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Syntheses of cellotriose and cellotetraose analogues as transition state mimics for mechanistic studies of cellulases

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ABSTRACT

Cellotriose and cellotetraose analogues carrying cyclohexene rings were developed as molecular probes which are expected to mimic the transition state conformation of hydrolysis by cellulases. The cyclohexene ring was placed at the pyranose ring being expected to locate the −1 subsite of the enzyme. In order to evaluate these probes, sulfur derivatives of cellotriose and cellotetraose were also synthesized as the enzyme tolerant analogues which mimic the stable conformations of the natural cellulose. The binding assays using differential scanning calorimetry revealed that introduction of the cyclohexene ring is effective to the complexation with an endoglucanase, NCE5 from *Humicola insolens*.

1. Introduction

Bioethanol and biodiesel generate energies without consuming fossil-fuel, and are becoming very important from a view point of carbon neutral as well as global environment.[1] Ethanol production in these days depends on fermentations of edible grain such as corn, rice, and wheat, and that has led to serious increment of food prices in the markets.[2,3] Development of a technology for cellulose–cellobiose transformation[4] with cellulases (β-1,4-glucanases) must provide valuable and alternative process for glucose, because this methodology enables us to utilize inedible pulp, dead leaves, and grasses, not competing with grain.[5] These technologies require stable and effective cellulases. When we design artificial cellulase mutants with both higher stability and activity than natural enzymes, it is indispensable to understand the detailed reaction mechanism in chemical functional levels.[6]

Investigations of the transition state structure in the enzymatic reaction would be most informative to analyze the mechanism. However, observation of this stage is quite difficult because of its short lifetime. The enzymes force the substrates to be distorted, and the reaction mostly undergoes. Inactivation techniques by point mutations of the enzymes or altering pH methodologies have been employed to obtain meaningful substrate–enzyme complexes. In this article, we describe cyclohexene derivatives **1a**, **1b**, and **2** as the molecular probes for cellulases by expecting that the stable conformation of the cyclohexene ring moiety would reproduce the strained half-chair conformation at the transition state in the enzymatic hydrolysis (Figs. 1 and 2). In fact, a cyclohexene substructure is found in acarbose[7,8] which is a potent inhibitor against α-amylases and α-glucosidases. Several complexes between acarbose and glucoamylases[9] or α-glycosidases[10] have been registered in Protein Data Bank.[11] In other words, cellulose analogues with cyclohexene substructure would be ideal to make complex with cellulases. Derivatives based on this idea also can be applied for safe agrochemicals such as pesticides against wood harmful insects or antibiotics for wood decaying fungi.

By taking the synthetic feasibility into account, the cyclohexene ring moiety was planned to be linked with a thioether. Since anomerization at the reductive-terminal end makes the detailed discussions complex, it was fixed in forms of α- and β-methyl glycosides. In order to evaluate our hypothesis, sulfur substituted cellotriose derivatives **3a**, **3b**, and cellotetraose derivative **4**[12] were also synthesized as enzyme tolerant analogues mimicking the stable conformations of the celluloses.

In the present study, we set NCE5, a homologue of *Humicola grisea* EGIV,[13–15] isolated from *Humicola insolens* as the target cellulase. The binding ability was determined by differential scanning calorimetric (DSC) experiments. The K_I value of **1a**, **1b**, and **2** were compared with sulfur analogues **3a**, **3b**, and **4** in order to demonstrate the effectiveness of the cyclohexene ring residue.

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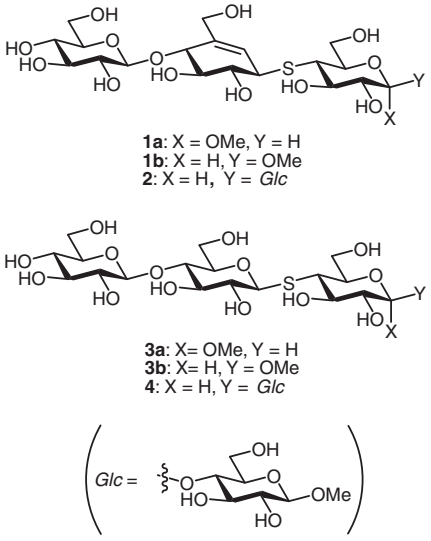


Figure 1. Structures of cyclohexene (**1a**, **1b**, **2**) and sulfur glycoside (**3a**, **3b**, **4**) analogues.

2. Results and discussion

2.1. Syntheses of transition state analogues

The syntheses of **1a, 1b**, and **2** commenced with phenyl hepta-*O*-acetyl-1-thio-β-D-cellobioside **5**[16] (Scheme 1). The acetyl esters of **5** were replaced with MPM ethers to afford **6** in 72% yield. Treatment of **6** with NBS under aqueous conditions liberated the anomeric hydroxyl group. The following reduction step with sodium borohydride in ethanol gave diol **7** quantitatively in two steps. When the reduction was performed in methanol, it proceeded very slowly and was not completed. The cyclohexene ring was then constructed according to a protocol by Halcomb[17] with some modifications. After protection of the primary alcohol by TBDMS ether (97% yield), *exo*-methylene was furnished to give **8** by Albright–Goldman oxidation,[18] followed by Wittig reaction in 92% overall yield. Desilylation with TBAF provided the corresponding primary alcohol, which was oxidized[19] to aldehyde **9** in 98% yield in two steps. Then, a vinyl group was introduced with vinylmagnesium bromide, giving a 1:1 diastereomeric mixture of allylic alcohol ***R*-10** and ***S*-10** in 90% yield. These were separated by medium pressured silica gel column chromatography. Stereochemistry of these compounds was determined after cyclization. Each diastereomer ***R*-10** and ***S*-10** was then independently heated with 3 mol % of Grubbs's second-generation catalyst[20] in toluene to give cyclohexenols β-**11** and α-**11** in 91% and 95% yield, respectively. The β-hydroxyl group of the undesired β-**11** was inverted to converge into α-**11** by Mitsunobu reaction followed by basic hydrolysis.

Since the ^{1}H NMR signals in β-**11** and α-**11** were not resolved well for detailed analysis, the stereochemistry of the hydroxyl groups in these compounds was determined after converting them into acetates β-**12** and α-**12**, respectively.[21] The C1H signal of β-**12** was 0.12 ppm more magnetically shielded than that of α-**12** due to the *pseudo*-axial geometry[22] as shown in Figure 3. These stereochemical assumptions were consistent with the dihedral angles ∠H-C5a-C1-H and ∠H-C1-C2-H, based on these coupling constants. The large coupling constant (7.5 Hz) between C1H and C2H in β-**12** indicated a *quasi*-antiperiplanar relationship. This molecule provided small coupling constant (1.5 Hz) between C1H and C5aH, to suggest nearly perpendicular relationship for the dihedral angle ∠H-C5a-C1-H. On the other hand, these coupling constants $^2J_{C5aH\text{-}C1H}$ and $^2J_{C1H\text{-}C2H}$ in the α-isomer α-**12** were both 3.7 Hz

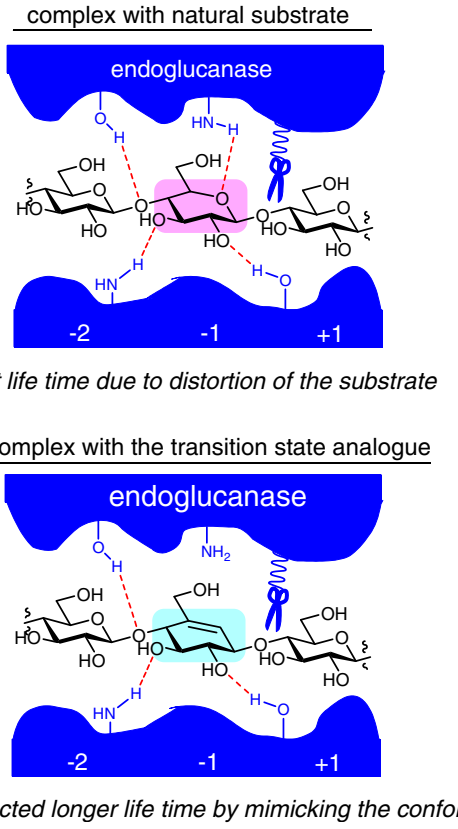


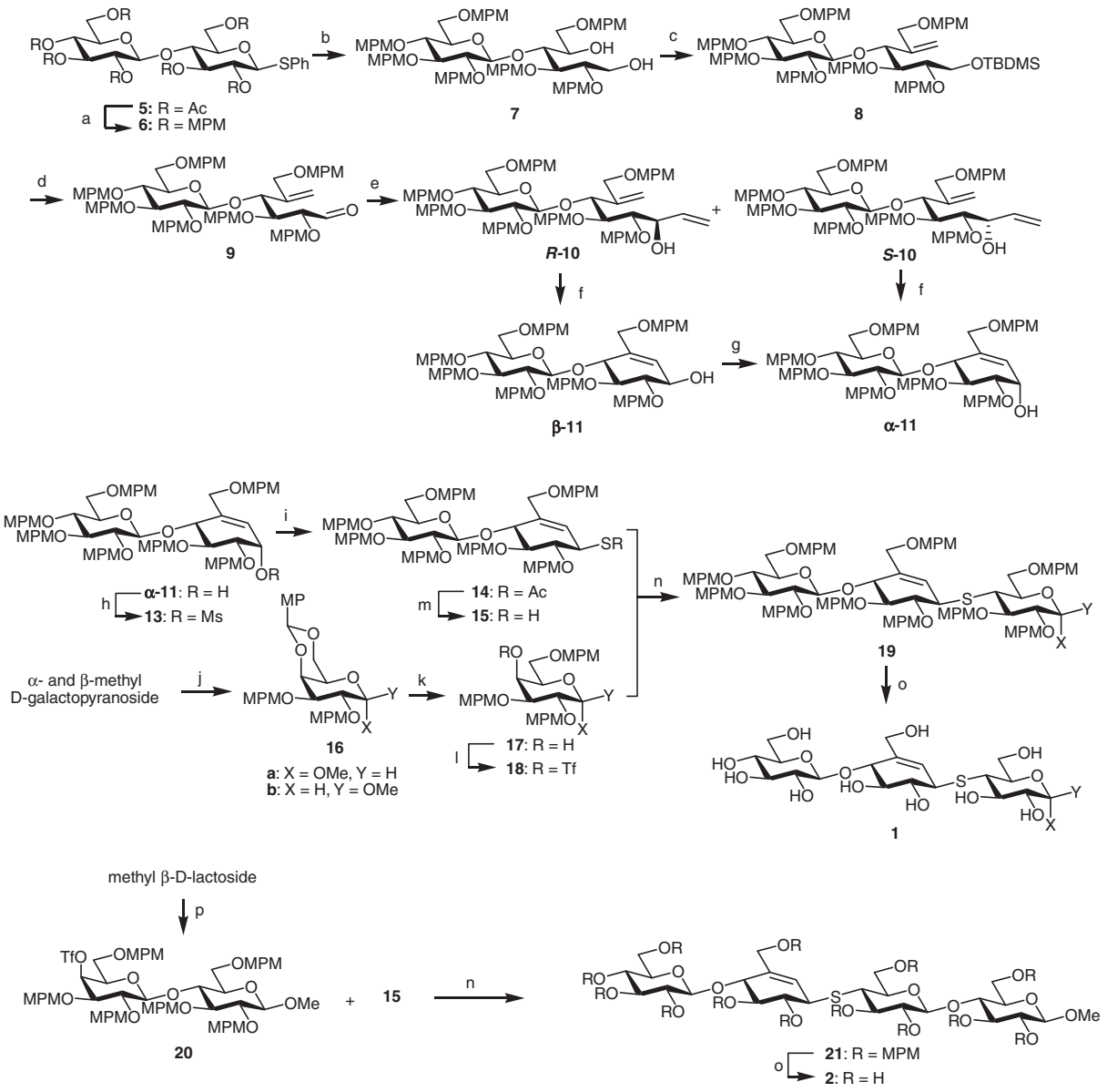
Figure 2. Design of the cyclohexene analogue.

which suggested gauche-like orientations for ∠H-C5a-C1-H and ∠H-C1-C2-H.

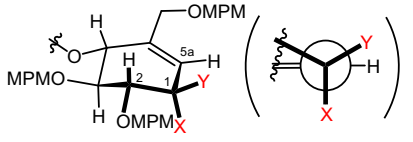
The hydroxy group in α-**11** was then converted to thioacetate **14** in 87% yield via mesylate **13**.[23] This transformation involved stereochemical inversion of the C1 position into the β-isomer.[24] Treatment of **14** with sodium methoxide cleaved-off the acetyl group to provide thiol **15**. Since **15** was unstable, it was immediately used for the next step.

The coupling partners **18a** and **18b** were prepared both in good yields from methyl α- and β-galactopyranoside, respectively, by (i) 4,6-*O*-(4-methoxybenzylidene)acetal formation, (ii) protection of the C2 and C3 alcohols as MPM ethers[25] (→**16a**, **16b**, respectively), and (iii) regioselective reductive cleavage of (4-methoxybenzylidene)acetal with $AlCl_3/BH_3{\cdot}Me_3N$/MSAW (acid washed molecular sieves),[26,27] giving alcohols **17a** and **17b**. Then, the hydroxyl groups were converted to trifluoromethanesulfonate esters, providing **18a** and **18b** in 80% and 84% yield, respectively. With thiol **15** and triflates **18a** and **18b** in hand, these were coupled to triose analogues by employing sodium hydride to afford **19a** and **19b** in 61% and 63% yields, respectively, in two steps. All MPM ethers of **19a** and **19b** were then successfully removed without affecting the oxidation-labile sulfide group[28] to afford **1a** and **1b**, respectively, by treatments with excess DDQ. Since the products **1a** and **1b** were soluble only in H_2O, almost all of the reddish 2,3-dichloro-5,6-dicyanohydroquinone (DDHQ) formed by the reaction and the remained DDQ could be removed from the aqueous mixture by washing with EtOAc.

Cellotetraose analogue was also synthesized from methyl β-D-lactoside.[29] Triflate **20** was obtained by conventional four steps [(i) *p*-methoxybenzylidene acetal formation, (ii) protection all of the remaining hydroxyl groups as PMP ethers,[25] (iii) regioselective reduction of the *p*-methoxybenzylideneacetal function,[27] and (iv) triflation of the newly generated alcohol]. In similar manner as



Scheme 1. Reagents and conditions: (a) (1) 2 M NaOH, MeOH, CH_2Cl_2, (98%); (2) MPMBr, NaH, DMF, (73%); (b) (1) NBS, acetone, H_2O; (2) $NaBH_4$, EtOH, CH_2Cl_2, (99% in two steps); (c) (1)TBSCl, imidazole, DMF, (97%); (2) DMSO, Ac_2O, (94%); (3) Ph_3PCH_3Br, *n*-BuLi, THF, (98%); (d) (1) TBAF, THF, (99%); (2) oxalyl chloride, DMSO, Et_3N, CH_2Cl_2, −78 °C, (99%); (e) $CH_2CHMgBr$, THF, −15 °C, (90%) (***R*-10**: 46%, ***S*-10**: (44%); (f) Grubbs′ II cat, toluene, 80 °C, α-**11**: 95%, β-**11**: 91%); (g) *p*-nitrobenzoic acid, DEAD, Ph_3P, THF, 0 °C; (2) 2 M NaOH, MeOH, CH_2Cl_2, (44% in two steps), (h) Ms_2O, Et_3N, CH_2Cl_2, −15 °C; (i) KSAc, DMF, 0 °C (87%, in two steps); (j) $MeOPhCH(OMe)_2$, *p*-TsOH, DMF, 100 °C; (2) MPMBr, NaH, DMF; (k) Me_3NBH_3, $AlCl_3$, MSAW 300, THF, 0 °C (**17a:** 45% from α-methyl galactopyranoside, **17b**: 48% from β-methyl galactopyranoside,), (l) Tf_2O, Py, CH_2Cl_2, 0 °C (**18a**:80%, **18b**: 84%), (m) NaOMe, MeOH, THF, 0 °C, (n) NaH, THF, 0 °C (**19a**: 61%, **19b**: 63%, **21**: 70% in two steps from **15**), (o) DDQ, CH_2Cl_2, H_2O, (**1a**: 87%, **1b**: 75%, **2**:62%); (p) (1) anisaldehyde dimethylacetal, cat *p*-TsOH, DMF; (2) NaH, MPMBr, DMF (50% in two steps); (3) Me_3NBH_3, $AlCl_3$, MSAW 300, THF, 0 °C (69%);(4) Tf_2O, Py, CH_2Cl_2, 0 °C (95%), (b) (1) NaH, THF, 0 °C (57%, in two steps from **5**); (2) DDQ, H_2O, CH_2Cl_2; (3) NaOH, MeOH, H_2O; (83% in two steps).



compound	X	Y	δ C1H	$^2J_{C1H\text{-}C5aH}$	$^2J_{C1H\text{-}C2H}$
β-**12**	H	OAc	5.45 ppm	1.5 Hz	7.5 Hz
α-**12**	OAc	H	5.57 ppm	3.7 Hz	3.7 Hz

Figure 3. The chemical shifts and the coupling constants of the acetates α-**12** and β-**12**.

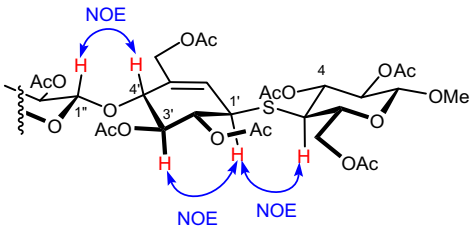


Figure 4. ROESY correlations and the stereochemistry of **22**.

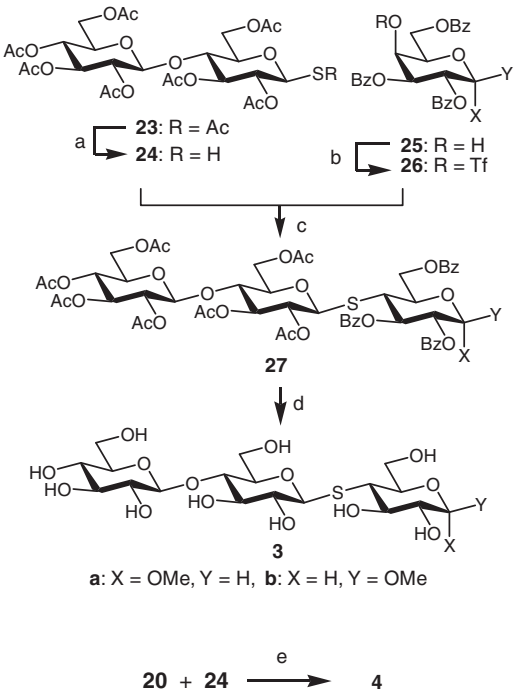
above, **20** was coupled with **15**, giving **21**. The cleavage of all MPM groups by DDQ afforded tetraose derivative **2** in 62%. The present synthetic route provided about 100 mg of each sample.

The above syntheses involved stereochemical inversion at the stage introducing the thioacetyl group. It was verified by NOE experiments employing peracetate **22**, prepared by acetylation of **1b** (in Fig. 4). The ^{1}H NMR signals required for the discussions were well resolved by measuring in benzene-d_6. The phase sensitive ROESY spectrum (mixing time = 300 ms) afforded the remarkable correlation signals between C1′H and C3′H, to establish the desired β-stereochemistry at the C1′ position.

2.2. Syntheses of thioglycoside analogues

In order to investigate the effect by the cyclohexene unit, we also synthesized sulfur analogues of cellotriose **3a**, **3b** and cellotetraose **4** as the comparison subjects. Since the synthesis of **4** had been reported by Driguez,[12] application of this methodology provided **3a**, **3b** in good yield as described below.

1-Thioacetylcellobiose heptaacetate **23** was prepared from a commercial cellobiose in good yield by the reported procedure.[30] The 1-thioacetyl group was selectively cleaved by sodium methoxide at low temperature, giving unstable thiol **24**, which was immediately coupled with triflates **26a** and **26b** to give **27a** and **27b**, respectively, both in moderate yields (Scheme 2). Triflates **26a** and **26b** were readily prepared from methyl α- and β-D-galactopyranosides, respectively.[31,32] Aqueous sodium hydroxide removed all esters of **27** to give sulfur-substituted analogues **3a** and **3b** after ion exchange column chromatography (Dowex 50 W, H^+ form). Cellotetraose derivative **4** was obtained via coupling between **20** and **24** followed by similar deprotection as mentioned above. Driguez and co-workers had reported **4** employing the similar triflate to **20** protected with acetyl esters but not with MPM ethers.



Scheme 2. Reagents and conditions: (a) NaOMe, MeOH, −15 °C; (b) Tf_2O, Py, CH2Cl2, 0 °C (**26a**: 92%, **26b**: 95%); (c) NaH, THF, 0 °C (**27a**: 73%, **27b**: 46%, in two steps from **23**); (d) NaOH, MeOH, H_2O (**3a**: 99, **3b**: 98%).(e) (1) NaH, THF, 0 °C (57%, in two steps from **23**); (2) DDQ, H_2O, CH_2Cl_2; (3) NaOH, MeOH, H_2O; (83% in two steps).

As described, we succeeded in synthesizing transition state analogues **1a**, **1b**, and **2** by taking advantage of cyclohexene ring as well as sulfur analogues **3a**, **3b**, and **4** as the comparison subjects. The ^{1}H NMR spectra of these compounds are shown in Figure 5. No signals due to impurities were found in these spectra, which fulfilled required purity for the next enzymatic investigations. The anomeric C1″H of **1a**, **1b**, **3a** and **3b** and C1′H, C1‴H of **2** and **4** signals appeared at around 4.5 ppm with large coupling constants (7.8–8.0 Hz) in the ^{1}H NMR spectra, which confirmed the β-glycosidic linkages. The stereochemistries of C1 positions could also be confirmed by their coupling constants (**1a**: 3.7 Hz, **1b**: 8.0 Hz, **2**: 8.0 Hz, **3a**, 3.7 Hz, **3b**: 8.0 Hz, **4**: 8.0 Hz). Notably, the methyl signals for α-methylglycosides **1a** and **3a** appeared at around 3.25 ppm, while those of β-methylglycosides **1b**, **2**, **3b**, and **4** were observed at around 3.40 ppm.

