (m, 1H), 3.51 (m, 1H), 3.21 (d, 2H, *J*=5.5 Hz), 0.93, 0.92, 0.89, 0.87, 0.67 (each s, each 3H); EIMS *m/z*: 584, 567, 368, 105. Anal. Calcd for $C_{60}H_{72}O_8S$: C, 75.60; H, 7.61. Found: C, 75.79; H, 8.03.

4.4. Procedure for preparation of 28–33

A solution of the trichloroacetimidate donor (**20**, **16**, or **17**, 0.37 mmol), aglycone (**1**, **5**, **24**, or **25**, 0.56–0.74 mmol), and 4 Å MS (1.0 g) in dry CH_2Cl_2 (10 mL) was stirred at room temperature for 30 min and then cooled to −50°C. A solution of TMSOTf (0.93 mL, 0.08 M) in CH_2Cl_2 was slowly added to the reaction. After being stirred for another 30 min, the reaction was quenched with triethylamine (0.1 mL) and filtered. The filtrates were concentrated in vacuo to give a residue, which was purified by flash column chromatography.

4.4.1. Cholesterol-3-yl 4-*O*-acetyl-2,3-di-*O*-benzoyl-6-*S*-phenyl-6-thio-β-D-glucopyranoside (28). Chromatography with petroleum ether–EtOAc (10:1) afforded **28** as a white foam (82%): $[\alpha]_D^{24}$=+57.3 (*c* 1.06, $CHCl_3$); ν_{max}(KBr) 3063, 2937, 1732, 1452, 1377, 1278 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.90–7.20 (m, 15H), 5.60 (t, 1H, *J*=9.6 Hz), 5.37 (dd, 1H, *J*=9.9, 9.6 Hz), 5.22 (m, 2H), 4.77 (d, 1H, *J*=8.0 Hz), 3.78 (m, 1H), 3.45 (m, 1H), 3.13 (d, 2H, *J*=5.5 Hz), 1.94 (s, 3H); EIMS *m/z*: 892, 891, 522, 505, 368, 105. Anal. Calcd for $C_{55}H_{70}O_8S$: C, 74.12; H, 7.92. Found: C, 73.75, H, 7.82.

4.4.2. Diosgenin-3-yl 4-*O*-acetyl-2,3-di-*O*-benzoyl-6-*S*-phenyl-6-thio-β-D-glucopyranoside (29). Chromatography with petroleum ether–EtOAc (6:1) afforded **29** as a white foam (85%): $[\alpha]_D^{29}$=−20.6 (*c* 1.15, $CHCl_3$); ν_{max}(KBr) 3063, 2952, 2872, 1751, 1732, 1602, 1585, 1452, 1378, 1280 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.92–7.21 (m, 15H), 5.62 (t, 1H, *J*=9.9 Hz), 5.39 (t, 1H, *J*=9.9 Hz), 5.23 (m, 2H), 4.80 (d, 1H, *J*=7.7 Hz), 3.81 (m, 1H), 3.47 (m, 2H), 3.38 (t, 1H, *J*=10.9 Hz), 3.15 (d, 2H, *J*=5.5 Hz), 1.96 (s, 3H); EIMS *m/z*: 919, 918, 522, 505, 396, 105. Anal. Calcd for $C_{55}H_{66}O_{10}S\cdot H_2O$: C, 70.49; H, 7.31. Found: C, 70.27; H, 7.03.

4.4.3. 1,2;3,4-Di-*O*-isopropylidene-6-*O*-(2,3,4-tri-*O*-acetyl-6-*S*-phenyl-6-thio-β-D-galactopyranosyl)-α-D-galactopyranoside (30). Chromatography with petroleum ether–EtOAc (4:1–3:1) afforded **30** as a white foam (92%): $[\alpha]_D^{27}$=−52.3 (*c* 1.10, $CHCl_3$); ν_{max}(KBr) 2990, 2939, 1754, 1483, 1440, 1374, 1253, 1220 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.41–7.20 (m, 5H), 5.50 (m, 2H), 5.19 (dd, 1H, *J*=10.4, 8.0 Hz), 4.98 (dd, 1H, *J*=10.4, 3.3 Hz), 4.59 (dd, 1H, *J*=8.0, 2.5 Hz), 4.52 (d, 1H, *J*=8.0 Hz), 4.29 (dd, 1H, *J*=5.0, 2.5 Hz), 4.18 (dd, 1H, *J*=8.0, 1.9 Hz), 4.01 (dd, 1H, *J*=11.3, 3.3 Hz), 3.94 (dd, 1H, *J*=7.4, 1.7 Hz), 3.68 (m, 2H), 3.18 (dd, 1H, *J*=14.0, 6.9 Hz), 2.95 (dd, 1H, *J*=14.0, 6.9 Hz), 2.12, 2.07, and 1.98 (each s, each 3H), 1.51, 1.46, 1.34, and 1.32 (each s, each 3H); EIMS *m/z*: 641, 640, 625, 381. Anal. Calcd for $C_{30}H_{40}O_{13}S$: C, 56.24; H, 6.29. Found: C, 55.78; H, 6.79.

4.4.4. Methyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4-tri-*O*-acetyl-6-*S*-phenyl-6-thio-β-D-galactopyranosyl)-α-D-glucopyranoside (31). Chromatography with petroleum ether–EtOAc (2:1–1:1) afforded **31** as a white foam (63%): $[\alpha]_D^{27}$=+30.7 (*c* 0.97, $CHCl_3$); ν_{max}(KBr) 3065, 2931, 2853, 1754, 1732, 1602, 1452, 1370, 1282, 1221 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 8.00–7.22 (m, 20H), 6.14 (t, 1H, *J*=9.3 Hz), 5.49 (d, 1H, *J*=3.0 Hz), 5.42 (t, 1H, *J*=9.8 Hz), 5.25 (m, 3H), 4.98 (dd, 1H, *J*=10.4, 3.3 Hz), 4.47 (d, 1H, *J*=8.0 Hz), 4.28 (t-like, 1H), 4.07 (d, 1H, *J*=9.6 Hz), 3.65 (m, 2H), 3.46 (s, 3H), 3.12 (dd, 1H, *J*=14.0, 6.9 Hz), 2.90 (dd, 1H, *J*=14.0, 6.6 Hz), 2.10 (s, 6H), 1.99 (s, 3H); EIMS *m/z*: 887, 886, 503, 381, 105. Anal. Calcd for $C_{46}H_{46}O_{16}S$: C, 62.35; H, 5.23. Found: C, 62.78; H, 5.64.

4.4.5. Methyl 2,3,4-tri-*O*-benzoyl-6-*O*-(2,3,4-tri-*O*-benzoyl-6-*S*-phenyl-6-thio-β-D-galactopyranosyl)-α-D-glucopyranoside (32). Chromatography with petroleum ether–EtOAc (3:1) gave **32** as a white foam (96%): $[\alpha]_D^{28}$=+72.4 (*c* 1.04, $CHCl_3$); ν_{max}(KBr) 3375, 1730, 1452, 1282, 1264, 1178, 1109, 1069 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 8.05–7.21 (m, 35H), 6.10 (t, 1H, *J*=9.9 Hz), 5.96 (d, 1H, *J*=3.3 Hz), 5.78 (dd, 1H, *J*=10.4, 8.0 Hz), 5.54 (dd, 1H, *J*=10.3, 3.3 Hz), 5.35 (t, 1H, *J*=9.9 Hz), 5.09 (dd, 1H, *J*=10.2, 3.6 Hz), 4.93 (d, 1H, *J*=3.6 Hz), 4.83 (d, 1H, *J*=8.0 Hz), 4.28 (t, 1H, *J*=8.4 Hz), 4.14 (d, 1H, *J*=9.9 Hz), 3.95 (t, 1H, *J*=6.7 Hz), 3.76 (dd, 1H, *J*=11.3, 7.7 Hz), 3.23 (dd, 1H, *J*=14.0, 7.2 Hz), 3.13 (s, 3H), 3.07 (dd, 1H,

J=14.0, 6.3 Hz); ESIMS m/z: 1096 (M+Na). Anal. Calcd for $C_{61}H_{52}O_{16}S$: C, 68.27; H, 4.88. Found: C, 68.33; H, 5.17.

4.4.6. Cholesterol-3-yl 2,3,4-tri-*O*-benzoyl-6-*S*-phenyl-6-thio-β-D-galactopyranoside (33). Chromatography with petroleum ether–EtOAc (10:1) afforded **33** as a white amorphous solid (94%): $[\alpha]_D^{28}$=+90.6 (c 0.66, $CHCl_3$); ν_{max}(KBr) 2938, 1728, 1452, 1285, 1263, 1093 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 8.10–7.21 (m, 20H), 5.94 (d, 1H, J=3.0 Hz), 5.73 (dd, 1H, J=10.3, 7.8 Hz), 5.52 (dd, 1H, J=10.4, 3.3 Hz), 5.25 (d, 1H, J=4.7 Hz), 4.82 (d, 1H, J= 8.0 Hz), 3.98 (t, 1H, J=6.6 Hz), 3.56 (m, 1H), 3.27 (dd, 1H, J=14.2, 7.6 Hz), 3.13 (dd, 1H, J=14.0, 5.8 Hz); EIMS m/z: 831, 584, 567, 444, 368, 105. Anal. Calcd for $C_{60}H_{72}O_8S$: C, 75.60; H, 7.61. Found: C, 75.77; H, 7.55.

4.5. Procedure for preparation of 34–40

A suspension of the trichloroacetimidate donor (**21**–**23** or **17**, 2.10 mmol), acceptor (**9** or **11**, 1.05 mmol), and 4 Å MS (2.0 g) in dry CH_2Cl_2 (15 mL) was stirred at room temperature for 30 min and then cooled to −50°C. A solution of TMSOTf (1.0 mL, 0.21 M) in CH_2Cl_2 was slowly added to the reaction. After being stirred for another 30 min, the reaction was quenched with triethylamine (0.2 mL) and filtered. The filtrates were concentrated in vacuo to give a residue, which was purified by flash column chromatography.