2.3. Evaluation of the dissociation constants by DSC

Dissociation constants of compounds **1**–**4** to an endoglucanase from *H. insolens*, NCE5, a homologue of *H. grisea* EGIV, were evaluated by DSC (differential scanning calorimetry) at pH 3.0. The method DSC has been used to evaluate dissociation constants by monitoring the thermodynamic parameters of the thermal transitions of the enzyme with/without each inhibitor. Since DSC indicates the stabilization effect of the ligands by reversible thermal transition of the enzyme, that requires total reversibility in the complexations. Nearly full reversibilities for all analogues (**1a**, **1b**, **2**, **3a**, **3b**, and **4**) were confirmed by re-scanning at the same pH with 1.0 K/min scanning rate. For example, the results with and without **2** are shown in Figure 6. The thermal transition of the enzyme requires energy to furnish the shown excess heat capacity curve (*black line*). The enzyme–inhibitor complex provided higher transition temperature (*red line*). Comparison of these curves and further analysis provided the dissociation constants K_I. Smaller K_I value means more stable analogue–enzyme complex. The evaluated K_I values are summarized in Table 1.

Sulfur substituted cellotriose analogues **3a** and **3b** gave the values larger than 30 mM, which indicated no stabilization effect in the mixture between these triose analogues and NCE5 under the conditions examined. On the other hand, tetraose derivative **4** indicated some stabilization, K_I = 3.9 mM. The re-heating reproduced the access curve which proved reversible process in the experiments. In other words, these analogues were stable and not hydrolyzed by the enzyme employed. However, there is a possibility that these analogues bind to other site than the catalytic domain by taking into account the results by Varrot et al.[34] They employed similar sulfur analogues to obtain the complex, but by avoiding the −1 subsite, the reaction site (1OCB).

As expected, considerable stabilizations (25 and 29 mM, respectively) were detected when **1a** and **1b**, cellotriose analogues mimicking the transition state by cyclohexene framework, were employed. Stereochemistry at the methylglycoside moiety (the reducing terminal) was not affected for the stabilization. By considering no stabilization by sulfur analogues **3a** and **3b**, cyclohexene moieties in **1a** and **1b** should participate in the complexation. We anticipate that the introduced cyclohexene ring mimicked the transition state conformation of the substrate. Their tetraose derivative **2** gave the smallest K_I value (1.6 mM) which suggested that the far-located subsites considerably contribute to the binding. This K_I value is comparable to that of the natural cellohexose (K_I = 0.42 mM in pH 4.0).[15] As preliminary result, **2** made roughly 75 times more stable complex with other enzyme, endoglucanase I isolated from *Trichoderma reesei*,[33] even those involved some minor problems to discuss the accurate K_I values by the series of these DSC experiments.

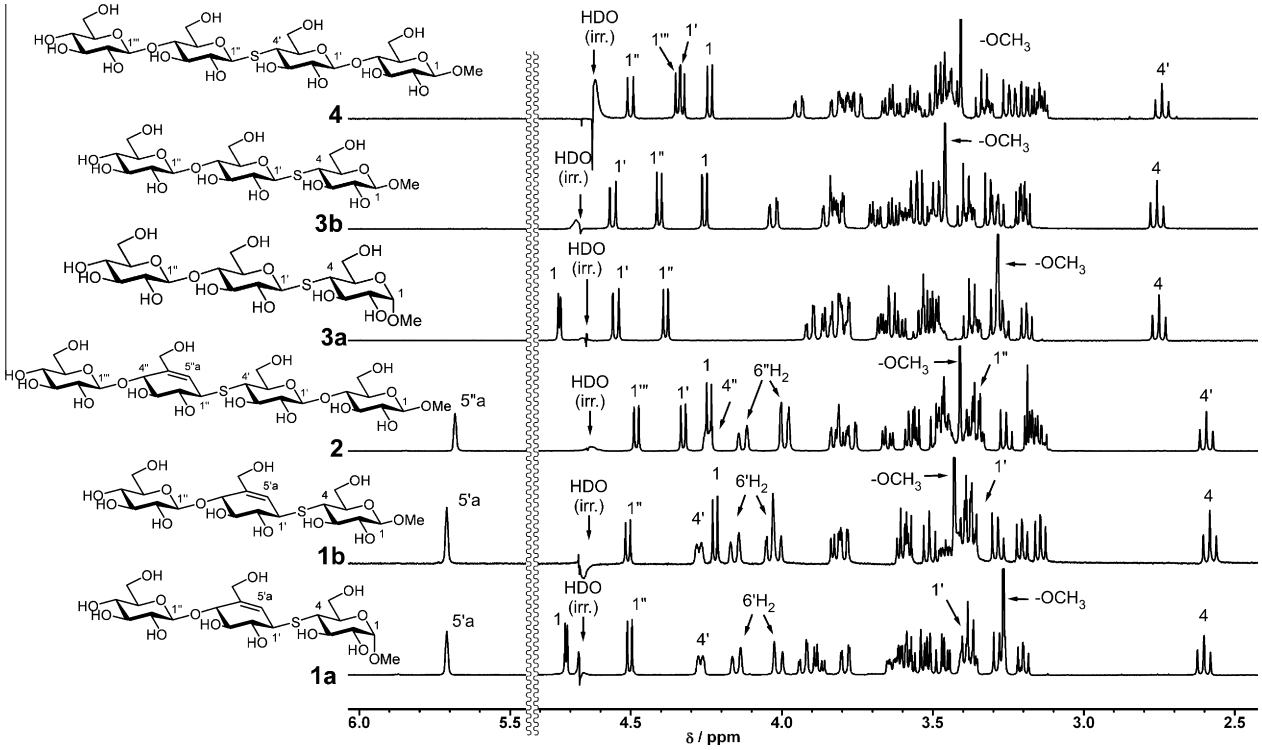


Figure 5. ^{1}H NMR spectra of model compounds in D_2O (500 MHz, homogated decoupling) and some signal assignments.

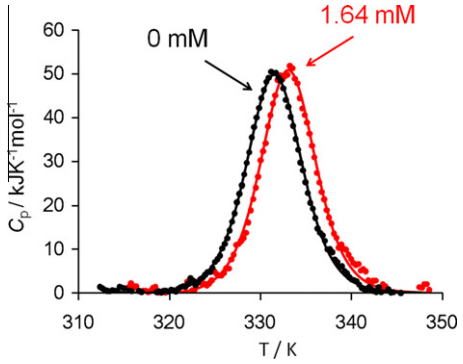


Figure 6. The excess heat capacity by the DSC with/without **2.**

Table 1
Dissociation constants of the inhibitors to the endoglucanase from *H. insolens*, NCE5, evaluated by DSC (pH 3.0, 59 °C)

Inhibitors	K_I (mM)
3a	No binding
3b	No binding
4	3.9
1a	25
1b	29
2	1.6

3. Conclusion

Cyclohexene analogues **1a**, **1b** and **2** were designed as molecular probes for endoglucanase and synthesized in the present study. The DSC experiments disclosed that these analogues bound effectively to endoglucanase NCE5 isolated from *H. insolens*. Comparison of their K_I values with those of sulfur substituted analogues (**3a**, **3b**, and **4**) indicated that the cyclohexene ring contributed for stabilization of the complex, probably by mimicking the half-chaired transition state conformation of the pyranose ring. Since detailed discussions for DSC experiments require further experiments (other temperature, pH, concentration, scan rate, etc) as well as more theoretical discussions, these will be reported elsewhere shortly.

4. Experimental

4.1. General methods

Melting points were determined with a Yanako MP-J3 micro melting point apparatus and were uncorrected. Optical rotations were measured on a HORIBA SEPA300 high-sensitivity polarimeter. ^{1}H NMR spectra were measured on JEOL ALPHA 400 (400 MHz) and JNM-ECA 500 (500 MHz) spectrometers. The chemical shifts are expressed in ppm downfield from the signal of tetramethylsilane used as an internal standard in the case of $CDCl_3$. When other solvents were employed, the remained proton signals in deuterosolvents C_6HD_5 (7.15 ppm) or HDO (4.63 ppm) were used as the internal standards. Splitting patterns are designated as s (singlet), d (doublet), t (triplet), m (multiplet), and br (broad). ^{13}C NMR spectra were recorded also on JEOL ALPHA 400 (100 MHz) and JNM-ECA 500 (125 MHz) spectrometers. The isotope ^{13}C in the solvents were used as the internal standard ($^{13}CDCl_3$; 77.0 ppm or $^{13}C_6D_6$; 128.0 ppm). For ^{13}C NMR spectra measured in D_2O, default offset was employed and did not corrected. Assignments of the signals are according to the numbering based on IUPAC nomenclature if not mentioned. For carbohydrate derivatives, numberings based on carbohydrate nomenclature are employed. The cyclohexene units also followed carbohydrate numbering for convenience. Measurment of IR spectra were carried out with a HORIBA FT-720 fourier transform infrared spectrometer on a KBr cell. Measurements of field desorption (FD) and fast atom

bombardment (FAB) mass spectra were performed on a JEOL JMS AX500 or JEOL JMS AX102A spectrometers. Electron spray ionization mass spectra were obtained by a HITACHI NanoFrontier LD spectrometer. MS analyses for unstable compounds such as glycosyl imidates were not performed. DSC experiments were performed with a high sensitive MicroCal VP-DSC calorimeter. Concentration of the enzyme was determined employing a JASCO UB-35 spectrometer.

Analytical and preparative thin-layer chromatographies were carried out using precoated silica gel plates, Merck silica gel $60F_{254}$ (Art. 1.05715). Silica gel used for column chromatography was Merck silica gel 60 (Art. 1.07734). Medium-pressure column chromatographies were performed employing Yamazen ULTRA PACK ODS-SM-50B or Yamazen ULTRA PACK SI-40B equipped with FMI LAB PUMP RP-SY. All reactions were carried out under N_2 or Ar atmosphere using dried solvents except for aqueous conditions. Dichloromethane and tetrahydrofuran were freshly distilled from diphosphorus pentoxide and benzophenone-ketyl, respectively.

4.2. 4-*O*-[2′,3′,4′,6′-Tetrakis-*O*-(4-methoxyphenylmethyl)-β-D-glucopyranosyl]-2,3,6-tris-*O*-(4-methoxyphenylmethyl)-D-glucopyranose β-phenylthioglycoside (6)

A solution of phenyl hepta-*O*-acetyl-1-thio-β-D-cellobioside **5**[16] (848 mg, 1.16 mmol) in a mixture of MeOH (5.0 mL) and CH_2Cl_2 (5.0 mL) was stirred with 2 M NaOH (300 μL) at room temperature for 10 min. After dilution with H_2O (50 mL), the mixture was passed through an ion-exchange column (DOWEX 50 W, H^+ form). Concentration of the eluent gave the corresponding crude heptaol (494 mg, 98%). This sample was immediately used for the next step. To a suspension of sodium hydride (washed with hexane, 383 mg, 16 mmol) in DMF (20 mL), the crude heptanol (494 mg, 1.14 mmol) in DMF (10 mL) was added at room temperature. Upon the addition, H_2 gas was vigorously bubbled. After stirring for 10 min, MPMBr [3.2 g, 15.9 mmol, freshly prepared from anisic alcohol (2.2 g) and PBr_3 (2.2 g) in diethyl ether (20 mL)] in toluene (10 mL) was added at 0 °C. After 10 min, the cooling bath was removed, and the mixture was stirred at room temperature for 40 min. Methanol (1.0 mL) and triethylamine (1.0 mL) were added successively in order to decompose the excess reagent. After stirring for an additional 30 min, the mixture was poured into H_2O (100 mL) and extracted with EtOAc (70 mL × 3). The organic layers were washed with H_2O (100 mL), and brine (100 mL), combined, dried over $MgSO_4$ and then concentrated in vacuo. Silica gel column chromatography of the residue with EtOAc/benzene = 6:94 afforded **6** (1.06 g, 73%) as amorphous powder. $[\alpha]_D^{25}$+9.80 (*c* 1.00, $CHCl_3$); IR (film) 2910, 1610, 1515, 1250, 1070, 1040, 820 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 3.27 (1H, ddd, *J* = 1.6, 4.4, 9.7 Hz, C5′*H*), 3.31 (1H, dd, *J* = 7.9, 9.0 Hz, C2′*H*), 3.36 (1H, ddd, *J* = 1.8, 4.0, 8.8 Hz, C5*H*), 3.42 (1H, dd, *J* = 8.8, 9.8 Hz, C2*H*), 3.45 (1H, t, *J* = 9.0 Hz, C3′*H*), 3.55 (1H, dd, *J* = 4.4, 11.0 Hz, C6′*H*H), 3.56 (1H, dd, *J* = 9.0, 9.7 Hz, C4′*H*), 3.60 (1H, t, *J* = 8.8 Hz, C3*H*), 3.69 (1H, dd, *J* = 1.6, 11.0 Hz, C6′*H*H), 3.71 (1H, dd, *J* = 1.8, 10.7 Hz, C6*H*H), 3.72, 3.73, 3.76, 3.76, 3.78, 3.79, 3.80 (each 3H, s, OC*H*$_3$), 3.81 (1H, dd, *J* = 4.0, 10.7 Hz, C6*H*H), 3.99 (1H, t, *J* = 8.8 Hz, C4*H*), 4.37 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.37, 4.41 (each 1H, d, *J* = 11.6 Hz, ArC*H*$_2$O), 4.42 (1H,d, *J* = 7.9 Hz, C1′*H*), 4.43 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 4.50 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.61 (1H, d, *J* = 9.8 Hz, C1*H*), 4.62 (1H, d, *J* = 10.8 Hz, ArC*H*HO), 4.63 (1H, d, *J* = 10.3 Hz, ArC*H*HO), 4.63, 4.68 (each 1H, d, *J* = 10.3 Hz, ArC*H*$_2$O), 4.70 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 4.71 (1H, d, *J* = 10.3 Hz, ArC*H*HO), 4.71, 4.80 (each 1H, d, *J* = 10.6 Hz, ArC*H*$_2$O), 5.04 (1H, d, *J* = 10.8 Hz, ArC*H*HO), 6.73 (2H, br d, *J* = 8.6 Hz, *aromatic protons*), 6.79–6.85 (12H, *aromatic protons*), 7.07 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.18–7.24 (11H, *aromatic protons*), 7.25–7.30 (4H, *aromatic protons*), 7.55 (2H, *aromatic protons*); ^{13}C NMR (125 MHz, $CDCl_3$) δ 55.13 (OCH_3 ×3), 55.16, 55.19 (each OCH_3), 55.21, 55.21 (OCH_3 ×2), 67.83 (*C*6), 68.59 (*C*6′), 72.79, 72.82, 72.85, 74.41, 74.52, 74.94, 74.98 (each ArCH_2O), 74.98 (*C*5′), 75.20 (ArCH_2O), 76.22 (*C*4), 77.68 (*C*4′), 79.30 (*C*5), 79.82 (*C*2), 82.48 (*C*2′), 84.61 (*C*3), 84.67 (*C*3′), 87.47 (*C*1), 102.44 (*C*1′), 113.43, 113.63, 113.63, 113.63, 113.66, 113.70, 113.70, 127.25, 128.55, 128.78, 129.04, 129.25, 129.28, 129.38, 129.47, 129.66, 129.76, 130.30, 130.42, 130.44, 130.50, 130.60, 130.90, 131.34, 131.83, 133.93, 158.85, 158.94, 159.02, 159.07, 159.07, 159.15, 159.18 (*aromatic carbons*); FABMS (%, rel int.) *m/z*: 1297 (12, $[M+Na]^+$), 121 (100, $[CH_3OPh\text{-}CH_2]^+$); FAB-HR-MS: calcd for $C_{74}H_{82}O_{17}SNa$ $[M+Na]^+$ 1297.5170; found, *m*/*z* 1297.5197.

4.3. 4-*O*-[2,3,4,6-*O*-Tetrakis-(4-methoxyphenylmethyl)-β-D-glucopyranosyl]-2,3,6-tris-*O*-(4-methoxyphenylmethyl)-D-glucitol (7)

A solution of **6** (1.60 g, 1.25 mmol) in a mixture of acetone (100 mL) and H_2O (10 mL) was stirred with NBS (558 mg 3.10 mmol) at 0 °C for 5 min. Aqueous 10% $Na_2S_2O_3$ solution (6.0 mL) was added and the mixture was neutralized by the addition of saturated aqueous $NaHCO_3$ solution (12 mL). After acetone was removed by rotary evaporator, the resulting aqueous solution was extracted with EtOAc (100 mL × 3). The organic layers were washed with H_2O (100 mL), combined, dried over $MgSO_4$, and then concentrated in vacuo. The residue was passed through silica gel pad to give a residue, which was dissolved in a mixture of EtOH (20 mL) and CH_2Cl_2 (10 mL) and it was cooled in a ice bath. To the solution, sodium borohydride (142 mg, 3.75 mmol) was added and the mixture was stirred for 30 min. The ice bath was removed and the mixture was further stirred at ambient temperature for 12 h. Aqueous 1.0 M HCl solution (2.0 mL) was added in order to decompose the excess hydride. After ethanol was removed by rotary evaporator, the resulting aqueous mixture was extracted with EtOAc (100 mL × 3). The organic layers were washed with H_2O (100 mL), and brine (100 mL) successively, combined, dried over $MgSO_4$, and then concentrated in vacuo. Purification of the residue by silica gel column chromatography (EtOAc/hexane = 54:46) gave **7** (1.48 g, 99%) as caramel. $[\alpha]_D^{26}$+11.4 (*c* 1.11, $CHCl_3$); IR (film) 3465, 2930, 1610, 1510, 1250, 1070, 1035, 820 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 2.58 (1H, t, *J* = 6.7 Hz, C1O*H*), 2.98 (1H, d, *J* = 5.8 Hz, C5O*H*), 3.26 (1H, ddd, *J* = 1.6, 5.3, 8.8 Hz, C5′*H*), 3.30 (1H, dd, *J* = 7.7, 8.8 Hz, C2′*H*), 3.39 (1H, t, *J* = 8.8 Hz, C4′*H*), 3.43 (1H, t, *J* = 8.8 Hz, C3′*H*), 3.49 (1H, dd, *J* = 5.3, 10.6 Hz, C6′*H*H), 3.51 (1H, dd, *J* = 3.1, 9.5 Hz, C6*H*H), 3.57 (1H, dd, *J* = 1.6, 10.6 Hz, C6′*H*H), 3.65 (2H, m, C1′*H*H, C6*H*H), 3.73, 3.75 (each 3H, s, OCH_3), 3.76 (1H, m, C1*H*H), 3.77, 3.77, 3.77, 3.79, 3.79 (each 3H, s, OCH_3), 3.90 (1H, dd, *J* = 1.7, 8.1 Hz, C4*H*), 3.94-3.99 (3H, C2′*H*, C3′*H*, C5*H*), 4.27 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.28 (1H, d, *J* = 7.7 Hz, C1′*H*), 4.37 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.38 (1H, d, *J* = 10.3 Hz, ArC*H*HO), 4.38, 4.43 (each 1H, d, *J* = 11.6 Hz, ArCH_2O), 4.58 (1H, d, *J* = 11.1 Hz, ArC*H*HO), 4.59 (1H, d, *J* = 11.0 Hz, ArC*H*HO), 4.64 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 4.67 (1H, d, *J* = 11.1 Hz, ArC*H*HO), 4.69 (1H, d, *J* = 10.3 Hz, ArC*H*HO), 4.71 (1H, d, *J* = 10.7 Hz, ArC*H*HO), 4.73 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 4.77 (1H, d, *J* = 11.0 Hz, ArC*H*HO), 4.83 (1H, d, *J* = 10.7 Hz, ArC*H*HO), 6.78–6.85 (14H, *aromatic protons*), 7.04 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.15 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.19 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.21–7.26 (8H, *aromatic protons*); ^{13}C NMR (125 MHz, $CDCl_3$) δ 55.15 (OCH_3 ×2), 55.19 (OCH_3 ×3), 55.23 (OCH_3 ×2), 62.69 (*C*1), 68.51 (*C*6′), 70.12 (*C*6), 70.49 (*C*5), 72.78, 72.95, 73.00 (each ArCH_2O), 74.30 (*C*5′), 74.34, 74.45, 74.51, 75.19 (each ArCH_2O), 76.85 (*C*4), 77.41 (*C*4′), 79.34, 79.62 (*C*2, *C*3), 81.74 (*C*2′), 84.44 (*C*3′),103.06 (*C*1′), 113.62, 113.66, 113.70, 113.73, 113.74, 113.77, 113.77, 129.27, 129.56, 129.59, 129.59, 129.59, 129.59, 129.60, 129.75, 130.09, 130.21, 130.54, 130.82, 130.86, 130.88, 159.08, 159.08,

159.08, 159.10, 159.18, 159.26, 159.26 (*aromatic carbons*); FABMS (%, rel int.) *m/z*: 1207 (37, $[M+Na]^+$), 121 (100, $[CH_3OPhCH_2]^+$); FAB-HR-MS: calcd for $C_{68}H_{80}O_{18}Na$ $[M+Na]^+$ 1207.5242; found, *m/z* 1207.5234.