4.5.1. Methyl 2,3-di-*O*-acetyl-6-*S*-phenyl-6-thio-4-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl)-α-D-glucopyranoside (34). Chromatography with petroleum ether–EtOAc (3:1) afforded **34** as a colorless syrup (70%): $[\alpha]_D^{13}$=+71.5 (c 1.22, $CHCl_3$); ν_{max}(neat) 3064, 1736, 1602, 1585, 1452, 1371, 1316, 1267, 1178, 1094, 1069, 1027 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 8.07–7.21 (m, 25H), 5.72 (t, 1H, J=9.6 Hz), 5.60 (t, 1H, J=9.6 Hz), 5.49 (t, 2H, J=9.3, 8.2 Hz), 4.82 (m, 3H), 4.64 (dd, 1H, J=12.1, 3.0 Hz), 4.43 (dd, 1H, J=12.4, 5.5 Hz), 3.98 (m, 1H), 3.88 (m, 2H), 3.41 (d, 1H, J=10.2 Hz), 3.29 (s, 3H), 3.11 (dd, 1H, J=13.5, 5.0 Hz), 2.05 and 1.97 (each s, each 3H); EIMS m/z: 948, 826, 579, 370,105. Anal. Calcd for $C_{51}H_{48}O_{16}S$: C, 64.55; H, 5.10. Found: C, 64.30, H, 5.14.

4.5.2. Methyl 2,3-di-*O*-acetyl-6-*S*-phenyl-6-thio-4-*O*-(2,3,4,6-tetra-*O*-acetyl-α-D-mannopyranosyl)-α-D-glucopyranoside (35). Chromatography with petroleum ether–EtOAc (2:1) afforded **35** as a colorless syrup (81%): $[\alpha]_D^{25}$=+86.3 (c 0.86, $CHCl_3$); ν_{max}(neat) 2945, 1751, 1584, 1483, 1440, 1372, 1228, 1190, 1118 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.41–7.18 (m, 5H), 5.51 (d, 1H, J= 2.5 Hz), 5.29 (m, 3H), 5.10 (dd, 1H, J=9.9, 4.9 Hz), 4.82 (m, 2H), 4.71 (m, 1H), 4.25 (dd, 1H, J=12.1, 4.4 Hz), 4.12 (dd, 1H, J=12.1, 2.7 Hz), 3.86 (m, 1H), 3.59 (m, 2H), 3.36 (s, 3H), 2.96 (dd, 1H, J=14.2, 8.4 Hz); EIMS m/z: 700, 370, 353, 331, 169. Anal. Calcd for $C_{31}H_{40}O_{16}S$: C, 53.14; H, 5.75. Found: C, 52.85, H, 5.96.

4.5.3. Methyl 2,3-di-*O*-acetyl-6-*S*-phenyl-6-thio-4-*O*-(2,3,4-tri-*O*-acetyl-α-L-rhamnopyranosyl)-α-D-glucopyranoside (36). Chromatography with petroleum ether–EtOAc (4:1–3:1) afforded **36** as a colorless syrup (92%): $[\alpha]_D^{29}$=+38.9 (c 1.17, $CHCl_3$); ν_{max}(neat) 2987, 1750, 1440, 1372, 1244, 1222, 1082, 1070, 1040 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.46–7.19 (m, 5H), 5.44 (t, 1H, J=9.3 Hz), 5.22 (dd, 1H, J=10.2, 3.0 Hz), 5.15 (m, 1H), 5.04 (t, 1H, J=9.9, 10.2 Hz), 4.86 (m, 2H), 4.80 (dd, 1H, J=10.2, 3.7 Hz), 3.98 (m, 1H), 3.86 (dd, 1H, J=9.9, 6.3 Hz), 3.73 (t, 1H, J=9.6 Hz), 3.52 (dd, 1H, J=13.5, 2.5 Hz), 3.39 (s, 3H), 3.12 (dd, 1H, J=13.5, 7.7 Hz), 2.14, 2.06, 2.05, 2.00 (each s, each 3H), 1.15 (d, 3H, J=6.3 Hz); EIMS m/z: 642, 611, 582, 511, 398, 353, 273. Anal. Calcd for $C_{29}H_{38}O_{14}S$: C, 54.19; H, 5.96. Found: C, 53.87, H, 6.14.

4.5.4. Methyl 3,4-*O*-isopropylidene-6-*S*-phenyl-6-thio-2-*O*-(2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl)-β-D-galactopyranoside (37). Chromatography with petroleum ether–EtOAc (5:1) afforded **37** as a white foam (99%): $[\alpha]_D^{25}$=+14.8 (c 1.04, $CHCl_3$); ν_{max}(KBr) 3375, 3246, 2987, 1732, 1602, 1452, 1267, 1110, 1069 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 8.01–7.21 (m, 25H), 5.91 (t, 1H, J= 9.6 Hz), 5.70 (t, 1H, J=9.9 Hz), 5.54 (t, 1H, J=9.3 Hz), 5.24 (d, 1H, J=8.0 Hz), 4.66 (dd, 1H, J=12.1, 3.3 Hz), 4.52 (dd, 1H, J=12.1, 5.2 Hz), 4.17 (m, 2H), 4.08 (dd, 1H, J=5.6, 1.8 Hz), 3.99 (t, 1H, J=6.1 Hz), 3.69 (m, 2H), 3.49 (s, 3H), 3.25 (m, 2H), 1.18 and 1.11 (each s, each 3H); EIMS m/z: 905, 904, 844, 579, 105. Anal. Calcd for $C_{50}H_{48}O_{14}\cdot 0.5H_2O$: C, 65.71; H, 5.40. Found: C, 65.87; H, 5.25.