4.4. (3*R*,4*S*,5*S*)-6-(*tert*-Butyldimethylsilyloxy)-4,5-bis(4-methoxyphenylmethyl)-2-((4-methoxyphenylmethyl) methyl)hex-1-en-3-yl 2,3,4,6-*O*-tetrakis-(4-methoxyphenyl methyl)-β-D-glucopyranoside (8)

A solution of **7** (825 mg, 696 μmol) in DMF (8.0 mL) was stirred with imidazole (95.0 mg, 1.40 mmol) and *tert*-butyldimethylchlorosilane (148 mg, 982 μmol) at room temperature for 1 h. The mixture was poured into H_2O (70 mL) and extracted with EtOAc (100 mL × 3). The organic layers were washed with H_2O (100 mL), and brine (100 mL) successively, combined, dried over $MgSO_4$, and then concentrated in vacuo. Silica gel column chromatography of the residue (EtOAc/hexane = 35:65) gave 4-*O*-[2,3,4,6-*O*-tetrakis-(4-methoxyphenylmethyl)-β-D-glucopyranosyl]-1-*O*-(*tert*-butyldimethylsilyl)-2,3,6-tris-*O*-(4-methoxyphenylmethyl)-D-glucitol (883 mg, 97%) as caramel. $[\alpha]_D^{25}$+20.5 (*c* 1.07, $CHCl_3$); IR (film) 3470, 2930, 1610, 1510, 1250, 1070, 1035, 820 cm^{-1}; ^1H NMR (500 MHz, C_6D_6) δ 0.18, 0.20 (each 3H, s, Si*CH*$_3$), 1.06 (9H, s, SiC(*CH*$_3$)$_3$), 3.27, 3.27, 3.29 (each 3H, s, O*CH*$_3$), 3.31, 3.31, 3.31, 3.31 (12H, s, O*CH*$_3$ ×4), 3.40–3.43 (2H, m, C2O*H*, C5′*H*), 3.57 (1H, dd, *J* = 8.1, 9.0 Hz, C2′*H*), 3.62 (1H,t, *J* = 9.0 Hz, C3′*H*), 3.68–3.74 (3H, C4′*H*, C6′*H*$_2$), 3.80 (1H, dd, *J* = 2.7, 10.0 Hz, C1*H*H), 4.01 (1H, dd, *J* = 3.8, 10.0 Hz, C1*H*H), 4.08 (1H, dd, *J* = 3.1, 11.0 Hz, C6*H*H), 4.26 (1H, dd, *J* = 4.5, 11.0 Hz, C6*H*H), 4.30 (1H, d, *J* = 11.8 Hz, ArC*H*HO), 4.31 (1H, ddd, *J* = 1.9, 3.1, 4.5 Hz, C5*H*), 4.45–4.48 (4H, C2*H*, C3*H*, ArC*H*HO ×2), 4.51 (1H, d, *J* = 11.5 Hz, ArC*H*HO), 4.52 (1H, dd, *J* = 1.9, 6.4 Hz, C4*H*), 4.58 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 4.74 (1H, d, *J* = 8.1 Hz, C1′*H*), 4.76, 4.81 (each 1H, d, *J* = 10.7 Hz, ArC*H*$_2$O), 4.81 (1H, d, *J* = 10.7 Hz, ArC*H*HO), 4.87 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 4.89 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 4.91 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 5.01 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 5.02 (1H, d, *J* = 10.7 Hz, ArC*H*HO), 5.06 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 6.77–6.82 (14H, *aromatic protons*), 7.16 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.21, 7.28, 7.35 (each 2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.37–7.40 (6H, *aromatic protons*); ^{13}C NMR (125 MHz, C_6D_6) δ −5.05, −4.93 (each Si*CH*$_3$), 18.58 (Si*C*), 26.27 (SiC(*CH*$_3$), 54.66 (O*CH*$_3$ ×2), 54.71 (O*CH*$_3$×4), 54.72 (O*CH*$_3$), 63.60 (*C*6), 69.33 (*C*6′), 70.96 (*C*1), 71.67 (*C*2), 73.09, 73.17, 73.34, 74.52, 74.57, 74.65 (each Ar*C*H$_2$O), 75.27 (*C*5′), 75.31 (Ar*C*H$_2$O), 76.60 (*C*3), 77.99 (*C*4′), 79.45 (*C*4), 80.63 (*C*5), 82.46 (*C*2′), 84.99 (*C*3′), 103.29 (*C*1′), 113.95, 114.02, 114.02, 114.02, 114.02, 114.14, 114.15, 129.50, 129.56, 129.57, 129.73, 129.89, 129.89, 130.11, 130.84, 130.93, 131.32, 131.32, 131.73, 131.81, 131.81, 159.56, 159.62, 159.64, 159.69, 159.72, 159.74, 159.76 (*aromatic carbons*); FABMS (%, rel int.) *m/z*: 1321 (50, $[M+Na]^+$), 131 (42, $[(CH_3)_3CSi(CH_3)_2O]^+$), 121 (100, $[CH_3OPhCH_2]^+$); FAB-HR-MS: calcd for $C_{74}H_{94}O_{18}SiNa$ $[M+Na]^+$ 1321.6107; found, *m/z* 1321.6097. A solution of the product thus obtained (883 mg, 679 μmol) in a mixture of DMSO (9.2 mL, 130 mmol) and acetic anhydride (6.10 mL, 63.7 mmol) was stirred at room temperature for 12 h. The mixture was poured into H_2O (300 mL), and extracted with EtOAc (150 mL × 3). The organic layers were washed with H_2O (100 mL), and brine (100 mL) successively, combined, dried over $MgSO_4$, and then concentrated in vacuo. Silica gel column chromatography (EtOAc/hexane = 30:70) of the residue afforded (3*S*,4*R*,5*S*)-6-(*tert*-butyldimethylsilyloxy)-1,4,5-tris-(4-methoxyphenylmethyl)-2-oxohexan-3-yl 2,3,5-O-tris-(4-methoxyphenylmethyl)-β-D-glucopyranoside (830 mg, 94%) as caramel. $[\alpha]_D^{25}$+24.3 (*c* 0.80, $CHCl_3$); IR (film) 2930, 1730, 1610, 1510, 1250, 1070, 1035, 820 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 0.01, 0.02 (each 3H, s, Si*CH*$_3$), 0.88 (9H, s, SiC(*CH*$_3$)$_3$), 3.31 1H, (ddd, *J* = 3.0, 3.5, 9.0 Hz, C5*H*), 3.39 (1H, dd, *J* = 7.7, 9.0 Hz, C2*H*), 3.50 (1H, t, *J* = 9.0 Hz, C4*H*), 3.54 (1H, t, *J* = 9.0 Hz, C3*H*), 3.60 (2H, m, C6*H*$_2$), 3.69–3.77 (3H, C5′*H*, C6′*H*$_2$), 3.735, 3.742, (each 3H, s, O*CH*$_3$), 3.760, (6H, s, O*CH*$_3$ ×2), 3.762, 3.78, 3.80 (each 3H, s, O*CH*$_3$), 4.03 (1H, t, *J* = 3.9 Hz, C4′*H*), 4.17 (1H, d, *J* = 11.5 Hz, ArC*H*HO), 4.19 (1H, d, *J* = 17.5 Hz, C1′*H*H), 4.21 (1H, d, *J* = 11.5 Hz, ArC*H*HO), 4.34 (1H, d, *J* = 7.7 Hz, C1*H*), 4.40 (1H, d, *J* = 17.5 Hz, C1′*H*H), 4.40–4.43 (3H, ArC*H*HO ×3), 4.43 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.47 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 4.48 (1H, d, *J* = 11.7 Hz, ArC*H*HO), 4.60 (1H, d, *J* = 3.9 Hz, C3′*H*), 4.61 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.69 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.70 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 4.71 (1H, d, *J* = 10.3 Hz, ArC*H*HO), 4.85 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 5.07 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 6.77–6.81 (12H, *aromatic protons*), 6.84 (2H, br d, *J* = 8.6 Hz, *aromatic protons*), 7.04, 7.11, 7.16 (each 2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.19–7.24 (6H, *aromatic protons*), 7.33 (2H, br d, *J* = 8.6 Hz, *aromatic protons*); ^{13}C NMR (100 MHz, $CDCl_3$) δ −5.31, −5.28 (each Si*CH*$_3$), 18.23 (Si*C*), 25.95 (SiC(*CH*$_3$)$_3$), 55.18 (O*CH*$_3$ ×3), 55.20 (O*CH*$_3$ ×2), 55.25, 55.26 (each O*CH*$_3$), 62.14 (*C*6′), 68.63 (*C*6), 72.61, 72.78, 73.13, 73.90, 74.27 (each Ar*C*H$_2$O), 74.32 (*C*1′), 74.53 (Ar*C*H$_2$O), 74.97 (*C*5), 75.31 (Ar*C*H$_2$O), 77.42 (*C*4), 78.86 (*C*3′), 78.92 (*C*5′), 80.00 (*C*4′), 81.85 (*C*2), 84.23 (*C*3), 102.21 (*C*1), 113.55, 113.67, 113.69, 113.70, 113.77, (*aromatic carbons*), 113.78 (*aromatic carbon* ×2), 128.32, 129.34, 129.37, 129.46, 129.55, 129.71, 129.78, 129.95, 129.99, 130.18, 130.27, 130.36, 130.71, 130.78, 130.96, 159.06 (*aromatic carbons*), 159.16 (*aromatic carbon* ×2), 159.21, 159.23, 159.27 (*aromatic carbons*), 205.74 (C2′); FABMS (%, rel int.) *m/z*: 1319 (33, $[M+Na]^+$), 131 (26, $[(CH_3)_3CSi(CH_3)_2O]^+$), 121 (100, $[CH_3OPhCH_2]^+$); FAB-HR-MS: calcd for $C_{74}H_{92}O_{18}SiNa$ $[M+Na]^+$ 1319.5951; found, *m/z* 1319.5962. Butyl lithium (0.75 M in hexane, 4.3 mL, 3.2 mmol) was added to a suspension of methyltriphenylphosphonium bromide (1.54 g, 4.3 mmol) in THF (7.0 mL) at room temperature. Upon the addition of butyl lithium, the white suspension turned to orange suspension. After stirring for 10 min, a solution of the product (1.4 g, 1.08 mmol) in THF (7.0 mL) was added at room temperature and the mixture was stirred for further 10 min. The mixture was poured into saturated aqueous NH_4Cl (50 mL), and extracted with EtOAc (80 mL × 3). The organic layers were washed with brine (50 mL), combined, dried over $MgSO_4$, and then concentrated in vacuo. Purification of the residue by silica gel column chromatography (EtOAc/hexane = 26:74) gave **8** (1.37 g, 98%) as an oil, $[\alpha]_D^{25}$+1.5 (*c* 0.80, $CHCl_3$); IR (film) 2930, 1610, 1510, 1250, 1070, 1040, 820 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 0.02, 0.03 (each 3H, s, Si*CH*$_3$), 0.89 (9H, s, SiC(*CH*$_3$)$_3$), 3.29 (1H, ddd, *J* = 2.4, 3.9, 9.4 Hz, C5*H*), 3.36 (1H, dd, *J* = 7.9, 9.2 Hz, C2*H*), 3.52–3.57 (2H, C3*H*, C4*H*), 3.61 (1H, dd, *J* = 2.4, 11.0 Hz, C6*H*H), 3.64 (1H, dd, *J* = 3.9, 11.0 Hz, C6*H*H), 3.69 (1H, dt, *J* = 4.9, 5.2 Hz, C5′*H*), 3.74 (3H, s, O*CH*$_3$), 3.75 (6H, s, O*CH*$_3$ ×2), 3.76 (6H, s, O*CH*$_3$ ×2),3.78, 3.79 (each 3H, s, O*CH*$_3$), 3.76–3.84 (3H, C4′*H*, C6′*H*$_2$), 3.95, 4.04 (each 1H, d, *J* = 13.5 Hz, C2′*CH*$_2$), 4.22, 4.27 (each d, 1H, *J* = 11.4 Hz, ArC*H*$_2$O), 4.37 (1H, d, *J* = 7.9 Hz, C1*H*), 4.41 (1H, d, *J* = 11.7 Hz, ArC*H*HO), 4.44 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 4.49 (1H, d, *J* = 11.4 Hz, ArC*H*HO), 4.53 (1H, d, *J* = 11.7 Hz, ArC*H*HO), 4.58 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 4.61 (1H, d, *J* = 11.4 Hz, ArC*H*HO), 4.64, 4.65, 4.70, 4.71 (each 1H, d, *J* = 10.6 Hz, ArC*H*HO ×4), 4.77 (1H, d, *J* = 4.6 Hz, C3′*H*), 4.84, 4.87 (each 1H, d, *J* = 10.6 Hz, ArC*H*HO ×2), 5.30, 5.40 (each 1H, br s, C1′*H*$_2$), 6.74–6.85 (14H, *aromatic protons*), 7.06, 7.15, 7.19 (each 2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.20-7.24 (8H, *aromatic protons*); ^{13}C NMR (125 MHz, $CDCl_3$) δ −5.33, (Si*CH*$_3$ ×2), 18.22 (Si*C*), 25.97 (SiC (*CH*$_3$)$_3$), 55.16 (O*CH*$_3$ ×2), 55.17 (O*CH*$_3$ ×3), 55.21, 55.23 (each O*CH*$_3$), 62.67 (*C*6′), 68.44 (*C*6), 69.80 (C2′*CH*$_2$), 71.96, 72.57, 73.06, 74.24 (each Ar*C*H$_2$O), 74.46 (Ar*C*H$_2$O ×2), 75.09 (*C*5), 75.27 (Ar*C*H$_2$O), 77.43 (*C*3′), 77.74 (*C*3), 79.85 (*C*4′), 80.36 (*C*5′), 82.02 (*C*2), 84.54 (*C*4), 99.10 (*C*1), 113.43, 113.50, 113.62, 113.64 (*aromatic carbons*), 113.68 (*aromatic carbon* ×2), 113.73 (*aromatic carbon*), 116.52

(*C*1′), 128.30, 128.89, 129.16, 129.32, 129.35, 129.48, 129.66, 129.70, 130.41, 130.49, 130.54, 130.74, 131.01 (*aromatic carbons*), 131.30 (*aromatic carbon* ×2), 142.03 (*C*2′), 158.86 (*aromatic carbon* ×2), 158.97 (*aromatic carbon*), 159.03 (*aromatic carbon* ×2), 159.07, 159.14 (*aromatic carbons*); FABMS (%, rel int.) *m/z*: 1317 (39, $[M+Na]^+$), 1051 (24, $[M-CH_3OPhCH_2-CH_3OPhCH_2O]^+$), 121 (100, $[CH_3OPhCH_2]^+$); FAB-HR-MS: calcd for $C_{75}H_{94}O_{17}SiNa$ $[M+Na]^+$ 1317.6158; found, *m/z* 1317.6147.

4.5. (3*R*,4*S*,5*R*)-4,5-bis(4-Methoxybenzyloxy)-2-((4-methoxybenzyloxy)methyl)-6-oxohex-1-en-3-yl 2,3,4,6-*O*-tetrakis-(4-methoxyphenylmethyl)-β-D-glucopyranoside (9)

A solution of **8** (288 mg, 222 μmol) in THF (5.0 mL) was stirred with tetrabutylammonium fluoride (1.0 M in THF, 400 μl) at room temperature for 1.5 h. The mixture was poured into H_2O (20 mL) and extracted with EtOAc (30 mL × 3). The organic layers were washed with brine (20 mL), combined, dried over $MgSO_4$, and then concentrated in vacuo. Purification of the residue by silica gel column chromatography (EtOAc/hexane = 50:50) gave the corresponding alcohol (259 mg, 99%) as an oil. $[\alpha]_D^{25}$+3.6 (*c* 1.28, $CHCl_3$), IR (film): 3460, 2915, 1610, 1510, 1250, 1070, 1035, 820 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 2.30 (1H, br, C6′O*H*), 3.29 (1H, ddd, *J* = 2.4, 4.2, 9.0 Hz, C5*H*), 3.39 (1H, dd, *J* = 7.9, 8.5 Hz, C2*H*), 3.50-3.56 (2H, C3*H*, C4*H*), 3.58 (1H, dd, *J* = 4.2, 11.0 Hz, C6*H*H), 3.61 (1H, dd, *J* = 2.4, 11.0 Hz, C6*H*H), 3.75–3.86 (4H, C5′*H*, C3′*H*, C6′H_2), 3.75 (3H, s, OCH_3), 3.76 (9H, OCH_3 ×3),, 3.77, 3.78, 3.79 (each 3H, s, OCH_3), 3.94, 4.06 (each 1H, br d, *J* = 13.1 Hz, C2′CH_2O), 4.24, 4.30 (each 1H, d, *J* = 11.5 Hz, ArCH_2O), 4.36 (1H, d, *J* = 7.9 Hz, C1*H*), 4.43 (1H, d, *J* = 11.7 Hz, ArC*H*HO), 4.44 (1H, d, *J* = 10.4 Hz, ArC*H*HO), 4.51 (1H, d, *J* = 11.7 Hz, ArC*H*HO), 4.53 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 4.54, 4.58 (each 1H, d, *J* = 11.2 Hz, ArCH_2O), 4.67 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.67 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 4.69 (1H, d, *J* = 10.4 Hz, ArC*H*HO), 4.69 (1H, m, C2′*H*), 4.72, 4.85 (each 1H, d, *J* = 10.7 Hz, ArC*H*HO), 4.89 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 5.37, 5.39 (each 1H, br s, C1′H_2), 6.75 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 6.78–6.85 (12H, *aromatic protons*), 7.07 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.16 (2H, br d, *J* = 8.6 Hz, *aromatic protons*), 7.18 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.21-–7.24 (8H, *aromatic protons*); ^{13}C NMR (125 MHz, $CDCl_3$) δ 55.18 (OCH_3 ×2), 55.20 (OCH_3 ×2), 55.21, 55.24, 55.25 (each OCH_3), 61.80 (*C*6′), 68.39 (*C*6), 70.52 (C2′CH_2), 71.90, 72.47, 73.08, 74.17, 74.52, 74.58 (each ArCH_2O), 74.96 (*C*5), 75.24 (ArCH_2O), 76.52 (*C*2′), 77.62 (*C*4), 79.66, 80.65 (*C*3′, *C*4′), 81.90 (*C*2), 84.48 (*C*3), 99.63 (*C*1), 113.58, 113.65, 113.70, 113.73, 113.73, 113.73, 113.73 (*aromatic carbons*), 116.62 (*C*1′), 129.02, 129.28, 129.35, 129.40, 129.59, 129.63, 129.73, 130.32, 130.35, 130.37, 130.58, 130.76, 130.85, 130.98 (*aromatic carbons*), 141.79 (*C*2′), 159.03, 159.06, 159.07, 159.07, 159.11, 159.11, 159.21 (*aromatic carbons*); FDMS (%, rel int.) *m/z*: 1181 (20, $[M+H]^+$), 1180 (31, $[M]^+$), 1059 (46, $[M-CH_3OPhCH_2]^+$), 121 (100, $[CH_3OPhCH_2]^+$); FD-HR-MS: calcd for $C_{69}H_{80}O_{17}$ $[M]^+$ 1180.5396; found, *m/z* 1180.5396. Oxalylchloride (264 mg, 2.08 mmol) was added to a solution of dimethylsulfoxide (325 mg, 4.2 mmol) in CH_2Cl_2 (3.0 mL) at −78 °C and the mixture was stirred for 20 min. A solution of the alcohol (620 mg, 525 μmol) in CH_2Cl_2 (5.0 mL) was added to the mixture, and the resulting mixture was stirred at the same temperature for 40 min. After triethylamine (526 mg, 5.21 mmol) was added, the cooling bath was removed. The mixture was further stirred at room temperature for additional 10 min. The mixture was poured into H_2O (30 mL) and extracted with EtOAc (30 mL × 3). The organic layers were washed with brine (30 mL), combined, dried over $MgSO_4$, and then concentrated in vacuo. Purification of the residue with silica gel column chromatography (EtOAc/hexane = 40:60) gave **9** (615 mg, 99%) as an oil. ^1H NMR (500 MHz, $CDCl_3$) δ 3.29 (1H, ddd, *J* = 2.7, 3.4, 9.1 Hz, C5*H*), 3.40 (1H, dd, *J* = 7.8, 8.3 Hz, C2*H*), 3.52–3.58 (2H, C3*H*, C4*H*), 3.62-3.67 (2H, C6H_2), 3.75 (6H, s, OCH_3 ×2), 3.76 (6H, s, OCH_3 ×3), 3.78, 3.79 (each 3H, s, OCH_3), 3.90 (1H, br d, *J* = 12.6 Hz, C5′C*H*HO), 3.97 (1H, dd, *J* = 0.9, 4.3 Hz, C2′*H*), 4.03–4.07 (2H, C3′*H*, C5′C*H*HO), 4.23, 4.28 (each 1H, d, *J* = 11.5 Hz, ArCH_2O), 4.33 (1H, d, *J* = 8.1 Hz, C1*H*), 4.42 (1H, d, *J* = 11.4 Hz, ArC*H*HO), 4.44 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.48 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 4.50 (1H, d, *J* = 11.4 Hz, ArC*H*HO), 4.54 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.54, 4.58 (each 1H, d, *J* = 10.9 Hz, ArCH_2O), 4.65 (1H, d, *J* = 10.7 Hz, ArC*H*HO), 4.71, 4.72 (each 1H, d, *J* = 10.6 Hz, ArC*H*HO), 4.80 (1H, d, *J* = 10.7 Hz, ArC*H*HO), 4.82 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 4.88 (1H, d, *J* = 5.0 Hz, C4′*H*), 5.32, 5.38 (each 1H, br s, C6′CH_2), 6.75–6.84 (14H, *aromatic protons*), 7.09 (2H, br d, *J* = 8.5 Hz, *aromatic protons*), 7.14–7.25 (12H, m, *aromatic protons*), 9.60 (1H, d, *J* = 0.9 Hz, C1′C*H*O). This sample was immediately used for next step.

4.6. (3*R*,4*S*,5*S*,6*R*)-6-Hydroxy-4,5-bis(4-methoxybenzyloxy)-2-((4-methoxybenzyloxy)methyl)octa-1,7-dien-3-yl 2,3,4,6-*O*-tetrakis-(4-methoxyphenylmethyl)-β-D-glucopyranoside (*R*-10) and its (3*R*,4*S*,5*S*,6*S*)-isomer (*S*-10)

A solution of **9** (615 mg, 0.52 mmol) in THF (3.0 mL) was stirred with vinylmagnesium bromide (1.0 M in THF, 1.1 mL) at −15 °C for 10 min. The mixture was poured into saturated aqueous NH_4Cl (30 mL) and extracted with EtOAc (30 mL × 3). The organic layers were washed with brine (30 mL), combined, dried over $MgSO_4$, and then concentrated in vacuo. Purification of the residue with silica gel column chromatography (EtOAc/hexane = 40:60) gave 1:1 mixture of ***S*-10** and ***R*-10** (573 mg, 0.48 mmol, 90%) as an oil. These were successfully separated by medium-pressured silica gel column chromatography (EtOAc/benzene = 9:91) to provide ***R*-10** (286 mg, 237 mmol, 46%) and ***S*-10** (280 mg, 44%).