4.5.5. Methyl 3,4-*O*-isopropylidene-6-*S*-phenyl-6-thio-2-*O*-(2,3,4-tri-*O*-acetyl-α-L-rhamnopyranosyl)-β-D-galactopyranoside (38). Chromatography with petroleum ether–EtOAc (5:1–3:1) afforded **38** as a white foam (99%): $[\alpha]_D^{25}$=−41.9 (c 1.13, $CHCl_3$); ν_{max}(KBr) 2989, 2940, 1750, 1373, 1224, 1137, 1077, 1048 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.42–7.21 (m, 5H), 5.31 (m, 1H), 5.24 (dd, 1H, J=10.0, 3.6 Hz), 5.17 (s, br, 1H), 5.06 (t, 1H, J=9.9 Hz), 4.17 (m, 4H), 3.80 (td, 1H, J=6.9, 1.7 Hz), 3.68 (t, 1H, J=6.9 Hz), 3.53 (s, 3H), 3.32 (m, 2H), 2.15, 2.06 and 1.98 (each s, each 3H), 1.50 and 1.27 (each s, each 3H), 1.18 (d, 3H, J=6.3 Hz); EIMS m/z: 598, 567, 538, 273, 153; HRMS m/z Calcd for $C_{28}H_{38}O_{12}S$: 598.16344. Found: 598.20774. Anal. Calcd for $C_{28}H_{38}O_{12}S\cdot 2.5H_2O$: C, 52.25; H, 6.73. Found: C, 52.13, H, 6.81.

4.5.6. Methyl 3,4-*O*-isopropylidene-6-*S*-phenyl-6-thio-2-*O*-(2,3,4-tri-*O*-benzoyl-6-*S*-phenyl-6-thio-β-D-galactopyranosyl)-β-D-galactopyranoside (39). Chromatography with petroleum ether–EtOAc (5:1) afforded **39** as a white foam (99%): $[\alpha]_D^{25}$=+60.8 (c 0.98, $CHCl_3$); ν_{max}(KBr) 1732, 1602, 1452, 1283, 1263, 1069, 1026 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 8.10–7.21 (m, 25H), 5.98 (d, 1H, J=3.3 Hz), 5.75 (dd, 1H, J=10.4, 8.0 Hz), 5.56 (dd, 1H, J=10.4, 3.3 Hz), 5.08 (d, 1H, J=8.2 Hz), 4.22 (d, 1H, J=8.0 Hz), 4.02 (m, 3H), 3.68 (m, 2H), 3.55 (s, 3H), 3.33–3.10 (m, 4H), 1.11 and 1.07 (each s, each 3H); EIMS m/z: 892, 861, 783, 567, 105. Anal. Calcd for $C_{49}H_{48}O_{12}S_2$: C, 65.90; H, 5.42. Found: C, 65.89, H, 5.25.

4.5.7. Methyl 2,3-di-*O*-acetyl-6-*S*-phenyl-6-thio-4-*O*-(2,3,4-tri-*O*-benzoyl-6-*S*-phenyl-6-thio-β-D-galactopyranosyl)-α-D-glucopyranoside (40). Chromatography with petroleum ether–EtOAc (4:1) afforded **40** as a white foam (83%): $[\alpha]_D^{25}$=+74.5 (c 1.00, $CHCl_3$); ν_{max}(KBr) 3063, 1733, 1452, 1282, 1245, 1027 cm^{-1}; δ_H (300 MHz,

$CDCl_3$) 8.06–7.19 (m, 25H), 5.92 (d, 1H, J=3.0 Hz), 5.64 (dd, 1H, J=10.4, 7.8 Hz), 5.54 (m, 1H), 5.26 (dd, 1H, J=10.4, 3.3 Hz), 4.90 (m, 2H), 4.69 (d, 1H, J=7.7 Hz), 4.03 (m, 1H), 3.93 (t, 1H, J=9.5 Hz), 3.80 (t, 1H, J=6.9 Hz), 3.40 (dd, 1H, J=13.3, 3.0 Hz), 3.34 (s, 3H), 3.17 (dd, 1H, J=13.9, 6.7 Hz), 3.05 (m, 2H), 2.09 and 1.95 (each s, each 3H); EIMS *m/z*: 937, 936, 660, 567, 505, 353, 105. Anal. Calcd for $C_{50}H_{48}O_{14}S_2$: C, 64.09; H, 5.16. Found: C, 63.83, H, 5.45.

4.5.8. Methyl 2,3,4-tri-*O*-benzoyl-6-*O*-(3,4-di-*O*-acetyl-6-*S*-phenyl-6-thio-α-D-galactopyranosyl)-α-D-glucopyranoside (41). A white foam, 32%. $[\alpha]_D^{27}$=+56.8 (*c* 1.71, $CHCl_3$); ν_{max}(KBr) 3518, 2939, 1731, 1602, 1452, 1373, 1317, 1282, 1252 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 8.01–7.21 (m, 20H), 6.19 (t, 1H, J=9.5 Hz), 5.83 (t, 1H, J=9.9 Hz), 5.47 (d, 1H, J=2.7 Hz), 5.30 (m, 2H), 4.89 (dd, 1H, J=10.2, 3.6 Hz), 4.22 (m, 3H), 3.95 (dd, 1H, J=10.2, 7.7 Hz), 3.69 (t, 1H, J=7.2 Hz), 3.64 (dd, 1H, J=11.3, 3.8 Hz), 3.50 (s, 3H), 3.18 (dd, 1H, J=14.0, 7.4 Hz), 2.95 (dd, 1H, J=14.0, 5.8 Hz), 2.12 and 2.07 (each s, each 3H); EIMS *m/z*: 845, 844, 507, 503, 339, 105. Anal. Calcd for $C_{44}H_{44}O_{15}S$: C, 62.55; H, 5.25. Found: C, 62.23; H, 5.57.

4.6. Representative procedure for the conversion of 6-phenylsulfides to methyl glucuronides or galacturonides

To a solution of **36** (436 mg, 0.68 mmol) in CCl_4 (10 mL) at 0°C were added pyridine (0.11 mL) followed by slow addition of SO_2Cl_2 (0.11 mL). The resulting solution was stirred at this temperature for 5 h, and then diluted with CH_2Cl_2. The mixture was washed with water, dried over $MgSO_4$, and concentrated in vacuo to give a residue, which was used in the next step without any purification. The above crude material was dissolved in MeOH–H_2O–CH_2Cl_2 (2:1:1, 10 mL), then pyridine (0.11 mL) and $HgCl_2$ (1.8 g) was added. After the mixture was stirred for 48 h at room temperature, the solvent was evaporated and the residue was dissolved in EtOAc–Et_2O (1:1, 50 mL). The resulting solution was then washed with half saturated NaCl solution, dried over $MgSO_4$, and concentrated in vacuo. The residue was purified by flash column chromatography (petroleum ether–EtOAc 3:1) to afford **48** (349 mg, 88%) as a white foam.

4.6.1. Methyl (1,2;3,4-di-*O*-isopropylidene-α-D-galactopyranoside)uronate (7). Chromatography with petroleum ether–EtOAc (8:1–5:1) gave **7** as a white foam (66%): $[\alpha]_D^{28}$=−74.3 (*c* 1.08, $CHCl_3$); ν_{max}(KBr) 2990, 2939, 1772, 1737, 1456, 1440, 1384, 1375, 1258, 1214, 1168, 1143 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 5.67 (d, 1H, J=5.0 Hz, H-1), 4.68 (dd, 1H, J=7.7, 2.5 Hz, H-2), 4.59 (dd, 1H, J=7.7, 2.2 Hz, H-3), 4.46 (d, 1H, J=2.2 Hz, H-4), 4.38 (q, 1H, J=2.5 Hz, H-5), 3.83 (s, 3H), 1.53 and 1.46 (each s, each 3H), 1.35 (s, 6H); EIMS *m/z*: 287, 273, 219, 43; HRMS *m/z* Calcd for $C_{12}H_{17}O_7$ (M−CH_3): 273.09741. Found: 273.09852. Anal. Calcd for $C_{13}H_{20}O_7{\cdot}0.5H_2O$: C, 52.50; H, 7.12. Found: C, 52.00; H, 6.70.

4.6.2. Methyl [methyl (2,3,4-tri-*O*-benzoyl-β-D-glucopyranosyl)uronate]-(1→6)-2,3,4-tri-*O*-benzoyl-α-D-glucopyranoside (42). Chromatography with petroleum ether–EtOAc (3:1) gave **42** as a white foam (85%): $[\alpha]_D^{28}$=+11.8 (*c* 1.20, $CHCl_3$); ν_{max}(KBr) 3071, 2955, 1736, 1602, 1452, 1316, 1280, 1263 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.99–7.22 (m, 30H), 6.09 (t, 1H, J=9.9 Hz), 5.93 (t, 1H, J=9.3 Hz), 5.68 (t, 1H, J=9.3 Hz), 5.59 (t, 1H, J=9.3 Hz), 5.34 (t, 1H, J=9.9 Hz), 5.11 (dd, 1H, J=10.2, 3.6 Hz), 5.00 (d, 1H, J=7.7 Hz), 4.92 (d, 1H, J=3.6 Hz), 4.35 (d, 1H, J=9.6 Hz), 4.23 (m, 1H), 4.16 (m, 1H), 3.79 (dd, 1H, J=11.5, 8.2 Hz), 3.67 (s, 3H), 3.10 (s, 3H); ESIMS *m/z*: 1033 (M+Na+1). Anal. Calcd for $C_{56}H_{48}O_{18}{\cdot}0.5H_2O$: C, 66.07; H, 4.85. Found: C, 66.22; H, 5.01.

4.6.3. Methyl (diosgenin-3-yl 4-*O*-acetyl-2,3-di-*O*-benzoyl-β-D-glucopyranoside) uronate (43). Chromatography with petroleum ether–EtOAc (8:1–5:1) afforded **43** as a white foam (68%): $[\alpha]_D^{26}$=−38.5 (*c* 1.12, $CHCl_3$); ν_{max}(KBr) 2953, 2874, 1762, 1733, 1602, 1452, 1376, 1315, 1276, 1225, 1178, 1096 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 7.94–7.36 (m, 10H), 5.70 (t, 1H, J=9.6 Hz), 5.45 (m, 2H), 4.88 (d, 1H, J=7.7 Hz), 4.39 (m, 1H), 4.24 (m, 3H), 3.80 (s, 3H), 3.46 (m, 1H), 3.37 (t, 1H, J=10.2 Hz), 1.95 (s, 3H); EIMS *m/z*: 853, 441, 105. Anal. Calcd for $C_{50}H_{62}O_{12}{\cdot}0.5H_2O$: C, 69.50; H, 7.35. Found: C, 69.23; H, 7.05.