4.6.1. Physical data for *R*-10

$[\alpha]_D^{26}$+12.2 (*c* 0.64, $CHCl_3$); IR (film) 3470, 2920, 1610, 1510, 1245, 1070, 1030, 820 cm^{-1}, ^1H NMR (400 MHz, $CDCl_3$) δ 2.65 (1H,d, *J* = 7.7 Hz, C6′O*H*), 3.30 (1H, ddd, *J* = 2.7, 3.5, 9.3 Hz, C5*H*), 3.39 (1H, dd, *J* = 7.8, 9.2 Hz, C2*H*), 3.52–3.58 (2H, C3*H*, C4*H*), 3.58, 3.60 (2H, C6H_2), 3.76 (9H, s, OCH_3 ×3), 3.77 (6H, s, OCH_3 ×2), 3.78 (3H, s, OCH_3), 3.79 (1H, m, C5′*H*), 3.80 (s, 3H, OCH_3), 3.84 (1H, dd, *J* = 2.8, 7.4 Hz, C4′*H*), 3.95, 4.06 (1H, br d, *J* = 13.0 Hz, C2′*CH*HO), 4.24, 4.30 (each 1H, d, *J* = 11.6 Hz, ArCH_2O), 4.37 (1H, d, *J* = 7.8 Hz, C1*H*), 4.39 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.44 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.48 (1H, m, C6′*H*), 4.49 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.50 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 4.54 (1H, d, *J* = 10.7 Hz, ArC*H*HO), 4.65 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 4.68 (1H, d, *J* = 10.7 Hz, ArC*H*HO), 4.69 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.70 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 4.71 (1H, m, C3′*H*), 4.73, 4.86 (each 1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.92 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 5.09 (1H, dt, *J* = 1.5, 10.4 Hz, C8′*H*H), 5.33 (1H, dt, *J* = 1.5, 17.1 Hz, C8′*H*H), 5.38, 5.41 (each 1H, br s, C1′CH_2), 5.96 (ddd, 1H, *J* = 5.0, 10.4, 17.1 Hz, C7′*H*), 6.74–6.86 (14H, *aromatic protons*), 7.06 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.16-7.26 (12H, *aromatic protons*); ^{13}C NMR (100 MHz, $CDCl_3$) δ 55.19 (OCH_3 ×2), 55.21 (OCH_3 ×3), 55.25, 55.26 (each OCH_3), 68.50 (*C*6), 70.55 (C2′CH_2), 71.80 (*C*6′), 71.93, 73.06, 74.43 (each ArCH_2O), 74.53 (ArCH_2O ×2), 74.53, 74.61 (each ArCH_2O), 74.85 (*C*5), 75.28 (ArCH_2O), 76.55 (*C*3′), 77.66 (*C*4), 80.79 (*C*4′), 81.83 (*C*5′), 81.91 (*C*2), 84.46 (*C*3), 99.69 (*C*1), 113.53, 113.63, 113.67, 113.69, 113.71, 113.74, 113.76 (*aromatic carbons*), 114.93 (*C*8′), 116.24 (*C*1′), 129.04, 129.29, 129.32, 129.37, 129.56, 129.60, 129.78, 130.30, 130.41, 130.41, 130.59, 130.79, 130.99, 131.12 (*aromatic carbons*), 139.17 (*C*7′), 141.87 (*C*2′), 158.93, 159.10, 159.10, 159.10, 159.10, 159.11, 159.21 (*aromatic carbons*); FDMS (%, rel int.) *m/z*: 1229 (7.2, $[M+Na]^+$), 1207 (4.3, $[M+H]^+$), 1206 (12, $[M]^+$), 1085 (42, $[M-CH_3OPhCH_2]^+$), 121 (100, $[CH_3OPhCH_2]^+$); FD-HR-MS: calcd for $C_{71}H_{82}O_{17}$ $[M]^+$ 1206.5552; found, *m/z* 1206.5557.

4.6.2. Physical data for *S*-10

$[\alpha]_D^{26}$–7.40 (*c* 1.13, $CHCl_3$); IR (film) 3465, 2930, 1610, 1510, 1250, 1070, 1035, 820 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 3.27 (1H, br, C6′O*H*), 3.32 (1H, ddd, *J* = 1.5, 4.6, 9.5 Hz, C5*H*), 3.42 (1H, dd, *J* = 7.8, 8.5 Hz, C2*H*), 3.51-3.58 (2H, C4*H*, C3*H*), 3.58 (1H, dd, *J* = 4.6, 11.3 Hz, C6*H*H), 3.63 (1H, dd, *J* = 1.5, 11.3 Hz, C6*H*H), 3.69 (1H, t, *J* = 4.6 Hz, C5*H*), 3.74, 3.75 (each 3H, s, OCH_3), 3.76 (6H, s, OCH_3 ×2), 3.77, 3.78, 3.79 (each 3H, s, OCH_3), 3.82 (1H, t, *J* = 4.6 Hz, C4′*H*), 3.89, 4.02 (each 1H, br d, *J* = 13.0 Hz, C2′CH_2), 4.22, 4.30 (each 1H, d, *J* = 11.4 Hz, ArCH_2O), 4.36 (1H, d, *J* = 7.8 Hz, C1*H*), 4.43 (1H, d, *J* = 11.9 Hz, ArC*H*HO), 4.46 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.51 (2H, d, *J* = 11.9 Hz, ArC*H*HO ×2), 4.55 (1H, m, C6′*H*), 4.59 (1H, d, *J* = 11.9 Hz, ArC*H*HO), 4.59, 4.63, 4.68 (each 1H, d, *J* = 10.7 Hz, ArCH_2O, ArC*H*HO), 4.71 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.72 (1H, d, *J* = 10.2 Hz, ArC*H*HO), 4.82 (1H, d, *J* = 4.6 Hz, C3′*H*), 4.84 (1H, d, *J* = 10.2 Hz, ArC*H*HO), 4.87 (1H, d, *J* = 10.7 Hz, ArC*H*HO), 5.15 (1H,br d, *J* = 10.6 Hz, C8′*H*H), 5.34, 5.36 (each 1H, br s, C1′H_2), 5.37 (1H, br d, *J* = 17.3 Hz, C8′*H*H), 5.86 (1H, ddd, *J* = 5.5, 10.6, 17.3 Hz, C7′*H*), 6.75-6.85 (14H, *aromatic protons*), 7.08 (2H, br d, *J* = 8.6 Hz, *aromatic protons*), 7.15-7.25 (12H, *aromatic protons*); ^{13}C NMR (100 MHz, $CDCl_3$) δ 55.15, 55.17 (each OCH_3), 55.20 (OCH_3 ×3), 55.25 (each OCH_3 ×2), 68.40 (*C*6), 70.15 (C2′CH_2), 72.05 (*C*6′), 72.05, 72.75, 73.01, 73.91, 74.54, 74.58 (each ArCH_2O), 75.12 (*C*5), 75.25 (ArCH_2O), 77.39 (*C*3′), 77.76 (*C*4), 80.10 (*C*5′), 80.58 (*C*4′), 81.98 (*C*2), 84.59 (*C*3), 99.23 (*C*1), 113.60, 113.67, 113.67, 113.70, 113.70, 113.74, 113.74 (*aromatic carbons*), 116.02 (*C*8′), 117.44 (*C*1′), 129.11, 129.26, 129.29, 129.39, 129.58, 129.60, 129.85, 130.29, 130.32, 130.38, 130.58, 130.60, 130.62, 130.95 (*aromatic carbons*), 137.80 (*C*7′), 141.61 (*C*2′), 159.03, 159.07, 159.07, 159.07, 159.11, 159.11, 159.21 (*aromatic carbons*); FABMS (%, rel int.) *m/z*: 1229 (17, $[M+Na]^+$), 121 (100, $[CH_3OPhCH_2]^+$); FAB-HR-MS: calcd for $C_{71}H_{82}O_{17}Na$ $[M+Na]^+$ 1229.5450; found, *m/z* 1229.5450.

4.7. [2,3,4,6-*O*-Tetrakis-(4-methoxyphenylmethyl)-β-D-glucopyranosyl]-(1→4)-β-2,3,6-tris-*O*-(4-methoxypheny lmethyl)-$\Delta^{5,5a}$carbaglucopyranose (β-11)

A solution of ***R*-10** (56.3 mg, 46.6 μmol) in toluene (10.0 mL) was stirred in the presence of Grubbs's second-generation catalyst[20] (1.2 mg, 1.4 μmol) at 80 °C. After 10 min, the mixture was concentrated in vacuo. Purification of the residue was performed with silica gel column chromatography (EtOAc/benzene = 14:86) to give β-**11** (52.0 mg, 95%) as a white amorphous. $[\alpha]_D^{26}$ −20.5 (*c* 1.44, $CHCl_3$); IR (film) 3470, 2910, 1610, 1510, 1250, 1070, 1035, 820 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 2.50 (1H, d, *J* = 7.4 Hz, C1O*H*), 3.35 (1H, dd, *J* = 7.9, 8.7 Hz, C2′*H*), 3.38 (1H, ddd, *J* = 2.0, 4.7, 9.4 Hz, C5′*H*), 3.51-3.57 (2H, C4*H*, C3′*H*), 3.58-3.61 (2H, C6*H*H, C2*H*), 3.64 (1H, dd, *J* = 2.0, 11.0 Hz, C6′*H*H), 3.74 (3H, s, OCH_3),3.76 (6H, s, OCH_3 ×2), 3.76 (3H, s, OCH_3), 3.77 (6H, s, OCH_3 ×2), 3.79 (6H, s, OCH_3 ×2), 3.81 (1H, br d, *J* = 12.1 Hz, C6C*H*H), 4.13 (1H, m, C1*H*), 4.16 (1H, dd, *J* = 4.0, 6.5 Hz, C3*H*), 4.26 (1H, d, *J* = 11.5 Hz, ArC*H*HO), 4.29 (1H, br d, *J* = 12.1 Hz, C6C*H*H), 4.36 (1H, d, *J* = 11.5 Hz, ArC*H*HO), 4.38, 4.42 (each 1H, d, *J* = 11.4 Hz, ArCH_2O), 4.43–4.47 (3H, C4*H*, ArC*H*HO×2), 4.56 (1H, d, *J* = 11.3 Hz, ArC*H*HO), 4.58 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 4.63 (1H, d, *J* = 7.9 Hz, C1′*H*), 4.72 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.71-4.76 (3H, ArC*H*HO ×3), 4.78 (1H, d, *J* = 11.3 Hz, ArC*H*HO), 4.83 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 5.88 (1H, br d, *J* = 3.0 Hz, C5a*H*), 6.77–6.84 (14H, *aromatic protons*), 7.07 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.16–7.24 (12H, *aromatic protons*); ^{13}C NMR (100 MHz, $CDCl_3$) δ 55.14 (OCH_3), 55.18 (OCH_3 ×3), 55.21 (OCH_3), 55.23(OCH_3 ×2), 68.59 (*C*1), 68.76 (*C*6′), 70.08 (*C*6), 71.33, 72.34, 72.90, 73.33, 74.45, 74.52 (ArCH_2O ×6), 74.76 (*C*5′), 75.10 (*C*4), 75.28 (ArCH_2O), 77.66 (*C*4′), 79.06 (*C*2), 79.26 (*C*3), 82.40 (*C*2′), 84.55 (*C*3′), 104.21 (*C*1′), 113.59, 113.64, 113.67, 113.73, 113.74, 113.74 113.79 (*aromatic carbons*), 128.10 (*C*5a), 129.20, 129.36, 129.39, 129.43, 129.51, 129.54, 129.57 (*aromatic carbons*), 130.21 (*aromatic carbon* ×2), 130.35, 130.53, 130.60, 130.73, 130.88 (*aromatic carbons*), 134.93 (*C*5), 159.03, 159.08, 159.08, 159.10, 159.11, 159.14, 159.22 (*aromatic carbons*); FDMS (%, rel int.) *m/z*: 1179 (1.6, $[M+H]^+$), 1178 (4.3, $[M]^+$), 1057 (100, $[M-CH_3OPhCH_2]^+$), 121 (18, $[CH_3OPhCH_2]^+$); FD-HR-MS: calcd for $C_{69}H_{78}O_{17}$ $[M]^+$ 1178.5239; found, *m/z* 1178.5227.

4.8. [2,3,4,6-*O*-Tetrakis-(4-methoxyphenylmethyl)-β-D-glucopyranosyl]-(1→4)-α-2,3,6otris-*O*-(4-methoxypheny lmethyl)-$\Delta^{5,5a}$carbaglucopyranose (α-11)

In a similar manner described in Section 4.7, ***S*-10** (64.3 mg, 53.3 μmol) was treated with Grubbs's second-generation catalyst (1.4 mg, 1.6 μmol) in toluene (10 mL). Following the same purification gave α-**11**(57.0 mg, 91%) as an oil, $[\alpha]_D^{25}$+4.6 (*c* 1.42, $CHCl_3$), IR (film) 3460, 2910, 1610, 1510, 1250, 1070, 1035, 820 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 2.69 (1H, d, *J* = 9.1 Hz, C1O*H*), 3.34 (1H, dd, *J* = 8.0, 8.9 Hz, C2′*H*), 3.39 (1H, ddd, *J* = 2.3, 4.0, 8.9 Hz, C5′*H*), 3.53 (1H, t, *J* = 8.9 Hz, C4′*H*), 3.56 (1H, t, *J* = 8.9 Hz, C3′*H*), 3.62-3.63 (2H, m, C6′H_2), 3.65 (1H, t, *J* = 5.1 Hz, C2*H*), 3.74 (3H, s, OCH_3), 3.76 (6H, s, OCH_3 ×2), 3.77 (6H, s, OCH_3 ×2), 3.79, 3.79 (6H, s, OCH_3 ×2), 3.80 (1H, m, C6*H*H), 4.24 (1H, d, *J* = 11.4 Hz, ArC*H*-HO), 4.25 (2H, C6*H*H, C4*H*), 4.33 (1H, d, *J* = 11.4 Hz, ArC*H*HO), 4.34–4.36 (2H, C1*H*, C3*H*), 4.39 (1H, d, *J* = 11.2 Hz, ArC*H*HO), 4.39, 4.43 (each 1H, d, *J* = 13.2 Hz, ArCH_2O), 4.45 (1H, d, *J* = 10.4 Hz, ArC*H*HO), 4.53 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.57 (1H, d, *J* = 8.0 Hz, C1*H*), 4.57 (1H, d, *J* = 11.4 Hz, ArC*H*HO), 4.68 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.73 (1H, d, *J* = 10.4 Hz, ArC*H*HO), 4.73 (2H, d, *J* = 11.2 Hz, ArC*H*HO ×2), 4.73 (1H, d, *J* = 10.4 Hz, ArC*H*HO), 4.76 (1H, d, *J* = 11.4 Hz, ArC*H*HO), 4.84 (1H, d, *J* = 10.4 Hz, ArC*H*HO), 5.78 (1H, br d, *J* = 1.7 Hz, C5a*H*), 6.78-6.84 (14H, *aromatic protons*), 7.08 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.15–7.22 (12H, *aromatic protons*); ^{13}C NMR (125 MHz, $CDCl_3$) δ: 55.15 (OCH_3), 55.19, 55.19 (OCH_3 ×4), 55.24, (OCH_3 ×2), 65.05 (*C*1), 68.80 (*C*6′), 70.21 (C6), 71.19, 71.43, 72.51, 72.92 (each ArCH_2O), 74.42 (*C*4), 74.50, 74.54 (each ArCH_2O), 74.70 (*C*5′), 75.17 (*C*2), 75.32 (ArCH_2O), 75.48 (*C*3), 77.66 (*C*4′), 82.47 (*C*2′), 84.54 (*C*3′), 104.76 (*C*1′), 113.60, 113.62, 113.70, 113.71, 113.71, 113.75, 113.75 (*aromatic carbons*), 128.31 (*C*5a), 129.21, 129.34, 129.39, 129.42, 129.43, 129.50, 129.57, 130.13, 130.19, 130.31, 130.34, 130.77, 130.83, 130.85 (*aromatic carbons*), 135.29 (*C*5), 159.01, 159.06, 159.06, 159.11, 159.12, 159.16, 159.23 (*aromatic carbons*); FABMS (%, rel int.) *m/z*: 1201 (13, $[M+Na]^+$), 121 (100, $[CH_3OPhCH_2]^+$); FAB-HR-MS: calcd for $C_{69}H_{78}O_{17}Na$ $[M+Na]^+$ 1201.5137; found, *m/z* 1201.5162.

4.9. Stereochemical inversion of the C1OH group of β-11 into α-11

A solution of β-**11** (68.1 mg, 58.0 μmol) in THF (1.0 mL) was stirred with triphenylphosphine (46.0 mg, 175 μmol), *p*-nitrobenzoic acid (28.9 mg, 173 μmol), and diethyl azodicarboxylate (2.2 M solution in toluene, 79.0 μL, 174 μmol) at room temperature for 30 min. The mixture was poured into H_2O (20 mL) and extracted with EtOAc (20 mL × 3). The organic layers were washed with brine (20 mL), combined, dried over $MgSO_4$, and then concentrated in vacuo. Purification of the residue by silica gel column chromatography (EtOAc/hexane = 40:60) gave the oil containing the corresponding *p*-nitrobenzoate. Analytical sample was obtained by preparative silica gel TLC (EtOAc/hexane = 20:80). $[\alpha]_D^{23}$+37 (*c* 0.20, $CHCl_3$); IR (film) 2910, 1735, 1510, 1460, 1245, 1070 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 3.38 (1H, dd, *J* = 7.8, 9.0 Hz, C2′*H*), 3.38 (1H, m, C5′*H*), 3.57 (2H, C3′*H*, C4′*H*),3.62 (2H, m,C6′H_2), 3.73, 3.74, 3.756, 3.757, 3.78 (each 3H, OCH_3), 3.79 (6H,

s, OCH_3 ×2), 3.81 (1H, dd, *J* = 3.8, 7.2 Hz, C2*H*), 3.91 (1H, br d, *J* = 12.7 Hz, C6*H*H), 4.25 (1H, d, *J* = 11.3 Hz, ArC*H*HO), 4.27 (1H, br d, *J* = 12.7 Hz, C6*H*H), 4.31 (1H, dd, *J* = 4.2, 7.2 Hz, C3*H*), 4.32 (1H, d, *J* = 11.3 Hz, ArC*H*HO), 4.37 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.39 (1H, br d, *J* = 4.2 Hz, C4*H*), 4.43 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.45 (1H, d, *J* = 10.3 Hz, ArC*H*HO), 4.49, 4.61 (each 1H, d, *J* = 11.5 Hz, ArCH_2O), 4.63 (1H, d, *J* = 10.7 Hz, ArC*H*HO), 4.65 (1H, d, *J* = 7.8 Hz, C1′*H*), 4.69 (1H, d, *J* = 11.5 Hz, ArC*H*HO), 4.73 (1H, d, *J* = 10.3 Hz, ArC*H*HO), 4.74 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 4.74 (1H, d, *J* = 10.7 Hz, ArC*H*HO), 4.78 (1H, d, *J* = 11.5 Hz, ArC*H*HO), 4.82 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 5.79 (1H, vrt, *J* = 3.8 Hz, C1*H*), 5.89 (1H, br d, *J* = 3.8 Hz, C5a*H*), 6.70 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 6.77–.84 (14H, *aromatic protons*), 7.06–.24 (14H, *aromatic protons*), 8.15, 8.24 (each 2H, br d, *J* = 8.9 Hz, *aromatic protons*); ^{13}C NMR (125 MHz, $CDCl_3$) δ 55.16, 55.16, 50.20 (OCH_3), 55.21, 55.21, 55.26, 55.26 (OCH_3), 68.60 (*C*6′), 69.31 (*C*1), 69.79 (*C*6), 71.74, 71.82, 72.83, 72.96, 74.51 (ArCH_2O ×5), 74.57 (*C*2), 74.84 (*C*2′ or *C*5′), 74.84, 75.31 (ArCH_2O ×2), 76.37 (*C*4), 77.12 (*C*3), 77.62 (*C*3′ or *C*4′), 82.44 (*C*2′ or *C*5′), 84.66 (*C*3′ or *C*4′), 107.24 (*C*1′), 113.57, 113.58, 113.62, 113.70, 113.77, 113.77, 113.77 (*aromatic carbons*), 123.44 (*C*5a), 129.27, 129.32, 129.39, 129.39, 129.40, 129.43, 129.59, 130.05, 130.15, 130.21, 130.32, 130.68, 130.80, 130.84, 130.89, 135.69 (*aromatic carbons*), 140.01 (*C*5), 150.19, 159.02, 159.04, 159.07, 159.12, 159.15, 159.15, 159.26 (*aromatic carbons*), 164.23 (*C*═O), ESIMS (%, rel int.) *m/z* 1366.5027 (45, calcd for $C_{76}H_{81}O_{20}NK$ $[M+K]^+$: 1366.4989), 1350.5250 (50, calcd for $C_{76}H_{81}O_{20}NNa$ $[M+Na]^+$: 1350.5929), 1345.5730 (100, calcd for $C_{76}H_{85}N_2O_{20}$ $[M+NH_4]^+$: 1345.5696). The *p*-nitrobenzoate was diluted with MeOH (4.0 mL) and stirred with NaOH (11.6 mg, 290 μmol) at room temperature for 2 h. The mixture was poured into H_2O (20 mL) and extracted with AcOEt (20 mL × 3). The organic layers were washed with brine (20 mL), combined, dried over $MgSO_4$, and then cocncentrated in vacuo. Silica gel column chromatography of the residue (EtOAc/hexane = 30:70) gave **α-11** (30.7 mg, 44%). The ^{1}H NMR spectrum and R_f value in the silica gel TLC were identical to the authentic **α-11** described in Section 4.8.