4.6.4. Methyl [methyl (2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl)uronate]-(1→6)-2,3,4-tri-*O*-benzoyl-α-D-glucopyranoside (44). Chromatography with petroleum ether–EtOAc (3:1) gave **44** as a white foam (86%): $[\alpha]_D^{28}$=+88.0 (*c* 1.13, $CHCl_3$); ν_{max}(KBr) 3065, 1732, 1602, 1452, 1280, 1267, 1178, 1094, 1069 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 8.10–7.20 (m, 30H), 6.18 (d, 1H, J=3.3 Hz), 6.10 (t, 1H, J=9.6 Hz), 5.86 (dd, 1H, J=10.2, 7.7 Hz), 5.64 (dd, 1H, J=10.4, 2.5 Hz), 5.35 (t, 1H, J=9.6 Hz), 5.08 (dd, 1H, J=10.2, 3.6 Hz), 4.96 (d, 1H, J=8.0 Hz), 4.83 (d, 1H, J=3.3 Hz), 4.29 (m, 2H), 3.70 (s, 3H), 3.28 (d, 1H, J=14.3 Hz), 3.12 (m, 4H); ESIMS *m/z*: 1031 (M+Na). Anal. Calcd for $C_{56}H_{48}O_{18}{\cdot}2.5H_2O$: C, 63.81; H, 5.07. Found: C, 63.91, H, 4.62.

4.6.5. Methyl (cholesterol-3-yl 2,3,4-tri-*O*-benzoyl-β-D-galactopyranoside)uronate (45). Chromatography with petroleum ether–EtOAc (10:1–8:1) gave **45** as a white amorphous solid (65%): $[\alpha]_D^{24}$=+73.5 (*c* 1.05, $CHCl_3$); ν_{max}(KBr) 2952, 2869, 1735, 1452, 1282, 1262, 1177, 1108, 1095 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 8.13–7.26 (m, 15H), 6.18 (d, 1H, J=2.2 Hz), 5.78 (dd, 1H, J=10.3, 8.1 Hz), 5.59 (dd, 1H, J=10.4, 3.3 Hz), 4.93 (d, 1H, J=8.0 Hz), 4.60 (d-like, 1H, J=1.1 Hz), 4.38 (m, 1H), 4.22 (d, 1H, J=2.5 Hz), 3.73 (s, 3H); EIMS *m/z*: 886, 503, 402, 366, 105. Anal. Calcd for $C_{55}H_{68}O_{10}{\cdot}0.5H_2O$: C, 73.55; H, 7.74. Found: C, 73.70; H, 7.82.

4.6.6. Methyl 2,3,4,6-tetra-*O*-benzoyl-β-D-glucopyranosyl-(1→4)-(methyl 2,3-di-*O*-acetyl-α-D-glucopyranoside)-uronate (46). Chromatography with petroleum ether–EtOAc (2:1) gave **46** as a white foam (88%): $[\alpha]_D^{26}$=+26.2 (*c* 1.13, $CHCl_3$); ν_{max}(KBr) 2958, 1736, 1453, 1371, 1268, 1069 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 8.10–7.25 (m, 20H), 5.90 (t, 1H, J=9.6 Hz), 5.64 (t, 1H, J=9.6 Hz), 5.51 (m, 1H), 5.44 (dd, 1H, J=9.6, 8.0 Hz), 5.07 (d, 1H, J=8.0 Hz), 4.90 (d, 1H, J=3.8 Hz), 4.81 (dd, 1H, J=10.2, 3.8 Hz), 4.64 (dd, 1H, J=12.2, 2.9 Hz), 4.45 (dd, 1H, J=12.2, 5.8 Hz), 4.15 (m, 3H), 3.40 and 3.38 (each s, each 3H),

2.05 and 1.98 (each s, each 3H); EIMS *m/z*: 853, 793, 579, 105. Anal. Calcd for $C_{46}H_{44}O_{18}$: C, 62.44; H, 5.01. Found: C, 62.03; H, 5.01.

4.6.7. Methyl 2,3,4,6-tetra-*O*-acetyl-α-D-mannopyranosyl-(1→4)-(methyl 2,3-di-*O*-acetyl-α-D-glucopyranoside)-uronate (47). Chromatography with petroleum ether–EtOAc (2:1) gave **47** as a white foam (86%): $[\alpha]_D^{26}$= +89.0 (*c* 0.98, $CHCl_3$); ν_{max}(KBr) 2958, 1755, 1442, 1373, 1240, 1049 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 5.49 (d, 1H, *J*= 2.2 Hz), 5.37 (t, 1H, *J*=9.8 Hz), 5.23 (t, 1H, *J*=9.9 Hz), 5.17 (dd, 1H, *J*=9.9, 3.9 Hz), 4.96 (d, 1H, *J*=3.8 Hz), 4.90 (dd, 1H, *J*=10.2, 3.8 Hz), 4.52 (m, 1H), 4.26 (d, 1H, *J*= 9.9 Hz), 4.20 (m, 1H), 4.12 (dd, 1H, *J*=12.4, 2.5 Hz), 3.84 (s, 3H), 3.69 (t, 1H, *J*=9.3 Hz), 3.65 (m, 1H), 3.40 (s, 3H); EIMS *m/z*: 605, 545, 331, 43. Anal. Calcd for $C_{26}H_{36}O_{18}\cdot 0.5H_2O$: C, 48.37; H, 5.78. Found: C, 48.25; H, 5.63.

4.6.8. Methyl 2,3,4-tri-*O*-acetyl-α-L-rhamnopyranosyl-(1→4)-(methyl 2,3-di-*O*-acetyl-α-D-glucopyranoside)-uronate (48). Chromatography with petroleum ether–EtOAc (3:1–2:1) gave **48** as a white foam (89%): $[\alpha]_D^{26}$= +43.1 (*c* 1.11, $CHCl_3$); ν_{max}(KBr) 1751, 1444, 1374, 1222, 1049 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 5.46 (t, 1H, *J*=9.6 Hz), 5.12 (dd, 1H, *J*=10.2, 3.3 Hz), 5.03 (m, 1H), 4.99 (t, 1H, *J*=10.2 Hz), 4.92 (d, 1H, *J*=3.6 Hz), 4.78 (dd, 1H, *J*=10.2, 3.6 Hz), 4.77 (m, 1H), 4.26 (d, 1H, *J*=9.9 Hz), 3.97 (t, 1H, *J*=9.6 Hz), 3.83 (m, 4H), 3.44 (s, 3H), 1.12 (d, 3H, *J*= 6.1 Hz); EIMS *m/z*: 547, 487, 273, 43. Anal. Calcd for $C_{24}H_{34}O_{16}\cdot H_2O$: C, 48.32; H, 6.09. Found: C, 48.15; H, 5.69.

4.6.9. Methyl [methyl (2,3,4-tri-*O*-benzoyl-β-D-galactopyranosyl)uronate]-(1→4)-(methyl 2,3-di-*O*-acetyl-α-D-glucopyranoside)uronate (49). Chromatography with petroleum ether–EtOAc (2:1–1:1) gave **49** as a white foam (72%): $[\alpha]_D^{27}$=+138.3 (*c* 0.90, $CHCl_3$); ν_{max}(KBr) 2950, 1736, 1602, 1452, 1373, 1283, 1262 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 8.05–7.26 (m, 15H), 6.11 (d, 1H, *J*=2.5 Hz), 5.58 (m, 3H), 5.08 (d, 1H, *J*=7.4 Hz), 4.94 (d, 1H, *J*=3.6 Hz), 4.87 (dd, 1H, *J*=10.4, 3.6 Hz), 4.55 (s, 1H), 4.23 (t, 1H, *J*=9.5 Hz), 4.13 (d, 1H, *J*=9.9 Hz), 3.72 (s, 3H), 3.50 (s, 3H), 3.39 (s, 3H), 2.19 and 2.08 (each s, each 3H); EIMS *m/z*: 505, 381, 289, 105. Anal. Calcd for $C_{40}H_{40}O_{18}\cdot H_2O$: C, 58.11; H, 5.13. Found: C, 58.14; H, 5.63.