4.10. [2,3,4,6-*O*-Tetrakis-(4-methoxyphenylmethyl)-β-D-glucopyranosyl]-(1→4)-β-2,3,6-tris-*O*-(4-methoxyphenyl methyl)-$\Delta^{5,5a}$carbaglucopyranosyl acetate (β-12)

A mixture of β-**11** (17.0 mg, 14.0 μmol) and acetic anhydride (300 μL) and *N*,*N*-dimetyl-4-aminopyridine (1.7 mg, 14.0 μmol) in pyridine (1.1 mL) was stirred at room temperature for 10 min. After concentration in vacuo, the residue was purified with silica gel column chromatography (EtOAc/hexane = 60:40) to give β-**12** (16.1 mg, 92%). $[\alpha]_D^{24}$ −47.5 (*c* 0.62, $CHCl_3$); IR (film) 2910, 1735, 1510, 1460, 1245, 1070 cm^{-1}; ^{1}H NMR (500 MHz, C_6D_6) δ 1.98 (3H, s, CH_3CO), 3.32 (1H, m, C5′*H*), 3.36 (1H, dd, *J* = 7.7, 9.0 Hz, C2′H), 3.52-3.57 (3H, C3′*H*, C4′*H*, C6′*H*H), 3.64 (1H, d, *J* = 7.5, 9.6 Hz, C2*H*), 3.67 (1H, m, C6′*H*H), 3.75 (1H, m, C6*H*H), 3.74, 3.747, 3.753 (each 3H, s, ArOCH_3), 3.78 (6H, s, ArOCH_3 ×2), 3.788, 3.793 (each 3H, s, ArOCH_3), 3.81 (1H, dd, *J* = 70., 9.6 Hz, C3*H*), 4.25 (1H, d, *J* = 11.3 Hz, ArC*H*HO), 4.29 (1H, br d, *J* = 11.7 Hz, C6*H*H), 4.30 (1H, d, *J* = 11.3 Hz, ArC*H*HO), 4.39 (2H, s, ArCH_2O), 4.44 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.53 (1H, d, *J* = 11.2 Hz, ArC*H*HO), 4.57 (1H, br d, *J* = 7.0 Hz, C4*H*), 4.67 (1H, d, *J* = 7.7 Hz, C1′*H*), 4.68 (1H, dd, *J* = 11.1 Hz, ArC*H*HO), 4.69 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 4.72 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.72 (1H, d, *J* = 11.1 Hz, ArC*H*HO), 4.74 (1H, d, *J* = 11.1 Hz, ArC*H*HO), 4.74 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.85 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.96 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 5.45 (1H, br dd, *J* = 1.5, 7.5 Hz, C1*H*), 5.58 (1H, br d, *J* = 1.5 Hz, C5a*H*), 6.76–6.85 (14H, *aromatic protons*), 7.06-7.30 (14H, *aromatic protons*); ^{13}C NMR (125 MHz, C_6D_6) δ 20.70 (3H, s, COCH_3), 54.68, 54.69, 54.70, 54.71, 54.72, 54.74, 54.75 (ArOCH_3 ×7), 69.12 (*C*6′), 70.14 (*C*6), 72.01, 73.19 (ArCH_2O ×2), 73.34 (*C*1), 74.34, 74.55, 74.91, 74.95, 74.34 (ArCH_2O ×5), 75.76 (*C*5′), 77.54 (*C*4), 78.21 (*C*4′), 80.60 (*C*2), 82.62 (*C*3), 83.03 (*C*2′), 85.25 (*C*3′), 103.38 (*C*1′), 113.90, 113.93, 113.93, 114.03, 114.04, 114.05, 114.18 (*aromatic carbons*), 125.57 (*C*5a), 130.69, 131.11, 131.32, 131.35, 131.53, 131.79, 132.11 (*aromatic carbons*), 138.66 (*C*5′), 159.59, 159.60, 159.63, 159.65, 159.66, 159.77, 159.79 (*aromatic carbon*), 169.87 (*C*═O), ESIMS (%, rel int.) *m/z* 1259.5900 (28, calcd for $C_{71}H_{80}O_{18}K$ $[M+K]^+$: 1259.4928), 1243.5282 (25, calcd for $C_{71}H_{80}O_{18}Na$ $[M+Na]^+$: 1243.5242), 1238.5698 (100, calcd for $C_{71}H_{86}NO_{19}$ $[M+NH_4]^+$ 1238.5688).

4.11. [2,3,4,6-*O*-Tetrakis-(4-methoxyphenylmethyl)-β-D-glucopyranosyl]-(1→4)-α-2,3,6-tris-*O*-(4-methoxyphenyl methyl)-$\Delta^{5,5a}$carbaglucopyranosyl acetate (α-12)

In the same manner as described in Section 4.10, α-**17** (23.2 mg, 20.0 μmol) was treated with acetic anhydride (1.0 mL) and *N*,*N*-dimetyl-4-aminopyridine (2.4 mg, 19.7 mmol) in pyridine (1.6 mL) to give α-**11** (23.6 mg, 96%). $[\alpha]_D^{23}$+13 (*c* 0.59, $CHCl_3$), IR (film) 2910, 1735, 1610, 1510, 1460, 1245, 1070 cm^{-1}, ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.08 (3H, s, CH_3CO), 3.35 (1H, m, C5′*H*), 3.37 (1H, dd, *J* = 7.7, 8.7 Hz, C2′*H*), 3.56 (2H, C3′*H*, C4′*H*), 3.61 (2H, m, C6H_2), 3.67 (1H, dd, *J* = 3.7, 7.2 Hz, C2*H*), 3.74, 3.75 (each 3H, s, ArOCH_3), 3.76 (6H, s, ArOCH_3 ×2),3.77, 3.78, 3.79 (each 3H, s, ArOCH_3), 3.85 (1H, br d, *J* = 12.5 Hz, C6*H*H), 4.23 (1H, dd, *J* = 4.1, 7.2 Hz, C3*H*), 4.23 (1H, d, *J* = 11.4 Hz, ArC*H*HO), 4.27 (1H, br d, *J* = 12.5, C6*H*H), 4.30 (1H, d, *J* = 11.4 Hz, ArC*H*HO), 4.33 (1H, br d, *J* = 4.1 Hz, C4*H*), 4.35, 4.42 (each 1H, d, *J* = 11.8 Hz, ArCH_2O), 4.45 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.50, 4.58 (each 1H, d, *J* = 11.5 Hz, ArCH_2O). 4.63 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 4.63 (1H, d, *J* = 11.3 Hz, ArC*H*HO), 4.64 (1H, d, *J* = 10.9 Hz, C1*H*), 4.72, 4.73 (each 1H, d, *J* = 10.5, ArC*H*HO), 4.74 (1H, d, *J* = 11.3 Hz, ArC*H*HO), 4.76 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 4.82 (1H, d, *J* = 10.5, ArC*H*HO), 5.57 (1H, t, *J* = 3.7 Hz, C1*H*), 5.78 (1H, br d, *J* = 3.7 Hz, C5a*H*), 6.77–6.84 (14H, *aromatic protons*), 7.07 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.13–7.24 (12H, *aromatic protons*), ^{13}C NMR (125 MHz, C_6D_6) δ 20.78 (SCOCH_3), 54.67, 54.67, 54.69, 54.70, 54.70, 54.73 (each ArOCH_3), 67.84 (*C*1), 69.17 (*C*6′), 70.45 (*C*6), 71.99, 72.16, 73.20, 73.62, 74.56, 74.79, 75.33 (each ArCH_2O), 75.56 (*C*5′), 76.06 (*C*2), 76.79 (*C*4), 78.13 (*C*4′), 78.31 (*C*3), 82.91 (*C*2′), 85.18 (*C*3′), 104.59 (*C*1′), 113.94, 113.96, 113.96, 113.99, 114.01, 114.05, 114.17 (*aromatic carbons*), 123.60 (*C*5′a), 129.50, 129.53, 129.67, 129.68, 129.77, 129.84, 129.91, 130.84, 131.26, 131.34, 131.40, 131.75, 131.94 (*aromatic carbons*), 140.21 (C5), 159.60, 159.63, 159.65, 159.65, 159.67, 159.67, 159.76 (*aromatic carbons*), 170.04 (*C*═O), ESIMS (%, rel int.) *m/z* 1259.4909 (45, calcd for $C_{71}H_{80}O_{18}K$ $[M+K]^+$: 1259.4928), 1243.5165 (20, calcd for $C_{71}H_{80}O_{18}Na$ $[M+Na]^+$: 1243.5242), 1238.5617 (100, calcd for $C_{71}H_{82}O_{19}$ $[M+H_2O]^+$ 1238.5450).

4.12. [2,3,4,6-*O*-Tetrakis-(4-methoxyphenylmethyl)-β-D-glucopyranosyl]-(1→4)-β-2,3,6-tris-*O*-(4-methoxyphenyl methyl)-1-acetylthio-$\Delta^{5,5a}$carbaglucopyranosyl acetate (14)

A solution of α-**11** (244 mg, 207 μmol) in CH_2Cl_2 (2.0 mL) was stirred with methansulfonic anhydride (154 mg, 885 μmol) and triethylamine (290 mL, 3.9 mmol) at −15 °C for 20 min. The mixture was poured into H_2O (25 mL) and extracted with Et_2O (25 mL × 3). The ethereal solutions were washed with brine (20 mL), combined, dried over $MgSO_4$ and then cocncentrated in vacuo. Silica gel column chromatography of the residue (EtOAc/hexane = 40:60) gave the crude mesylate which was immediately diluted with DMF (2.0 mL). Potassium thioacetate (240 mg, 2.11 mmol) was added to the solution at 0 °C. After stirring for 30 min at the same temperature, the cooling bath was removed

and the mixture was further stirred at room temperature for additional 1 h. The mixture was poured into H_2O (25 mL) and extracted with EtOAc (25 mL × 3). The organic solutions were washed with brine (20 mL), combined, dried over $MgSO_4$ and then concentrated in vacuo. Silica gel column chromatography of the residue (EtOAc/hexane = 40:60) gave **14** (223 mg, 87%) as caramel. $[\alpha]_D^{23}$ −59.5 (*c* 18.6, $CHCl_3$); IR (film) 2915, 2835, 1685, 1610, 1510, 1460, 1245 cm^{-1}; ^1H NMR (400 MH_Z, $CDCl_3$) δ 2.31 (3H, s, SCOC*H*$_3$), 2.34 (1H, dd, *J* = 7.7, 9.6 Hz, C2′*H*), 3.35 (1H, m, C5′*H*), 3.53 (2H, C3′*H*, C4′*H*), 3.61 (2H, C6′H_2), 3.67 (1H, dd, *J* = 4.8, 6.0 Hz, C2′*H*), 3.73, 3.748, 3.753, 3.76, 3.779, 3.788, 3.791 (each 3H, s, OC*H*$_3$), 4.12 (1H, dd, *J* = 3.9, 6.0 Hz, C3*H*), 4.23 (1H, d, *J* = 11.4 Hz, ArC*H*HO), 4.28 (1H, br d, *J* = 12.6 Hz, C6*H*H), 4.32 (1H, d, *J* = 11.4 Hz, ArC*H*HO), 4.36 (1H, br d, *J* = 3.9 Hz, C4*H*), 4.39 (1H, d, *J* = 11.8 Hz, ArC*H*HO), 4.40 (1H, br dd, *J* = 3.8, 4.8 Hz, C1*H*), 4.42 (1H, d, *J* = 11.8 Hz, ArC*H*HO), 4.44 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.48 (1H, d, *J* = 11.0 Hz, ArC*H*HO), 4.58 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.60 (1H, d, *J* = 7.7 Hz, C1′*H*), 4.67 (1H, d, *J* = 11.0 Hz, ArC*H*HO), 4.71 (1H, d, *J* = 10.5 Hz, ArC*H*HO),4.72 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.72 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.74 (1H, d, *J* = 10.6 Hz, ArC*H*HO), 4.83 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 5.67 (1H, br d, *J* = 3.8 Hz, C5a*H*), 6.76-6.85 (14H, *aromatic protons*), 7.08, 7.14 (each 2H, br d, *J* = 8.6 Hz, *aromatic protons*), 7.16–7.2 (8H, *aromatic protons*), 7.23 (2H, br d, *J* = 7.3 Hz, *aromatic protons*); ^{13}C NMR (100 MHz, $CDCl_3$) δ 30.26 (SCOC*H*$_3$), 41.98 (*C*1), 51.15, 55.18, 55.18, 55.19, 55.19, 55.24, 55.24 (OC*H*$_3$ ×6), 67.86 (*C*6′), 70.06 (*C*6), 71.26, 72.34, 72.8, 72.92 (OC*H*$_3$), 74.42 (*C*4), 74.43 (OC*H*$_3$), 74.50 (*C*5′), 74.82, 75.26 (OC*H*$_3$), 77.41 (*C*2), 77.69 (*C*4′), 78.64 (*C*3), 82.34 (*C*2′), 84.54 (*C*3′), 104.38 (*C*1′), 113.51, 113.55, 113.59, 113.68, 113.71, 113.73 (*aromatic carbons*), 125.65 (*C*5a), 129.17, 129.22, 129.27, 129.39, 129.50, 129.56, 129.60, 130.23, 130.32, 130.42, 130.52, 130.78, 130.93, 130.97 (*aromatic carbons*), 135.03 (*C*5), 158.93, 158.97, 159.02, 159.06, 159.07, 159.10, 159.21 (*aromatic carbon*), 195.29 (SC=O), ESIMS (%, rel int.) *m/z* 1275.4811 (17, calcd for $C_{71}H_{80}O_{17}SK$ $[M+K]^+$: 1366.4989), 1259.5075 (50, calcd for $C_{71}H_{80}O_{17}SNa$ $[M+Na]^+$: 1259.5014), 1254.5507 (100, calcd for $C_{71}H_{84}O_{17}SN$ $[M+NH_4]^+$: 1254.5460).

4.13. Methyl 2,3-*O*-bis-(4-methoxyphenylmethyl)-4,6-*O*-(4-methoxyphenylmethylidene)-α-D-galactopyranoside (16a)

A solution of methyl α-D-galactopyranoside (122 mg, 628 μmol) in DMF (1.0 mL) was stirred with *p*-anisaldehyde dimethylacetal (171 mg, 940 μmol) in the presence of camphorsulfonic acid (1.5 mg, 6.5 μmol) at 80 °C for 30 min. The mixture was poured into saturated aqueous $NaHCO_3$ solution (20 mL) and extracted with EtOAc (15 mL × 3). The organic solutions were washed with H_2O (20 mL) and brine (15 mL), combined, dried over $MgSO_4$ and then concentrated in vacuo. Silica gel column chromatography of the residue (MeOH/EtOAc = 10:90) gave methyl 2,3-*O*-bis-(4-methoxyphenylmethyl)-α-D-galactopyranoside (164 mg, 83%) as an oil. $[\alpha]_D^{23}$ +130 (*c* 0.80, $CHCl_3$); IR (film) 3470, 3400, 2910, 1620, 1515, 1035 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 2.13 (1H, d, *J* = 7.8 Hz, C2O*H*), 2.37 (1H, d, *J* = 9.1 Hz, C3O*H*), 3.46 (3H, s, C1OC*H*$_3$), 3.69 (1H, q, *J* = 1.5 Hz, C5*H*), 3.80 (3H, s, ArOC*H*$_3$), 3.87 (1H, ddd, *J* = 3.4, 9.1, 10.0 Hz, C3*H*), 3.93 (1H, ddd, *J* = 3.4, 7.8, 10.0 Hz, C2*H*), 4.07 (1H, dd, *J* = 1.5, 12.6 Hz, C6*H*H), 4.25 (1H, dd, *J* = 1.5, 3.4 Hz, C4*H*), 4.28 (1H, dd, *J* = 1.5, 12.6 Hz, C6*H*H), 4.93 (1H, d, *J* = 3.4 Hz, C1*H*), 5.51 (1H, s, ArC*H*), 6.90 and 7.42 (each 2H, br d, *J* = 7.4 Hz, aromatic protons); ^{13}C NMR (100 MHz, $CDCl_3$) δ 55.30 (ArOCH_3), 55.72 (C1OCH_3), 62.72 (C5), 69.30 (C6), 69.90, 69.95 (C2, C3), 75.80 (C4), 100.19 (C1), 101.26 (ArCH), 113.62, 127.59, 130.04, 160.27 (*aromatic carbons*). Sodium hydride (washed with hexane 240 mg, 10.0 mmol) was added slowly to a DMF solution (10 mL) of the diol (780 mg, 2.5 mmol) at room temperature. Upon the addition of the substrate, H_2 gas was bubbled. After stirring for 10 min, 50% 4-methoxybenzyl bromide (4.0 g, 9.9 mmol) in toluene (5.0 mL) was added at 0 °C. After stirring at 0 °C for 10 min, the cooling bath was removed and the mixture was stirred at room temperature for 30 min. Methanol (2.0 mL) and Et_3N (2.0 mL) were successively added to decompose excess reagent. After stirring for additional 30 min, the mixture was poured into H_2O (100 mL), and extracted with EtOAc (70 mL × 3). The organic layers were washed successively with H_2O (100 mL), and brine (100 mL), combined, dried over $MgSO_4$, and then concentrated in vacuo to give the crude solid. Recrystallization from EtOAc/hexane (30:70) gave **16a** (1.10 g, 80%) as needles. mp 107–109 °C; $[\alpha]_D^{23}$ +61.5 (*c* 1.00, $CHCl_3$); IR (film) 2910, 1615, 1515, 1250, 1100, 1035, 825 cm^{-1}, ^1H NMR (400 MH_Z, $CDCl_3$) δ 3.37 (3H, s, OC*H*$_3$), 3.55 (1H,dt, *J* = 0.8, 1.5 Hz, C5*H*), 3.80 (6H, s, OC*H*$_3$ ×2), 3.81 (each 3H, s, OC*H*$_3$), 3.92 (1H, dd, *J* = 3.4, 10.2 Hz, C3*H*), 3.97 (1H, dd, *J* = 1.5, 12.6 Hz, C6*H*H), 4.01 (1H, dd, *J* = 3.4, 10.2 Hz, C2*H*), 4.11 (1H, dd, *J* = 0.8, 3.4 Hz, C4*H*), 4.17 (1H, dd, *J* = 1.5, 12.6 Hz, C6*H*H), 4.59 (1H, d, *J* = 11.8 Hz, ArC*H*HO), 4.66 (1H, d, *J* = 11.9 Hz, ArC*H*HO), 4.69 (1H, d, *J* = 3.4 Hz, C1*H*), 4.75 (1H, d, *J* = 11.9 Hz, ArC*H*HO), 4.79 (1H, d, *J* = 11.8 Hz, ArC*H*HO), 5.42 (1H, s, ArC*H*), 6.84–6.89 (6H, *aromatic protons*), 7.29 (2H, br d, *J* = 8.6 Hz, *aromatic protons*), 7.32 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.43 (2H, br d, *J* = 8.8 Hz, *aromatic protons*), ^{13}C NMR (100 MHz, $CDCl_3$) δ: 55.23, 55.23 (OCH_3 ×2), 55.26, 55.45 (each OCH_3), 62.40 (*C*5), 69.33 (*C*6), 71.82, 73.40 (each ArCH_2O), 74.86 (*C*4), 74.98 (*C*2), 75.54 (*C*3), 99.55 (*C*1), 101.03 (ArCH), 113.42, 113.67, 113.70, 127.67, 129.19, 129.67, 130.50, 130.74, 130.89, 159.09, 159.22, 159.99 (*aromatic carbons*); FABMS (%, rel int.) *m/z*: 575 (8.9, $[M+Na]^+$), 553 (19, $[M+H]^+$), 431 (90, $[M-CH_3OPh-CH_2]^+$), 121 (100, $[CH_3OPhCH_2]^+$); FAB-HR-MS: calcd for $C_{31}H_{36}O_9Na$ $[M+Na]^+$ 575.2257; found, *m/z* 575.2259.

4.14. Methyl 2,3-*O*-bis-(4-methoxyphenylmethyl)-4,6-*O*-(4-methoxyphenylmethylidene)-β-D-galactopyranoside (16b)

In a similar manner as described in Section 4.13, methy β-D-galactopyranoside (300 mg, 1.50 mmol) was treated with *p*-anisaldehyde dimethylacetal (410 mg, 2.3 mmol), *p*-TsOH (4.5 mg, 19.4 μmol) in DMF (2.0 mL) at 100 °C for 30 min. The similar work-up that then followed gave the corresponding 4,6-*O*-(4-methoxyphenylmethylidene)acetal (337 mg, 73%) as amorphous powder. $[\alpha]_D^{23}$ −13.2 (*c* 1.05, CH_3OH); IR (film) 3400, 2840, 1615, 1515, 1250, 1070, 1055, 990, 820 cm^{-1}; ^1H NMR (400 MH_Z, $CDCl_3$) δ 2.49 (1H, d, *J* = 9.6 Hz, C3O*H*), 2.50 (1H, d, *J* = 1.9 Hz, C2O*H*), 3.49 (1H, ddd, *J* = 1.3, 1.5, 1.9 Hz, C5*H*), 3.59 (3H, s, OC*H*$_3$), 3.68 (1H, dt, *J* = 3.9, 9.6 Hz, C3*H*), 3.75 (1H, ddd, *J* = 1.9, 7.6, 9.6 Hz, C2*H*), 3.81 (3H, s, OC*H*$_3$), 4.08 (1H, dd, *J* = 1.9, 12.5 Hz, C6*H*H), 4.20 (1H, dd, *J* = 1.3, 3.9 Hz, C4*H*), 4.22 (1H, d, *J* = 7.6 Hz, C1*H*), 4.35 (1H, dd, *J* = 1.5, 12.5 Hz, C6*H*H), 5.51 (1H, s, ArC*H*), 6.88, 7.43 (each br d, 2H, *J* = 8.8 Hz, *aromatic protons*); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 55.30, 57.20 (each OCH_3), 66.70 (*C*5), 69.12 (*C*6), 71.90 (*C*2), 72.78 (*C*3), 75.25 (*C*4), 101.43 (ArCH), 103.77 (*C*1), 113.58, 127.75, 129.97, 160.27 (*aromatic carbons*); ESIMS (%, rel int.) *m/z*: 335.1118 (8.2, calcd for $C_{15}H_{20}O_7Na$ $[M+Na]^+$: 335.1107), 313.1297 (100, calcd for $C_{15}H_{21}O_7$ $[M+H]^+$: 313.1287). In a similar manner as described for **16a**, the obtained acetal (714 mg, 2.28 mmol mmol) was treated with NaH (110 mg, 4.58 mmol) and 4-methoxybenzyl bromide (924 mg, 4.6 mmol) in DMF (16 mL) to give **16b** (924 g, 73%) as needles after recrystallization from EtOAc/hexane (30:70). mp 182–184 °C; $[\alpha]_D^{23}$ +57.7 (*c* 0.70, $CHCl_3$); IR (film) 2850, 1610, 1515, 1250, 1085, 1035, 825 cm^{-1}, ^1H NMR (400 MH_Z, $CDCl_3$) δ 3.29 (1H, ddd, *J* = 0.7, 1.4, 1.5 Hz, C5*H*), 3.50 (1H, dd, *J* = 3.5, 9.7 Hz, C3*H*), 3.58 (3H, s, OC*H*$_3$), 3.79 (1H, dd, *J* = 7.7, 9.7 Hz, C2*H*), 3.795 (3H, s, OC*H*$_3$), 3.801, (6H, s, OC*H*$_3$ ×2), 3.99 (1H, dd, *J* = 1.6, 12.4 Hz, C6*H*H), 4.04 (1H, dd, *J* = 0.7, 3.5 Hz, C4*H*), 4.28 (1H, d, *J* = 7.7 Hz, C1*H*), 4.28 (1H, dd,

J = 1.4, 12.4 Hz, C6*H*H), 4.66, 4.70 (each1H, d, *J* = 12.0 Hz, ArCH_2O), 4.69 (1H, d, *J* = 10.4 Hz, ArC*H*HO), 4.81 (1H, d, *J* = 10.4 Hz, ArC*H*HO), 5.44 (1H, s, ArC*H*), 6.83, 6.86, 6.87, 7.28, 7.31, 7.47 (each 2H, br d, *J* = 8.8 Hz, *aromatic protons*), ^{13}C NMR (100 MHz, $CDCl_3$) δ: 55.25, 55.27, 55.29, 57.03 (each OCH_3), 66.38 (*C*5), 69.17 (*C*6), 71.63 (ArCH_2O), 74.03 (*C*4), 74.89 (ArCH_2O), 78.21 (*C*2), 78.75 (*C*3), 101.30 (Ar*C*H), 104.74 (*C*1), 113.45, 113.67, 113.70, 127.86, 129.34, 129.68, 130.51, 130.51, 131.13, 159.13, 159.18, 160.04 (*aromatic carbons*); ESIMS (%, rel int.) *m/z* 591.1971 (18, calcd for $C_{31}H_{36}O_9K$ $[M+K]^+$:591.1996), 575.2233 (12, calcd for $C_{31}H_{36}O_9Na$ $[M+Na]^+$: 575.2257), 570.2677 (100, calcd for $C_{31}H_{40}O_9N$ $[M+NH_4]^+$: 570.2703), 553.2414 (25, calc for $C_{31}H_{37}O_9$ $[M+H]^+$: 553.2438), 431.1699 (14, calcd for $C_{23}H_{27}O_8$ $[M-CH_3OPhCH_2]^+$: 431.1706).

4.15. Methyl 2,3,6-*O*-tris-(4-methoxyphenylmethyl)-α-D-galactopyranoside (17a)

A suspension of **16a** (64.1 mg, 115 μmol) and finely powdered molecular sieves (acid washed type, Fluka #69841, activated 200 °C for 20 min under vacuumed condition before use, 30 mg) in THF (1.0 mL) was stirred with boran trimethylamine complex (50.0 mg, 686 μmol) and $AlCl_3$ (93.0 mg, 698 μmol) at room temperature for 10 min. Saturated aqueous potassium tartarate (5 mL) was added and the mixture was further stirred at room temperature for 20 min. After filtration, the mixture was extracted with EtOAc (10 mL × 3), washed with brine (20 mL), combined, dried over $MgSO_4$, and then concentrated in vacuo. Silica gel column chromatography of the residue (EtOAc/hexane = 30:70) gave **17a** (37.2 mg, 57%) as caramel. $[\alpha]_D^{23}$+17.9 (*c* 0.87, $CHCl_3$); IR (film) 3500, 2910, 1610, 1510, 1460, 1250, 1090 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.60 (1H, s, C4O*H*), 3.35 (3H, s, C1OCH_3), 3.61 (1H, dd, *J* = 6.2, 10.2 Hz, C6*H*HO), 3.68 (1H, dd, *J* = 5.4, 10.2 C6*H*HO), 3.78, 3.79 (each 3H, s, ArOCH_3), 3.80 (2H, C2*H*, C3*H*), 3.84 (1H, br dd, *J* = 5.4, 6.2 Hz, C5*H*), 3.99 (1H, br s, C4*H*), 4.47, 4.50 (each 1H, d, *J* = 11.5 Hz, ArCH_2O), 4.58 (1H, d, *J* = 11.8 Hz, ArC*H*HO), 4.60 (1H, d, *J* = 2.3 Hz, C1*H*), 4.61, 4.70 (1H, dd, *J* = 11.3 Hz, ArCH_2O), 4.70 (1H, dd, *J* = 11.8 Hz, ArC*H*HO), 6.82–6.95 (6H, *aromatic protons*), 7.22–7.30 (6H, *aromatic protons*); ^{13}C NMR (100 MHz, $CDCl_3$) δ 55.18 (ArOCH_3, and C1OCH_3), 55.23 (ArOCH_3), 68.09 (*C*4), 68.27 (*C*5), 69.23 (*C*6), 72.35, 73.09, 73.20 (ArCH_2O ×3), 75.23 (*C*2 or *C*3), 77.22 (*C*2 or *C*3), 98.63 (*C*1), 113.73, 113.81, 129.25, 129.39, 129.58, 130.07, 130.30, 130.50, 159.18, 159.26, 159.28 (*aromatic carbons*), ESIMS (%, rel int.) *m/z* 593.2150 (12, calcd for $C_{31}H_{38}KO_9$ $[M+K]^+$: 593.2159), 577.2412 (18, calcd for $C_{31}H_{38}NaO_9$ $[M+Na]^+$: 577.2414, 572.2865 (100, calcd for $C_{31}H_{42}NO_9$ $[M+NH_4]^+$: 572.2860).

4.16. Methyl 2,3,6-*O*-tris-(4-methoxyphenylmethyl)-β-D-galactopyranoside (17b)

In a similar manner as described in Section 4.15, **16b** (187 mg, 338 μmol) was treated with the finely powdered molecular sieves (60.0 mg), boran trimethylamine complex (157 mg, 2.15 mmol) and $AlCl_3$ (277 mg, 2.07 mmol) in THF (4.0 mL) to give **17b** (125 mg, 66%) as caramel after work-up. $[\alpha]_D^{23}$+5.4 (*c* 0.97, $CHCl_3$); IR (film) 3490, 2910, 2835, 1610, 1510, 1460, 1250, 1095 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.50 (1H, d, *J* = 1.7 Hz, O*H*), 3.44 (1H, dd, *J* = 3.3, 9.4 Hz,. C3*H*), 3.51 (1H, br dd, *J* = 5.9, 6.1 Hz, C5*H*), 3.55 (3H, C1OCH_3), 3.58 (1H, dd, *J* = 7.8, 9.4 Hz, C2*H*), 3.69 (1H, dd, *J* = 5.9, 9.9 Hz, C6*H*H), 3.76 (1H, dd, *J* = 6.1, 9.9 Hz, C6*H*H), 3.78 (9H, s, ArOCH_3 ×3), 3.96 (1H, br d, *J* = 3.3 Hz, C4*H*), 4.24 (1H, d, *J* = 7.8 Hz, C1*H*), 4.50, 4.62 (each 2H, s, ArCH_2O ×2), 4.63, 4.79 (each 1H, d, *J* = 10.6 Hz, ArCH_2O), 6.82–6.90 (6H, *aromatic protons*), 7.21–7.30 (6H, *aromatic protons*); ^{13}C NMR (100 MHz, $CDCl_3$) δ 55.19 (ArOCH_3 ×3), 56.85 (C1OCH_3), 66.81 (*C*4), 66.86 (*C*6), 71.98 (ArCH_2O), 73.11 (*C*5), 73.30, 74.70 (each ArCH_2O), 78.64 (*C*2), 80.18 (*C*3), 113.65, 113.78, 179.37, 129.39, 129.63, 129.97, 130.05, 130.83, 159.13, 159.24, 159.30 (each *aromatic carbon*), ESIMS (%, rel int.) *m/z* 593.2150 (8.2, calcd for $C_{31}H_{38}KO_9$ $[M+K]^+$: 593.2153), 577.2412 (16, calcd for $C_{31}H_{38}NaO_9$ $[M+Na]^+$: 577.2413), 572.2865 (100, calcd for $C_{31}H_{42}NO_9$ $[M+NH_4]^+$: 572.2860).

4.17. Methyl 2,3,6-*O*-tris-(4-methoxyphenylmethyl)-4-*O*-trifluoromethanesulfonyl-α-D-galactopyranoside (18a)

Trifluoromethanesulfonic anhydride (259 mg, 921 μmol) was added to a mixture of **17a** (335 mg, 604 μmol) and pyridine (145 mg, 1.83 μmol) in CH_2Cl_2 (2.0 mL) at 0 °C. After 20 min, the mixture was poured into H_2O (30 mL), and extracted with EtOAc (30 mL × 3). The organic layers were washed with brine (50 mL), dried over $MgSO_4$, combined, and then concentrated in vacuo. The residue was purified by silica gel column chromatography (EtOAc/hexane = 20:80) to give **18a** (334 mg, 80%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.34 (3H, s, C1OCH_3), 3.53 (2H, m, C6H_2), 3.72 (1H, dd, *J* = 3.5, 10.0 Hz, C2*H*), 3.79 (9H, s, ArOCH_3 ×3), 3.93 (1H, dd, *J* = 2.6, 10.0 H, C3*H*), 4.02 (1H, br t, *J* = 4.0 Hz, C5*H*), 4.37, 4.51 (each 1H, d, *J* = 11.1 Hz, ArCH_2O), 4.54)1H, d, *J* = 3.5 Hz, C1*H*), 4.56 (1H, d, *J* = 11.0 Hz, ArC*H*HO), 4.57, 4.74 (each 1H, d, *J* = 11.4 Hz, ArCH_2O),4.77 (1H, d, *J* = 11.0 Hz, ArC*H*HO), 5.35 (1H, br d, *J* = 2.6 Hz, C4*H*), 6.80-6.90 (6H, *aromatic protons*), 7.20–7.35 (6H, *aromatic protons*). This sample was immediately used for the next step.

4.18. Methyl 2,3,6-*O*-tris-(4-methoxyphenylmethyl)-4-*O*-trifluoromethanesulfonyl-β-D-galactopyranoside (18b)

In a similar manner as described in Section 4.17, **17b** (187 mg, 336 μmol) was treated with trifluoromethanesulfonic anhydride (142 mg, 500 μmol) and pyridine (80 mg, 1.00 mmol) in CH_2Cl_2 (1.5 mL) to give **18b** (194 mg, 84%) as an oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.50–3.56 (2H, C2*H*, C3*H*), 3.54 (3H, s, C1OCH_3), 3.59 (1H, dd, *J* = 4.5, 10.8 Hz, C6*H*H), 3.65–3.72 (2H, C5*H*, C6*H*H),3.78, 3.796, 3.784 (each 3H, s, ArOCH_3), 4.26, d, *J* = 7.1 Hz, C1*H*), 4.36 (1H, d, *J* = 11.0 Hz, ArC*H*HO), 4.51 (1H, d, *J* = 11.4 Hz, ArC*H*HO), 4.56 (1H, d, *J* = 11.0 Hz, ArC*H*HO), 4.64, 4.75 (each 1H, d, *J* = 10.4 Hz, ArCH_2O), 4.78 (1H, d, *J* = 11.4 Hz, ArC*H*HO), 6.23, 6.82, 6.89, 7.23, 7.26, 7.27 (each 2H, br d, *J* = 8.7 Hz, *aromatic protons*). This sample was immediately used for the next step.

4.19. Methyl [[2,3,4,6-*O*-tetrakis-(4-methoxyphenylmethyl)-β-D-glucopyranosyl]-(1→4)-β-[2,3,6-tris-*O*-(4-methoxyphenylmethyl)-1-thio-$\Delta^{5,5a}$carbaglucopyranosyl]-(1→4)-β-[2,3,6-*O*-tris-(4-methoxyphenylmethyl)-α-D-glucopyranoside]] (19a)

A solution of **14** (38.0 mg, 31 μmol) in a mixture of methanol (2 mL) and CH_2Cl_2 (2 mL) was stirred with sodium methoxide (6.8 mg, 126 μmol) at room temperature for 4 h. The mixture was poured into H_2O (20 mL) and extracted with EtOAc (20 mL × 3). The organic solutions were washed with brine (20 mL), combined, dried over $MgSO_4$, and then concentrated in vacuo to give the crude thiol **15**, which was immediately used for the next step without purification. A mixture of **15** thus obtained and **18a** prepared in Section 4.17 was stirred in THF (0.4 mL) with NaH (1.6 mg, 67 μmol) at room temperature for 40 min. The mixture was poured into H_2O (50 mL) and extracted with EtOAc (50 mL × 3). The organic solutions were washed with brine (50 mL), combined, dried over $MgSO_4$, and then concentrated in vacuo. Silica gel column chromatography of the residue (EtOAc/hexane = 34:66) gave **18a** (137 mg, 63%) as a caramel. $[\alpha]_D^{23}$ −14.9 (*c* 0.68, $CHCl_3$), IR (film) 2900, 1610, 1460, 1250, 1070, 1035 cm

$^{-1}$; ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.86 (1H, t, J = 11.0 Hz, C4*H*), 3.27 (1H, ddd, J = 1.7, 4.6, 9.3 Hz, C5″*H*), 3.31 (1H, dd, J = 7.8, 8.8 Hz, C2″*H*), 3.34 (3H, s, C1OCH_3), 3.47-3.56 (7H, C2*H*, C1′*H*, C2′*H*, C3″*H*, C4″*H*, C6″*H*H), 3.59 (1H, dd, J = 1.6, 10.6 Hz, C6*H*H), 3.63 (2H, C3H, C6″*H*H), 3.65 ′3H, s, ArOCH_3), 3.68 (1H, m, C5*H*), 3.69, 3.708, 3.711, 3.73, 3.75, 3.785, 3.786, 3.79, 3.792, 3.793 (each 3H, s, ArOCH_3), 3.97 (1H, d, J = 3.5, 10.6 Hz, C6*H*H), 4.08, 4.25 (each 1H, d, J = 11.2 Hz, ArCH_2O), 4.26 (1H, d, J = 11.4 Hz, Ar*C*HO), 4.34 (1H, br d, J = 11.2 Hz, C6′*H*H), 4.34 (1H, d, J = 11.4 Hz, Ar*C*HO), 4.37, 4.40 (each 1H, d, J = 11.8 Hz, Ar*C*HO), 4.50 (1H, br d, J = 6.9 Hz, C4′*H*), 4.50 (1H, d, J = 10.3 Hz, Ar*C*HO), 4.55 (1H, d, J = 11.8 Hz, Ar*C*HO), 4.56 (1H, d, J = 3.7 Hz, C1*H*), 4.58 (1H, d, J = 10.7 Hz, Ar*C*HO), 4.66 (1H, d, J = 11.2 Hz, Ar*C*HO), 4.67 (1H, d, J = 7.8 Hz, C1″*H*), 4.698 (1H, d, J = 10.5 Hz, Ar*C*HO), 4.700 (1H, d, J = 10.4 Hz Ar*C*HO), 4.71 (1H, d, J = 11.8 Hz, Ar*C*HO), 4.75 (1H, d, J = 10.7 Hz, Ar*C*HO), 4.77 (1H, d, J = 10.3 Hz, Ar*C*HO), 4.82 (1H, d, J = 10.5 Hz, Ar*C*HO), 4.85 (2H, s, ArCH_2O), 4.88 (1H, d, J = 11.2 Hz, Ar*C*HO), 5.90 (1H, br s, C5′a*H*), 6.70–6.84 (20H, *aromatic protons*), 7.06–7.32 (20H, *aromatic protons*), ^{13}C NMR (125 MHz, $CDCl_3$) δ 48.33 (*C*1′), 49.77 (*C*4), 55.05, 55.12, 55.16, 55.16, 55.16, 55.17, 55.21, 55.24, 55.25, 55.25, 55.13 (OCH_3), 68.70 (*C*6″), 68.96 (*C*6), 70.37 (*C*6′), 71.13 (ArCH_2O), 71.85 (*C*5), 72.62, 72.84, 72.96, 73.78, 74.21, 74.42, 74.47 (ArCH_2O), 74.88 (*C*5″), 75.22 (ArCH_2O), 75.95, 76.01 (ArCH_2O, *C*4′), 77.82, 79.35, 79.96, 80.56, 84.55 (*C*2, *C*3, *C*2′, *C*3″, *C*4″), 81.71 (*C*3′), 82.62 (*C*2″), 98.46 (*C*1), 103.23 (*C*1″), 113.40, 113.46, 113.52, 113.63, 113.63, 113.80, 113.66, 113.70, 113.72, 113.74 (*aromatic carbons*), 129.08 (*C*5′a), 129.24, 129.33, 129.36, 129.43, 129.46, 129.52, 129.56, 129.74, 130.18, 130.38, 130.46, 130.50, 130.55, 130.79, 130.88, 131.09, 131.16, 131.35 (*aromatic carbons*), 133.73 (*C*5′), 158.79, 158.94, 158.97, 158.97, 158.99, 159.00, 159.06, 159.07, 159.16, 159.34 (*aromatic carbons*), ESIMS (%, rel int.) *m/z* 1769.7165 (12, calcd for $C_{100}H_{114}O_{24}SK$ $[M+K]^+$: 1769.7058), 1753.7450 (31, calcd for $C_{100}H_{114}O_{24}SNa$ $[M+Na]^+$: 1753.7318), 1748.7835 (100, calcd for $C_{104}H_{115}O_{24}SN$ $[M+NH_4]^+$ 1748.7765). 1731.7600 (95, calcd for $C_{100}H_{115}O_{24}S$ $[M+H]^+$ 1731.7499).

4.20. Methyl [[2,3,4,6-*O*-tetrakis-(4-methoxyphenylmethyl)-β-D-glucopyranosyl]-(1→4)-β-[2,3,6-tris-*O*-(4-methoxy phenyl methyl)-1-thio-$\Delta^{5,5a}$carbaglucopyranosyl]-(1→4)-β-[2,3,6-*O*-tris-(4-methoxyphenylmethyl)-β-D-glucopyranoside]] (19b)

In a similar manner as described in Section 4.19, **14** (269.0 mg, 217 μmol) was treated employing sodium methoxide (47.5 mg, 879 μmol) in MeOH (40 mL) and CH_2Cl_2 (30 mL). Resulting **15** and **18b** were stirred with NaH (6.0 mg, 300 μmol) in THF (2.0 mL) at room temperature for 40 min. The work-up that then followed gave **19b** (137 mg, 63%) as a caramel. $[\alpha]_D^{23}$ −2.4 (*c* 1.20, $CHCl_3$), IR (film) 2910, 1610, 1460, 1250, 1070, cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.82 (1H, t, J = 10.7 Hz, C4H), 3.27 (1H, ddd, J = 1.5, 4.6, 9.3 Hz, C5″*H*), 3.31 (1H, dd, J = 7.8, 9.0 Hz, C2″*H*), 3.32 (1H, dd, J = 8.5, 10.7 Hz, C3*H*), 3.36 (1H, dd, J = 7.5, 8.5 Hz, C2*H*), 3.40 (1H, ddd, J = 1.8, 4.2, 10.7 Hz, C5*H*), 3.48 (2H, C3″*H*, C4″*H*), 3.51 (1H, t, J = 7.9 Hz, C2′*H*), 3.52 (1H, d, J = 11.5 Hz, C6′*H*H), 3.54 (1H, m, C6′*H*H), 3.55 (3H, s, OCH_3), 3.58 (1H, m, C1′*H*), 3.63 (1H, dd, J = 1.5, 10.6 Hz, C6″*H*H), 3.681, 3.696, 3.706, 3.709, 3.73, 3.75, 3.782, 3.784, 3.787, 3.792 (each 3H, s, ArOCH_3), 3.80 (1H, m, C6*H*H), 3.81 (1H, dd, J = 5.5, 7.9 Hz, C3′*H*), 3.87 (1H, dd, J = 4.2, 10.5 Hz, C6*H*H), 4.09 (1H, d, J = 11.2 Hz, Ar*C*HO), 4.22 (1H, d, J = 7.5 Hz, C1*H*), 4.25 (1H, d, J = 11.2 Hz, Ar*C*HO), 4.31 (1H, br d, J = 11.5 Hz, C6′*H*H), 4.31 (1H, d, J = 11.5 Hz, Ar*C*HO), 4.38 (2H, s, ArCH_2O), 4.38 (1H, d, J = 11.3 Hz, Ar*C*HO), 4.42, 4.47 (each 1H, d, J = 10.4 Hz, ArCH_2O), 4.48 (1H, br d, J = 5.5 Hz, C4′*H*), 4.56 (1H, d, J = 11.6 Hz, Ar*C*HO), 4.62 (1H, d, J = 10.4 Hz, Ar*C*HO), 4.64 (1H, d, J = 11.3 Hz, Ar*C*HO), 4.65 (1H, d, J = 7.8 Hz, C1′*H*), 4.69 (1H, d, J = 10.5 Hz, Ar*C*HO), 4.70 (1H, d, J = 10.4 Hz, Ar*C*HO), 4.73 (1H, d, J = 10.6 Hz, Ar*C*HO), 4.75 (1H, d, J = 10.4 Hz, Ar*C*HO), 4.82 (2H, s, ArCH_2O), 4.82 (1H, d, J = 10.5 Hz, Ar*C*HO), 4.83 (1H, d, J = 10.4 Hz, Ar*C*HO), 4.87 (1H, d, J = 11.3 Hz, Ar*C*HO), 5.87 (1H, br s, C5′a*H*), 6.72 (2H, br d, J = 8.7 Hz, *aromatic protons*), 6.76–6.84 (18, *aromatic protons*), 7.06 (2H, br d, 8.7 Hz, *aromatic protons*), 7.12-7.28 (18H, *aromatic protons*); ^{13}C NMR (125 MHz, $CDCl_3$) δ 48.10 (*C*1′), 49.82 (*C*4), 55.09, 55.14 (each ArOCH_3), 55.15 (ArOCH_3 ×3), 55.16, 55.20 (each ArOCH_3), 55.24 (ArOCH_3 ×2), 55.25 (ArOCH_3), 56.95 (C1OCH_3), 68.70 (*C*6″), 69.24 (*C*6), 70.34 (*C*6′), 71.15, 72.66, 72.83, 73.70, 79.97, 74.42 (each ArCH_2O), 74.45 (ArCH_2O ×2), 74.84 (C5″), 75.21, 75.80 (each ArCH_2O), 75.94 (*C*4′), 76.83 (*C*5), 77.81 (*C*4″), 77.84 (*C*2′), 81.45 (*C*3′), 82.54 (*C*2″), 82.70 (*C*3), 83.04 (*C*2), 84.55 (*C*3″), 103.28 (*C*1″), 104.53 (*C*1), 113.41, 113.50, 113.54, 113.62, 113.64, 113.64, 113.70, 113.72, 113.73, 113.73 (*aromatic carbons*), 128.72 (*C*5′a), 129.10, 129.17, 129.22, 129.33, 129.36, 129.44, 129.46, 129.52, 129.70, 129.73, 130.42, 130.46, 130.48, 130.50, 130.74, 130.76, 130.83, 130.89, 130.99 (*aromatic carbons*), 133.84 (*C*5′), 158.80, 158.93, 158.94, 158.98, 158.99, 159.01, 159.05, 159.07, 159.16, 159.16 (*aromatic carbons*), ESIMS (%, rel int.) *m/z* 1769.7074 (8, calcd for $C_{100}H_{114}O_{24}SK$ $[M+K]^+$: 1769.7058), 1753.7411 (26, calcd for $C_{100}H_{114}O_{24}SNa$ $[M+Na]^+$: 1753.7318), 1748.7764 (100, calcd for $C_{104}H_{115}O_{24}SN$ $[M+NH_4]^+$ 1748.7765). 1731.7500 (96, calcd for $C_{100}H_{115}O_{24}S$ $[M+H]^+$ 1731.7499).