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References

1. (a) Bhavanandan, V. P.; Davidson, E. A. In *Glycoconjugates*, Allen, H. J., Kisailus, E. C., Eds.; Marcel Dekker: New York, 1992; p. 167. (b) Kjellen, L.; Lindahl, U. *Annu. Rev. Biochem.* **1991**, *60*, 443.
2. (a) Lindberg, B.; Kenne, L. *The Polysaccharides*, Vol. 2; Academic: New York, 1985 p 287. (b) Lindberg, B. *Adv. Carbohydr. Chem. Biochem.* **1990**, *48*, 279.
3. Daas, P. J. H.; Voragen, A. G. J.; Schols, H. A. *Carbohydr. Res.* **2000**, *326*, 120 and references cited therein.
4. Hostettmann, K.; Marston, A. *Saponins*; Cambridge University: Cambridge, 1995.
5. For a comprehensive review on glucuronide synthesis, see: Stachulski, A. V.; Jenkins, A. N. *Nat. Prod. Rep.* **1998**, 173.
6. For recent examples on coupling using glycuronide donors, see: (a) Rukhman, I.; Yudovich, L.; Nisnevich, G.; Gutman, A. L. *Synthesis* **2000**, *9*, 1241. (b) Ferguson, J. R.; Harding, J. R.; Lumbard, K. W.; Scheinmann, F.; Stachulski, A. V. *Tetrahedron Lett.* **2000**, *41*, 389. (c) Suzuki, T.; Mabuchi, K.; Fukazawa, N. *Bioorg. Med. Chem. Lett.* **1999**, *9*, 659. (d) Werschkun, B.; Gorziza, K.; Thiem, J. *J. Carbohydr. Chem.* **1999**, *18*, 629.
7. For synthesis of glucuronide containing oligosaccharides by oxidation at a later stage, see for examples: (a) Yeung, B. K. S.; Hill, D. C.; Janicka, M.; Petillo, P. A. *Org. Lett.* **2000**, *2*, 1279. (b) Nilsson, M.; Svahn, C. M.; Westman, J. *Carbohydr. Res.* **1993**, *246*, 161. (c) Slaghek, T. M.; Hypponen, T. K.; Ogawa, T.; Kamerling, J. P.; Vliegenhart, J. F. G. *Tetrahedron Lett.* **1993**, *34*, 7939. (d) Slaghek, T. M.; Nakahara, Y.; Ogawa, T. *Tetrahedron Lett.* **1992**, *33*, 4971. (e) Ichikawa, Y.; Ichikawa, K.; Kuzuhara, H. *Carbohydr. Res.* **1985**, *141*, 273.
8. For synthesis of galacturonide containing oligosaccharides by oxidation at a later stage, see for examples: (a) Magaud, D.; Dolmazon, R.; Anker, D.; Doutheau, A. *Org. Lett.* **2000**, *2*, 2275. (b) Magaud, D.; Grandjean, C.; Doutheau, A.; Anker, D.; Shevchik, V.; Cotte-Pattat, N.; Robert-Baudouy, J. *Tetrahedron Lett.* **1997**, *38*, 241. (c) Nakahara, Y.; Ogawa, T. *Carbohydr. Res.* **1990**, *205*, 147 and references cited therein. (d) Nakahara, Y.; Ogawa, T. *Tetrahedron Lett.* **1987**, *28*, 2731. (e) Lönn, H.; Lönngren, J. *Carbohydr. Res.* **1984**, *132*, 39.
9. (a) Garegg, P. J.; Olsson, L.; Oscarson, S. *J. Org. Chem.* **1995**, *60*, 2200. (b) Krog-Jensen, C.; Oscarson, S. *Carbohydr. Res.* **1998**, *308*, 287.
10. Yu, B.; Zhu, X.; Hui, Y. *Org. Lett.* **2000**, *2*, 2539.
11. Gan, L.; Whistler, R. L. *Carbohydr. Res.* **1990**, *206*, 65.
12. Nakagawa, I.; Hata, T. *Tetrahedron Lett.* **1975**, *17*, 1409.
13. (a) Fortes, C. C.; Fortes, H. C.; Goncalves, D. C. R. G. *J. Chem. Soc., Chem. Commun.* **1982**, 857. (b) Fortes, C. C.; Souto, C. R. O.; Okino, E. A. *Synth. Commun.* **1991**, *21*, 2045.
14. Kovac, P.; Alfoldi, J.; Kosik, M. *Chem. Zvesti* **1974**, *28*, 820.
15. Williams, D. R.; Sit, S.-Y. *J. Am. Chem. Soc.* **1984**, *106*, 2949.
16. (a) Nicolaou, K. C.; Ladduwahetty, T.; Randall, J. L.; Chucholowski, A. *J. Am. Chem. Soc.* **1986**, *108*, 2466. (b) Ito, Y.; Ogawa, T. *Tetrahedron Lett.* **1987**, *28*, 2723. (c) Preuss, R.; Schmidt, R. R. *Synthesis* **1988**, 694. (d) Hashimoto, S.; Yanagiya, Y.; Honda, T.; Ikegami, S. *Chem. Lett.* **1992**, 1511. (e) Roush, W. R.; Sebesta, D. P.; Bennett, C. E. *Tetrahedron* **1997**, *53*, 8825. (f) Roush, W. R.; Sebesta, D. P.; James, R. A. *Tetrahedron* **1997**, *53*, 8837.
17. Harada, T.; Yamada, H.; Tsukamoto, H.; Takahashi, T. *J. Carbohydr. Chem.* **1995**, *14*, 165.
18. Betaneli, V. I.; Ott, A. Y.; Brukhanova, O. V.; Kochetkov, N. K. *Carbohydr. Res.* **1988**, *179*, 37.
19. Zuurmond, H. M.; van der Meer, P. H.; van der Klein, P. A. M.; van der Marel, G. A.; van Boom, J. H. *J. Carbohydr. Chem.* **1993**, *12*, 1091.
20. Garegg, P. J. *Adv. Carbohydr. Chem. Biochem.* **1995**, *52*, 170.
21. (a) Schmidt, R. R. *Angew. Chem., Int. Ed. Engl.* **1986**, *25*, 212. (b) Schmidt, R. R.; Kinzy, W. *Adv. Carbohydr. Chem. Biochem.* **1994**, *50*, 21.

22. (a) Lönn, H. *Carbohydr. Res.* **1985**, *105*, 115. (b) Lönn, H. *J. Carbohydr. Chem.* **1987**, *6*, 301.
23. (a) Garegg, P. J.; Kvarnstrom, I. *Acta Chem. Scand. B* **1976**, *30*, 655. (b) Garegg, P. J.; Konradsson, P.; Kvarnström, I.; Norberg, T.; Svensson, S. C. T.; Wigilius, B. *Acta Chem. Scand. B* **1985**, *39*, 569.
24. Yang, Z.; Lin, W.; Yu, B. *Carbohydr. Res.* **2000**, *329*, 879 and references therein.
25. Deng, S.; Yu, B.; Xie, J.; Hui, Y. *J. Org. Chem.* **1999**, *64*, 7265 and references therein.
26. Schmidt, R. R.; Michel, J.; Roos, M. *Liebigs Ann. Chem.* **1984**, 1343.
27. van der Ven, J. G. M.; Wijikmans, J. C. H. M.; Kamerling, J. P.; Vliegenthart, J. F. G. *Carbohydr. Res.* **1994**, *254*, 43.
28. Kitagawa, I.; Baek, N. I.; Ohashi, K.; Sakagami, M.; Yoshikawa, M.; Shibuya, H. *Chem. Pharm. Bull.* **1989**, *37*, 1131.