4.21. Methyl [β-D-glucopyranosyl-(1→4)-β-(1-thio-$\Delta^{5,5a}$ carbaglucopyranosyl)-(1→4)-β-(α-D-glucopyranoside)] (1a)

A suspension of **19a** (130 mg, 75 μmol) in a mixture of CH_2Cl_2 (2.0 mL) and H_2O (200 μL) was stirred with 2,3-dicyano-5,6-dichlorobenzoquinone (DDQ) (332 mg, 1.46 mmol) at room temperature for 13 h. The mixture was poured into water (10 mL) and washed with EtOAc (10 mL × 3). The aqueous solution was concentrated in vacuo. After dilution with small amount of H_2O (ca. 0.3 mL), the resulting solution was loaded on a ODS Sep-Pak® cartridge (5.0 g). After washing with MeOH/H_2O = 5:95, elution with MeOH/H_2O = 10:90 gave the fraction containing **1a**. After methanol was removed by rotary evaporator, the resulting aqueous solution was lyophilized to give **1a** (34.7 mg, 87%) as white amorphous powder. $[\alpha]_D^{23}$ +2.5 (*c* 0.52, H_2O); ^{1}H NMR (500 MHz, D_2O) δ 2.60 (1H, t, J = 10.9 Hz, C4*H*), 3.20 (1H, dd, J = 8.0, 9.2 Hz, C2″*H*), 3.26 (3H, s, OCH_3), 3.28 (1H, t, J = 9.4 Hz, C4″*H*), 3.37 (1H, ddd, J = 2.1, 6.1, 9.4 Hz, C5″*H*), 3.38 (1H, dd, J = 9.2, 9.4 Hz, C3″*H*), 3.40 (1H, br d, J = 9.0 Hz, C1′*H*), 3.46 (1H, dd, J = 3.7, 9.6 Hz, C2*H*), 3.51 (1H, dd, J = 9.0, 10.0 Hz, C2′*H*), 3.54 (1H, dd, J = 9.6, 10.9 Hz, C3*H*), 3.59 (1H, dd, J = 7.6, 10.0 Hz, C3′*H*), 3.60 (1H, dd, J = 6.1, 12.3 Hz, C6″*H*H), 3.63 (1 h, ddd, J = 2.2, 4.7, 10.9 Hz, C5*H*), 3.79 (1H, dd, J = 2.1, 12.3 Hz, C6″*H*H), 3.93 (1H, dd, J = 2.2, 12.1 Hz, C6*H*H), 4.01, 4.15 (each 1H, br d, J = 13.6 Hz, C6′*H*), 4.27 (1H, br d, J = 7.6 Hz, C4′*H*), 4.50 (1H, d, J = 8.0 Hz, C1″*H*), 4.71 (1H, 1H, d, J = 3.7 Hz, C1*H*), 5.71 (1H, br s, C5′a*H*); ^{13}C NMR (125 MHz, D_2O) δ 48.05 (*C*4), 48.46 (*C*18), 55.09 (C1OCH_3), 60.66 (*C*6″), 61.38 (*C*6), 61.41 (*C*6′), 69.53 (*C*4″), 71.27 (*C*3), 71.96 (*C*5), 72.18 (*C*2), 73.44 (*C*2″), 73.54 (*C*2′), 74.88 (*C*3′), 75.72 (*C*3″), 76.10 (*C*5″), 82.16 (*C*4′), 99.36 (*C*1), 103.13 (*C*1″), 126.67 (*C*5′a), 136.25 (*C*5′), ESIMS (%, rel int.) *m/z*: 569.1313 (10, calcd for $C_{20}H_{34}O_{14}SK$ $[M+K]^+$: 569.1306), 553.1570 (100, calcd for $C_{20}H_{34}O_{14}SNa$ $[M+Na]^+$: 553.1567), 531.1754 (17, calcd for $C_{20}H_{35}O_{14}S$ $[M+H]^+$ 531.1754).

4.22. Methyl [β-D-glucopyranosyl-(1→4)-β-(1-thio-$\Delta^{5,5a}$ carbaglucopyranosyl)-(1→4)-β-(β-D-glucopyranoside)] (1b)

In a similar manner as described in Section 4.21, **19b** (139 mg, 80 μmol) was treated employing DDQ (370 mg, 1.63 mmol), CH_2Cl_2

(2.0 mL), and H_2O (0.2 mL). The work-up that then followed gave **1b** (32 mg, 75%) as white amorphous powder. $[\alpha]_D^{23}$ −81.2 (*c* 0.65, H_2O), ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.59 (1H, t, *J* = 10.8 Hz, C4*H*), 3.15 (1H, dd, *J* = 8.0, 9.0 Hz, C2*H*), 3.21 (1H, dd, *J* = 8.0, 9.3 Hz, C2″*H*), 3.30 (1H, dd, *J* = 9.6, 9.6 Hz, C4″*H*), 3.38 (1H, dd, *J* = 9.0, 10.8 Hz, C3*H*), 3.39 (1H, m, C5″*H*), 3.40 (1H, t, *J* = 9.3 Hz, C3″*H*), 3.42 (1H, br d, *J* = 9.0 Hz, C1′*H*), 3.44 (1H, 3H, s, OCH_3), 3.47 (1H, ddd, *J* = 2.1, 5.5, 10.8 Hz, C5*H*), 3.52 (1H, dd, *J* = 9.0, 10.1 Hz, C2′*H*), 3.60 (1H, dd, *J* = 7.4, 10.1 Hz, C3′*H*), 3.61 (1H, dd, *J* = 5.8, 12.5 Hz, C6*H*H), 3.80 (1H, dd, *J* = 2.2, 12.5 Hz, C6*H*H), 3.83 (1H, dd, *J* = 5.3, 12.3 Hz, C6*H*H), 4.03 (1H, dd, *J* = br d, *J* = 13.5 Hz, C6′*H*H), 4.05 (1H, dd, *J* = 2.1, 12.3 Hz, C6*H*H), 4.17 (1H, br d, *J* = 13.5 Hz, C6′*H*H), 4.23 (1H, d, *J* = 8.0 Hz, C1*H*), 4.28 (1H, 1H, br d, *J* = 7.4 Hz, C4′*H*), 4.51 (1H, d, *J* = 8.0 Hz, C1″*H*), 5.71 (1H, br s, C5′a*H*); ^{13}C NMR (125 MHz, $CDCl_3$) δ 48.21 (*C*4), 48.64 (*C*1′), 57.10 (C1O*C*H3), 60.63 (*C*6″), 61.37 (*C*6′), 61.54 (*C*6), 69.52 (*C*4″), 73.43 (*C*2″), 73.52 (*C*2′), 74.12 (*C*2), 74.56 (*C*3), 74.88 (*C*3′), 75.71 (*C*3″), 76.10 (*C*5″), 76.41 (*C*5), 82.14 (*C*4′), 103.02 (*C*1), 103.13 (*C*1″), 126.57 (*C*5′a), 136.33 (*C*5); ESIMS (%, rel int.) *m/z* 569.1294 (10, calcd for $C_{20}H_{34}O_{14}SK$ $[M+K]^+$: 569.1306), 553.1552 (100, calcd for $C_{20}H_{34}O_{14}SNa$ $[M+Na]^+$: 553.1567), 531.1733 (17, calcd for $C_{20}H_{35}O_{14}S$ $[M+H]^+$ 531.1754).

4.23. Methyl 2,3,6,2′,3′6′-*O*-hexakis-(4-methoxyphenyl methyl)-4′-*O*-trifluoromethanesulfonyl-β-D-lactoside (20)

Methyl β-D-lactoside[29] (112 mg, 314 μmol) was stirred with anisaldehyde dimethylacetal (145 mg, 796 μmol) in DMF (1.0 mL) in the presence of catalytic *p*-toluenesulfonic acid hydrate (600 μg) at 70 °C for 1 h. The mixture was diluted H_2O (15 mL) and passed through anion exchange resin (DIAION WA30 OH^- form). The eluate was then lyophilized to give the crude acetal which was diluted with DMF (2.0 mL) without purification. To the solution, NaH (137 mg, 3.14 mmol) and MPMBr [prepared from anisic alcohol (520 mg) and PBr_3 (508 mg)] were successively added at room temperature. After stirring for 10 min, triethylamine (200 μL) and MeOH (200 μL) were added in order to destroy the excess reagents. After stirring for additional 30 min, the mixture was poured into H_2O (50 mL) and extracted with EtOAc (30 mL × 3). The combined extracts were washed with brine, dried over $MgSO_4$ and then concentrated in vacuo. Silica gel column chromatography of the residue (EtOAc/hexane = 40:60) gave methyl 4′,6′-*O*-*p*-methoxybenzylidene-2,3,6,2′,3′-pentakis-*O*-methoxyphenylmethyl-β-D-lactoside (169 mg, 50% from β-methyl lactoside) as needles. mp 153–154 (from EtOAc/hexane 20:80), $[\alpha]_D^{27}$ +17.3 (*c* 1.15, $CHCl_3$); IR (film) 2910, 1610, 1510, 1460, 1250, 1090, 820 cm^{-1}; ^{1}H NMR (500 MHz, C_6D_6) δ 2.57 (1H, br s, C5′*H*), 3.12, 3.28, 3.30, 3.31, 3.32 (each 3H, s, ArOCH_3) 3.34 (1H, dd, *J* = 1.6, 12.4 Hz, C6′*H*H), 3.39 (3H, s, C1OCH_3), 3.41 (1H, dd, *J* = 3.6, 9.6 Hz, C3′*H*), 3.41 (1H, ddd, *J* = 1.4, 3.5, 9.6 Hz, C5*H*), 3.68 (1H, dd, *J* = 7.8, 9.0 Hz, C2*H*), 3.70 (1H, d, *J* = 3.6 Hz, C4′*H*), 3.80 (1H, t, *J* = 9.0 Hz, C3*H*), 3.82 (1H, dd, *J* = 1.4, 11.1 Hz, C6*H*H), 4.07 (1H, dd, *J* = 7.9, 9.6 Hz, C2′*H*), 4.08 (1H, dd, *J* = 1.0, 12.4 Hz, C6′*H*H), 4.22 (1H, dd, *J* = 3.5, 11.1 Hz, C6*H*H), 4.31 (1H, d, *J* = 7.8 Hz, C1*H*), 4.36 (1H, dd, *J* = 9.0, 9.6 Hz, C4*H*), 4.42 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.59 (2H, d, *J* = 11.6 Hz, ArC*H*HO), 4.66 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.73 (1H, d, *J* = 7.9 Hz, C1′*H*), 4.82 (2H, s, ArCH_2O), 4.86 (1H, d, *J* = 11.0 Hz, ArC*H*HO), 4.99 (1H, d, *J* = 10.3 Hz, ArC*H*HO), 5.00 (1H, d, *J* = 11.0 Hz, ArC*H*HO), 5.31 (1H, s, ArC*H*), 5.50 (1H, d, *J* = 10.3 Hz, ArC*H*HO), 6.74 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 6.77 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 6.79 (2H, br d, *J* = 8.6 Hz, *aromatic protons*), 6.83 (4H, br d, *J* = 8.6 Hz, *aromatic protons*), 6.93 (2H, br d, *J* = 8.6 Hz, *aromatic protons*), 7.24 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.36 (2H, br d, *J* = 8.6 Hz, *aromatic protons*), 7.38 (4H, br d, *J* = 8.6 Hz, *aromatic protons*), 7.68 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.76 (2H, br d, *J* = 8.6 Hz, *aromatic protons*); ^{13}C NMR (125 MHz, C_6D_6) δ 54.64, 54.66, 54.67, 54.74, 54.75 (each ArO*C*H$_3$), 56.50 (C1O*C*H$_3$), 66.76 (*C*5′), 68.37 (*C*6), 68.99 (*C*6′), 71.33, 73.16 (each Ar*C*H$_2$O), 73.79 (*C*4′), 74.71, 75.39, 75.71 (each Ar*C*H$_2$O), 75.91 (*C*5), 78.00 (*C*4), 79.32 (*C*2′), 80.24 (*C*3′), 82.26 (*C*2), 83.10 (*C*3), 101.25 (Ar*C*H), 103.50 (*C*1′), 105.24 (*C*1), 113.75, 113.87, 113.90, 113.96, 114.01, 114.10, 128.30, 129.39, 129.53, 129.74, 129.84, 130.86, 131.25, 131.30, 131.57, 131.80, 131.83, 132.42, 159.56, 159.61, 159.64, 159.69, 159.79, 160.46 (*aromatic carbons*); ESIMS (%, rel int.) *m/z*: 1092.4939 (100, calcd for $C_{61}H_{74}NO_{17}$ $[M+NH_4]^+$: 1092.4957), 1097.4490 (34, calcd for $C_{61}H_{70}O_{17}Na$ $[M+Na]^+$: 1097.4511). A suspension of the product (45.5 mg, 42.0 μmol) and finely powdered molecular sieves (acid washed type, Fluka #69841, activated 200 °C for 20 min under vacuumed condition before use, 60 mg) in THF (0.7 mL) was stirred with boran trimethylamine complex (9.2 mg, 129 μmol) and $AlCl_3$ (16.9 mg, 129 μmol) at room temperature for 3 h min. Saturated aqueous potassium tartarate (5 mL) was added and the mixture was further stirred at room temperature for 20 min. After filtration, the mixture was extracted with EtOAc (10 mL × 3), washed with brine (20 mL), combined, dried over $MgSO_4$, and then concentrated in vacuo. Silica gel column chromatography of the residue (EtOAc/hexane = 30:70) gave 2,3,6,2′,3′6′-*O*-hexakis-(4-methoxyphenylmethyl)-β-D-lactoside (31.6 mg, 69%) as caramel after work-up. $[\alpha]_D^{27}$ +21.0 (*c* 1.26, $CHCl_3$); IR (film) 3480, 2910, 1610, 1510, 1460, 1245, 1090, 820 cm^{-1}; ^{1}H NMR (500 MHz, C_6D_6) δ 2.39 (1H, br s, C4O*H*), 3.277, 3.287, 3.292, 3.30, 3.31, 3.36 (each 3H, ArOCH_3), 3.40 (3H, s, C1OCH_3), 3.44 (2H, m, C5H and C5′H), 3.65 (1H, dd, *J* = 7.7, 9.1 Hz, C2*H*), 3.71 (1H, dd, *J* = 5.6, 9.7 Hz, C6′*H*H), 3.77 (1H, t, *J* = 9.1 Hz, C3*H*), 3.82 (1H, dd, *J* = 1.5, 11.0 Hz, C6*H*H), 3.83 (1H, dd, *J* = 7.9, 9.2 Hz, C2′*H*), 3.92 (1H, m, C4′*H*), 3.94 (1H, dd, *J* = 6.7, 9.7 Hz, C6′*H*H), 4.05 (1H, dd, *J* = 3.9, 11.0 Hz, C6*H*H), 4.32 (1H, d, *J* = 7.7 Hz, C1*H*), 4.36 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.378 (1H, d, *J* = 11.3 Hz, ArC*H*-HO), 4.386 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.392 (1H, t, *J* = 9.1 Hz, C4*H*), 4.42 (1H, d, *J* = 11.3 Hz, ArC*H*HO), 4.45 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.55 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.71 (1H, d, *J* = 7.9 Hz, C1′*H*), 4.81 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 4.84 (1H, d, *J* = 11.0 Hz, ArC*H*HO), 4.90 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 4.98 (1H, d, *J* = 10.4 Hz, ArC*H*HO), 5.01 (1H, d, *J* = 11.0 Hz, ArC*H*HO), 5.31 (1H, d, *J* = 10.4 Hz, ArC*H*HO), 6.77-6.82 (8H, *aromatic protons*), 6.85 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 6.93 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.18 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), .25 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.26 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.37 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.38 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.65 (2H, br d, *J* = 8.7 Hz, *aromatic protons*); ^{13}C NMR (125 MHz, C_6D_6) δ 54.67, 54.69, 54.73, 54.73, 54.75, 54.75 (each ArO*C*H$_3$), 56.49 (C1O*C*H$_3$), 66.64 (*C*4′), 68.40 (*C*6), 68.96 (*C*6′), 71.87, 73.06, 73.34 (each Ar*C*H$_2$O), 73.87 (*C*5′), 74.70, 75.20, 75.40 (each Ar*C*H$_2$O), 75.92 (*C*5), 76.84 (*C*4), 79.72 (*C*2′), 81.48 (*C*3′), 82.06 (*C*2), 83.08 (*C*3), 103.07 (*C*1′), 105.26 (*C*1), 113.80, 113.92, 114.02, 114.02, 114.10, 114.12, 129.45, 129.51, 129.55, 129.73, 129.85, 130.42, 130.80, 131.08, 131.25, 131.64, 131.83, 132.36, 159.58, 159.60, 159.64, 159.64, 159.76, 159.84 (*aromatic carbons*); ESIMS (%, rel int.) *m/z*: 1094.5137 (100, calcd for $C_{61}H_{76}NO_{17}$ $[M+NH_4]^+$: 1094.5113), 1099.4692 (17, calcd for $C_{61}H_{72}O_{17}Na$ $[M+Na]^+$: 1099.4667). In a similar manner as described in Section 4.17, the alcohol (598 mg, 555 μmol) was treated with trifluoromethane-sulfonic anhydride (234 mg, 833 μmol) and pyridine (131 mg, 1.66 mmol) in CH_2Cl_2 (10 mL) to give the corresponding triflate **20** (639 mg, 95%) as an oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.31 (1H, ddd, *J* = 1.5, 3.7, 9.8 Hz, C5*H*) 4.40 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 4.46 (1H, d, *J* = 11.2 Hz, ArC*H*HO), 4.49 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.60 (1H, d, *J* = 10.8 Hz, ArC*H*HO), 4.65 (1H, d, *J* = 10.8 Hz, ArC*H*HO), 4.66 (1H, d, *J* = 10.5 Hz, ArC*H*HO), 4.68 (1H, d, *J* = 10.1 Hz, ArC*H*HO), 4.77 (1H, d, *J* = 11.2 Hz, ArC*H*HO), 4.78 (1H, d, *J* = 10.1 Hz, ArC*H*HO),

4.79 (1H, d, J = 10.5 Hz, ArC*H*HO), 5.31 (1H, d, J = 2.9 Hz, C4′*H*), 6.76 (2H, br d, J = 8.6 Hz, *aromatic protons*), 6.81–6.89 (10H, *aromatic protons*), 7.12 (2H, br d, J = 8.6 Hz, *aromatic protons*), 7.15 (2H, br d, J = 8.6 Hz, *aromatic protons*), 7.21-7.30 (8H, *aromatic protons*)

4.24. Methyl [2,3,4-6-tetrakis-*O*-(4-methoxyphenylmethyl)-β-D-glucopyranosyl-(1→4)-β-(2,3,6-tris-*O*-(4-methoxyphenylmethyl)-1-thio-$\Delta^{5,5a}$carbaglucopyranosyl)-(1→4)-β-(2,3,6-tris-*O*-(4-methoxyphenylmethyl)-β-D-glucopyrano syl)-(1→4)-β-(2,3,6-tris-*O*-(4-methoxyphenylmethyl)-β-D-glucopyranoside] (21)

A crude **15** prepared from thioacetate **14** (60 mg, 48 μmol) in a similar manner as described in Section 4.19 and the triflate **20** (51.9 mg, 90 μmol) in THF (0.5 mL) was stirred with NaH (2.3 mg, 96 μmol) at 0 °C for 40 min. The mixture was poured into H_2O (50 mL) and extracted with EtOAc (25 mL × 3). The combined organic layer was washed with brine (25 mL), dried over $MgSO_4$ and then concentrated in vacuo. Silica gel column chromatography of the residue (35% EtOAc/hexane) gave **21** (76.5 mg, 70%) as an oil. $[\alpha]_D^{27}$+0.5 (c 1.67, $CHCl_3$); IR (film) 2910, 1610, 1510, 1465, 1250, 1070, 815 cm^{-1}; ^1H NMR (500 MHz, C_6D_6) δ 3.21 (1H, m, C4′*H*), 3.22, 3.280, 3.288, 3.289, 3.291, 3.291, 3.298, 3.301, 3.305, 3.312 (each 3H, ArOCH_3), 3.318 (1H, m, C3′*H*), 3.330, 3.331 (each 3H, ArOCH_3), 3.35 (1H, m, C5′*H*), 3.36, 3.40 (each 3H, ArOCH_3), 3.40 (1H, ddd, J = 1.7, 3.5, 9.3 Hz, C5*H*), 3.44 (1H, ddd, J = 1.9, 4.6, 9.2 Hz, C5‴*H*), 3.50 (1H, dd, J = 8.0, 8.6 Hz, C2′*H*), 3.60 (1H, dd, J = 7.9, 8.9 Hz, C2‴*H*), 3.66 (1H, dd, J = 7.6, 8.9 Hz, C2*H*), 3.678 (1H, dd, J = 4.6, 11.0 Hz, C6‴*H*H), 3.684 (1H, dd, J = 8.9, 9.2 Hz, C3‴*H*), 3.718 (1H, t, J = 8.2 Hz, C2″*H*), 3.721 (1H, br d, J = 11.3 Hz, C6″*H*H), 3.747 (1H, dd, J = 1.9, 11.0 Hz, C6‴*H*H), 3.750 (1H, t, J = 9.2 Hz, C4‴*H*), 3.787 (1H, dd, J = 8.9, 9.3 Hz, C3*H*), 3.788 (1H, dd, J = 1.7, 10.7 Hz, C6*H*H), 3.94 (1H, dd, J = 1.0, 10.5 Hz, C6′*H*H), 4.01 (1H, dd, J = 1.8, 8.2 Hz, C1″*H*), 4.09 (1H, dd, J = 3.5, 10.7 Hz, C6*H*H), 4.12 (1H, dd, J = 96.1, 8.2 Hz, C3″*H*), 4.22 (1H, dd, J = 3.5, 10.5 Hz, C6′*H*H), 4.24 (1H, d, J = 11.2 Hz, ArC*H*HO), 4.32 (1H, dd, J = 7.6 Hz, C1*H*), 4.33 (1H, d, J = 11.6 Hz, ArC*H*HO), 4.37 (1H, t, J = 9.3 Hz, C4*H*), 4.41 (1H, d, J = 11.5 Hz, ArC*H*HO), 4.41 (1H, d, J = 11.5 Hz, ArC*H*HO), 4.47 (1H, d, J = 11.2 Hz, ArC*H*HO), 4.48 (1H, d, J = 11.5 Hz, ArC*H*HO), 4.50 (1H, d, J = 11.5 Hz, ArC*H*HO), 4.56 (1H, d, J = 11.0 Hz, ArC*H*HO), 4.58 (1H, d, J = 11.6 Hz, ArC*H*HO), 4.67 (1H, br d, J = 11.3 Hz, C6″*H*H), 4.68 (1H, d, J = 8.0 Hz, C1′*H*), 4.70 (1H, d, J = 10.6 Hz, ArC*H*HO), 4.76 (1H, d, J = 11.0 Hz, ArC*H*HO), 4.79 (1H, d, J = 10.5 Hz, ArC*H*HO), 4.81 (1H, d, J = 11.1 Hz, ArC*H*HO), 4.87 (1H, d, J = 11.0 Hz, ArC*H*HO), 4.89 (1H, d, J = 10.8 Hz, ArC*H*HO), 4.90 (1H, d, J = 11.0 Hz, ArC*H*HO), 4.91 (1H, br d, J = 6.1 Hz, C4″*H*), 4.955 (1H, d, J = 11.4 Hz, ArC*H*HO), 4.959 (1H, d, J = 11.3 Hz, ArC*H*HO), 4.965 (1H, d, J = 10.6 Hz, ArC*H*HO), 4.971 (1H, d, J = 10.5 Hz, ArC*H*HO), 4.99 (1H, d, J = 11.1 Hz, ArC*H*HO), 5.03 (1H, d, J = 7.9 Hz, C1‴*H*), 5.06 (1H, d, J = 10.8 Hz, ArC*H*HO), 5.07 (1H, d, J = 10.8 Hz, ArC*H*HO), 5.14 (1H, d, J = 10.8 Hz, ArC*H*HO), 5.26 (1H, d, J = 11.3 Hz, ArC*H*HO), 5.41 (1H, d, J = 11.4 Hz, ArC*H*HO), 6.23 (1H, br d, J = 1.8 Hz, C5″a*H*), 6.75-6.91 (26H, *aromatic protons*), 7.24-7.36 (18H, *aromatic protons*), 7.40 (2H, br d, J = 8.7 Hz, *aromatic protons*), 7.47 (2H, br d, J = 8.7 Hz, *aromatic protons*), 7.56 (2H, br d, J = 8.7 Hz, *aromatic protons*), 7.59 (2H, br d, J = 8.7 Hz, *aromatic protons*); ^{13}C NMR (125 MHz, C_6D_6) δ 48.96 (*C*1″) 50.07 (*C*4′) 54.62, 54.67, 54.70, 54.70, 54.70, 54.70, 54.73, 54.73, 54.73, 54.73, 54.77, 54.80 (each 3H, ArOCH_3), 56.52 (C1OCH_3), 68.30 (*C*6), 69.19 (*C*6‴), 69.73 (*C*6′), 71.12 (*C*6″), 71.74, 73.00, 73.13, 73.29, 74.40, 74.47, 74.70, 74.78, 74.85, 74.91, 75.28 (each ArCH_2O), 75.56 (*C*5‴), 75.71 (*C*5), 76.13 (ArCH_2O), 76.51 (*C*4″), 77.12 (*C*4), 77.53 (*C*5′), 78.25 (*C*4‴), 80.57 (*C*2″), 81.98 (*C*2) 82.64 (*C*3″), 82.77 (*C*3), 83.05 (*C*2‴), 83.53 (*C*3′), 83.95 (*C*2′), 85.06 (*C*3‴), 102.76 (*C*1′), 103.87 (*C*1‴), 105.27 (*C*1), 113.86, 113.86, 113.90, 113.93, 113.94, 113.99, 114.01, 114.01, 114.05, 114.05, 114.07, 114.20, 114.23 (*aromatic carbons*), 129.19 (*C*5″a), 129.46, 129.48, 129.48, 129.48, 129.64, 129.77, 129.81, 129.85, 130.01, 130.03, 130.04, 130.08, 130.12, 130.74, 131.12, 131.22, 131.27, 131.37, 131.44, 131.48, 131.57, 131.77, 131.89, 131.90, 132.18, 132.46 (*aromatic carbons*), 134.65 (*C*5″), 159.49, 159.49, 159.56, 159.56, 159.60, 159.60, 159.62, 159.67, 159.67, 159.70, 159.77, 159.80, 159.80 (*aromatic carbons*), ESIMS (%, rel int.) m/z: 2253.9740 (6, calcd for $C_{130}H_{148}O_{32}S$ $[M+H]^+$: 2253.9753), 2271.0003 (9, calcd for $C_{130}H_{152}NO_{32}S$ $[M+NH_4]^+$: 2271.0018).

4.25. Methyl [β-D-glucopyranosyl-(1→4)-β-(1-thio-$\Delta^{5,5a}$carbaglucopyranosyl)-(1→4)-β-(β-D-glucopyranosyl)-(1→4)-β-(β-D-glucopyranoside)] (2)

In a similar manner as described in Section 4.21, **21** (103 mg, 46 μmol) was treated employing DDQ (275 mg, 1.19 mmol), CH_2Cl_2 (3.0 mL), and H_2O (0.3 mL). The work-up that then followed gave **2** (20 mg 62%) as white amorphous powder. $[\alpha]_D^{28}$−37.9 (c 1.24, H_2O); ^1H NMR (500 MHz, D_2O) δ 2.59 (1H, t, J = 10.6 Hz, C4′*H*), 3.14 (1H, dd, J = 8.0, 9.3 Hz, C2*H*), 3.17 (1H, dd, J = 8.0, 9.3 Hz, C2′*H*), 3.18 (1H, dd, J = 8.0, 9.3 Hz, C2‴*H*), 3.25 (1H, dd, J = 9.2, 9.7 Hz, C4‴*H*), 3.35 (1H, ddd, J = 2.2, 5.6, 12.2 Hz, C5‴*H*), 3.36 (1H, t, J = 9.2 Hz, C3‴*H*), 3.37 (1H, dd, J = 9.3, 10.6 Hz, C3′*H*), 3.39 (1H, br d, J = 9.0 Hz, C1″*H*), 3.41 (3H, s, C1OCH_3), 3.42–3.48 (4H, C3*H*, C4*H*, C5*H*, C5′*H*), 3.48 (1H, dd, J = 9.0, 10.0 Hz, C2″*H*), 3.56 (1H, dd, J = 7.5, 10.0 Hz, C3″*H*), 3.57 (1H, dd, J = 5.6, 12.3 Hz, C6‴*H*H), 3.65 (1H, dd, J = 4.6, 12.2 Hz, C6*H*H), 3.76 (1H, dd, J = 2.2, 12.3 Hz, C6‴*H*H), 3.80 (1H, dd, J = 5.4, 12.2 Hz, C6′*H*H), 3.82 (1H, dd, J = 2.0, 12.2 Hz, C6*H*H), 3.97 (1H, dd, J = 1.5, 12.2 Hz, C6′*H*H), 3.97 (1H, br d, J = 13.6 Hz, C6″*H*H), 4.13 (1H, br d, J = 13.6 Hz, C6″*H*H), 4.24(1H, br d, J = 7.5 Hz, C4″*H*), 4.24 (1H, d, J = 8.0 Hz, C1*H*), 4.32 (1H, d, J = 8.0 Hz, C1′*H*), 4.48 (1H, d, J = 8.0 Hz, C1‴*H*), 5.68 (1H, br s, C5″a*H*); ^{13}C NMR (125 MHz, D_2O) δ 55.73 (*C*4′), 56.38 (*C*1″), 65.02 (C1O*C*H_3), 67.81 (*C*6), 68.42 (*C*6‴), 69.14, 69.16 (*C*6′ or *C*6″), 77.28 (*C*4‴), 80.64 (*C*2), 81.19 (*C*2‴), 81.26 (*C*2″), 81.96 (*C*2′), 82.02 (*C*3′), 82.13 (*C*3), 82.53 (*C*5), 82.63 (*C*3″), 83.48 (*C*3‴), 83.86 (*C*5‴), 84.23 (*C*5′), 86.46 (*C*4), 89.91 (*C*4″), 110.15 (*C*1′), 110.86 (*C*1 or *C*1‴), 110.89 (*C*1 or *C*1‴), 134.31 (*C*5″a), 144.13 (*C*5″); ESIMS (%, rel int.) m/z: 693.2275 (58, calcd for $C_{26}H_{45}O_{19}S$ $[M+H]^+$: 693.2276), 715.2094 (100, calcd for $C_{26}H_{44}O_{19}NaS$ $[M+Na]^+$: 715.2095).

4.26. Methyl [2,3,4-6-tetra-*O*-acetyl-β-D-glucopyranosyl-(1→4)-β-(2,3,6-*O*-triacetyl-1-thio-$\Delta^{5,5a}$carbaglucopyranosyl)-(1→4)-β-(2,3,6-tri-*O*-acetyl-β-D-glucopyranoside)] (22)

A mixture of **1b** (5.2 mg, 9.8 μmol) and 4-(dimethylamino)pyridine (200 μg, 1.6 μmol) in a mixture of pyridine (1.0 mL) and acetic anhydride (200 μL) at 60 °C for 2 h. After concentration in vacuo, silica gel column chromatography of the residue with EtOAc/hexane = 80:20 gave **22** (7.8 mg, 87%). $[\alpha]_D^{23}$−52 (c 0.56, $CDCl_3$),IR (film) 2940, 1750, 1225, 1040 cm^{-1}, ^1H NMR (500 MHz, C_6D_6) δ 1.66, 1.67, 1.69, 1.77, 1.79, 1.82, 1.84, 1.89, 1.93, 1.97 (each 3H, s, OCOCH_3), 2.84 (1H, dd, J = 10.0, 11.0 Hz, C4*H*), 2.92 (1H, ddd, J = 1.9, 4.5, 11.0 Hz, C5*H*), 3.21 (3H, s, C1OCH_3), 3.46 (1H, ddd, J = 2.1, 4.6, 10.1 Hz, C5″*H*), 3.54 (1H, br dd, J = 3.7, 10.0 Hz, C1′*H*), 4.04 (1H, d, J = 7.6 Hz, C1*H*), 4.05 (1H, br d, J = 4.4 Hz, C4′*H*), 4.09 (1H, dd, J = 2.1, 12.4 Hz, C6″*H*H), 4.31 (1H, dd, J = 4.5, 12.0 C6*H*H), 4.37 (1H, dd, J = 4.6, 12.4, C6″*H*H), 4.54 (1H, d, J = 8.1 Hz, C1″*H*), 4.58 (2H, br d, J = 7.8 Hz, C6′H_2), 4.63 (1H, dd, J = 1.9, 12.4 Hz, C6*H*H), 5.21 (1H, dd, J = 8.1, 9.4 Hz, C2″*H*), 5.21 (1H, dd, J = 7.6, 9.4 Hz, C2*H*), 5.23 (1H, dd, J = 9.4, 10.1 Hz, C4″*H*), 5.25 (1H, dd, J = 9.4, 10.0 Hz, C3*H*)5.37 (1H, t, J = 9.4 Hz, C3″*H*), 5.40 (1H, dd, J = 5.0, 6.6 Hz, C2′*H*), 5.77 (1H, dd, J = 4.4, 6.6 Hz, C3′*H*), 5.92 (1H, br d, J = 3.7 Hz, C5a*H*), ^{13}C NMR (125 MHz, C_6D_6) δ 20.08, 20.13, 20.28, 20.32, 20.35, 20.36, 20.41, 20.45 (each CO*C*H_3), 20.54

($COCH_3$ ×2), 45.24 (*C*1′), 48.64 (*C*4), 56.21 (C1OCH_3), 61.59 (*C*6″), 63.65 (*C*6), 63.97 (*C*6′), 68.29 (*C*4″), 70.00 (*C*3′), 70.61 (*C*′), 72.14 (*C*2 or *C*2′), 72.49 (*C*5″), 73.13 (*C*2 or *C*2′), 73.53 (*C*3″), 73.60 (*C*5), 74.35 (*C*3), 76.70 (*C*4′), 101.55 (*C*1), 102.35 (*C*1″), 127.10 (*C*5′a), 131.50 (*C*5′), 169.07, 169.08, 169.18, 169.53, 169.57, 169.76, 169.90 (each O$COCH_3$), 170.10 ($OCOCH_3$ ×2), ESIMS (%, rel int.) *m/z* 989.2341 (33, calcd for $C_{40}H_{54}O_{24}SK$ $[M+K]^+$: 989.2362), 973.2610 (48, calcd for $C_{40}H_{54}O_{24}SNa$ $[M+Na]^+$: 973.2610), 968.3055 (100, calcd for $C_{40}H_{58}O_{24}SN$ $[M+NH_4]^+$ 968.3055).

4.27. 2,3,4,6-Tetra-*O*-acetyl-D-glucopyranosyl-1−4-β-D-1-thio-2,3,6-*O*-triacetylglucopyranoside (24)

A solution of acetyl 2,3,6-tri-*O*-acetyl-4-*O*-[2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyl]-1-thio-β-D-glucopyranoside **23**[30] (105 mg, 150 μmol) was stirred with sodium methoxide (32.6 mg 600 μmol) in a mixture of CH_2Cl_2 (2.0 mL) and MeOH (2.0 mL) at −15 °C for 30 min. The mixture was poured into aqueous HCl solution (5.0×10^{-3} M, 20 mL) and extracted with EtOAc (20 mL × 3). The organic layers were washed with brine (20 mL), dried over $MgSO_4$, combined, and then concentrated in vacuo to give crude thiol **24** with enough purity. ^{1}H NMR (500 MH_Z, $CDCl_3$) δ 1.98, 2.01, 2.02, 2.03, 2.07, 2.09, 2.14 (3H, s, CH_3CO_2), 2.56 (1H, d, *J* = 9.6 Hz, S*H*), 3.62 (1H, ddd, *J* = 2.0, 5.3, 9.6 Hz, C5*H*), 3.65 (1H,ddd, *J* = 2.2, 5.3, 9.3 Hz, C5′*H*), 3.78 (1H,t, *J* = 9.6 Hz, C4*H*), 4.04 (1H, dd, *J* = 2.2, 12.5 Hz, C6′*H*H), 4.09 (1H, dd, *J* = 5.3, 12.1 Hz, C6*H*H), 4.37 (1H, dd, *J* = 4.5, 12.5 Hz, C6′*H*H), 4.48 (1H, dd, *J* = 2.0, 12.1 Hz, C6*H*H), 4.50 (1H, d, *J* = 8.0 Hz, C1′*H*), 4.52 (1H, t, *J* = 9.6 Hz, C1*H*), 4.89 (1H, t, *J* = 9.6 Hz, C2*H*), 4.92 (H, dd, *J* = 8.0, 9.3 Hz, C2′*H*), 5.06 (1H, t, *J* = 9.3 Hz, C4′*H*), 5.14 (1H, t, *J* = 9.3 Hz, C3′*H*), 5.18 (1H, t, *J* = 9.6 Hz, C3*H*). This sample was immediately used for the next coupling reaction with **26** without purification.

4.28. Methyl 2,3,6-tri-*O*-benzoyl-4-*O*-trifluoromethane sulfonyl-α-D-galactopyranoside (26a)

Trifluoromethanesulfonic anhydride (42.3 mg, 150 μmol) was added to a mixture of methyl 2,3,6-tri-*O*-benzoyl α-D-galactopyranoside (**25a**, 68.0 mg, 130 μmol)[31,32] and pyridine (23.7 mg, 300 μmol) in CH_2Cl_2 (1.0 mL) at 0 °C and the mixture was stirred at the same temperature for 20 min. The mixture was poured into H_2O (30 mL), and extracted with EtOAc (30 mL × 3). The organic layers were washed with brine (30 mL), dried over $MgSO_4$, combined, and then concentrated in vacuo. The residue was purified by silica gel column chromatography (EtOAc/hexane = 10:90) to give **26a** (74.0 mg, 92%) as an oil, ^{1}H NMR (500 MH_Z, $CDCl_3$) δ 3.46 (3H, s, OCH_3), 4.35 (1H, dd, *J* = 7.0, 11.3 Hz, C6*H*H), 4.59 (1H, br t, *J* = 6.8 Hz, C5*H*), 4.69 (1H, dd, *J* = 6.5, 11.3 Hz, C6*H*H), 5.29 (1H, d, *J* = 3.7 Hz, C1*H*), 5.59 (1H, br d, *J* = 2.8 Hz, C4*H*), 5.60 (1H, dd, *J* = 3.7, 10.7 Hz, C2*H*), 5.95 (1H, dd, *J* = 2.8, 10.7 Hz, C3*H*), 7.34–7.61 (9H, *aromatic protons*), 7.96 (1H, br d, *J* = 1.2, 8.3 Hz, *aromatic protons*), 8.03–8.07 (4H, *aromatic protons*), This sample was immediately used for next step.

4.29. Methyl α-(2,3,4,6-tetra-*O*-acetyl-D-glucopyranosyl-(1→4)-β-(2,3,6-tri-*O*-acetyl-D-glucopyranosyl)-(1→4)-β-2,3,6-tri-*O*-benzoyl)-4-thio-D-glucoside (27a)

Sodium hydride (washed with hexane, 5.4 mg, 230 μmol) was added to a mixture of **24** and **26a** obtained in Sections 4.27 and 4.28, respectively, in THF (2.0 mL) at 0 °C. After the mixture was stirred for 1 h at the same temperature, the mixture was poured into 0.5 M aqueous HCl solution (20 mL) and extracted with EtOAc (20 mL × 3). The organic layers were washed with brine (20 mL), combined, dried over $MgSO_4$, and then concentrated in vacuo. Purification of the residue by silica gel column chromatography (EtOAc/benzene = 22:78) gave **27a** (120 mg, 73% in two steps) as an oil, $[\alpha]_D^{26}$+23.5 (*c* 1.17, $CHCl_3$); IR (film): 2955, 1750, 1270, 1230, 1040, 715 cm^{-1}; ^{1}H NMR (500 MH_Z, $CDCl_3$) δ 1.53, 1.97, 1.99, 2.01, 2.06, 2.09, 2.11 (each 3H, s, CH_3CO_2×7), 3.29 (1H, t, *J* = 11.1 Hz, C4*H*), 3.48 (3H, s, C1OCH_3), 3.65 (1H, ddd, *J* = 2.1, 4.5, 9.4 Hz, C5″*H*), 3.66 (1H, ddd, *J* = 2.0, 4.2, 9.1 Hz, C5′*H*), 3.74 (1H, t, *J* = 9.1 Hz, C4′*H*), 3.97 (1H, dd, *J* = 4.2, 12.2 Hz, C6′*H*H), 4.04 (1H, dd, *J* = 2.1, 12.5 Hz, C6″*H*H), 4.36 (1H, dd, *J* = 4.5, 12.5 Hz, C6″*H*H), 4.47 (1H, ddd, *J* = 2.1, 3.8, 11.1 Hz, C5*H*), 4.52 (1H, d, *J* = 7.9 Hz, C1″*H*), 4.66 (1H, dd, *J* = 2.0, 12.2 Hz, C6′*H*H), 4.76 (1H, dd, *J* = 2.1, 12.1 Hz, C6*H*H), 4.80 (1H, dd, *J* = 3.8, 12.1 Hz, C6*H*H), 4.84 (1H, dd, *J* = 9.1, 10.1 Hz, C2′*H*), 4.93 (1H, dd, *J* = 7.9, 9.4 Hz, C2″*H*), 4.98 (1H, d, *J* = 10.1 Hz, C1′*H*), 5.07 (1H, t, *J* = 9.4 Hz, C4″*H*), 5.15 (1H, t, *J* = 9.4 Hz, C3″*H*), 5.18 (1H, t, *J* = 9.1 Hz, C3′*H*), 5.20 (1H, d, *J* = 3.5 Hz, C1*H*), 5.25 (1H, dd, *J* = 3.5, 9.6 Hz, C2*H*), 6.00 (1H, dd, *J* = 9.6, 11.1 Hz, C3*H*), 7.35-7.40 (4H, *aromatic protons*), 7.48–7.54 (4H, *aromatic protons*), 7.61 (tt, 1H, *J* = 1.3, 8.3 Hz, *aromatic protons*), 7.97 (2H, br d, *J* = 8.5 Hz, *aromatic protons*), 7.99 (2H, br d, *J* = 8.4 Hz, *aromatic protons*), 8.08 (2H, br d, *J* = 8.3 Hz, *aromatic protons*); ^{13}C NMR (125 MHz, $CDCl_3$) δ 19.90, 20.45, 20.50, 20.51, 20.55, 20.62, 20.72 (each CH_3CO_2), 46.26 (*C*4), 55.67 (OCH_3), 61.14 (*C*6′), 61.48 (*C*6″), 63.98 (*C*6), 67.24 (*C*3), 67.71 (*C*4″), 69.24 (*C*5), 70.10 (*C*2′), 71.54 (*C*2″), 71.95 (*C*5″), 72.92 (*C*3″), 73.30 (*C*3′), 73.33 (*C*2), 75.73 (*C*4′), 76.31 (*C*5′), 80.97 (*C*1′), 97.26 (*C*1), 100.54 (*C*1″), 128.33, 128.40, 128.47, 128.97, 129.16, 129.64, 129.81, 129.86, 129.88, 133.18, 133.30, 133.38 (*aromatic carbons*), 165.51, 165.78, 166.11, 168.87, 169.26, 169.51, 169.55, 170.03, 170.24, 170.48 (*C*=O); ESIMS (%, rel int.) *m/z*: 1163.3041 (100, calcd for $C_{54}H_{60}O_{25}SNa$ $[M+Na]^+$: 1163.3042), 619 (41, calcd for $[M-C_{28}H_{25}O_8S]^+$: 619.1869).

4.30. Methyl β-(2,3,4,6-tetra-*O*-acetyl-D-glucopyranosyl-(1→4)-β-(2,3,6-tri-*O*-acetyl-D-glucopyranosyl)-(1→4)-β-2,3,6-tri-*O*-benzoyl)-4-thio-D-glucoside (27b)

Crude thiol **24** was prepared employing **23** (128 mg, 184 μmol) and sodium methoxide (59.6 mg, 1.10 mmol) in the same manner as described in Section 4.27. Triflate **26b** (108.1 mg, 169 μmol) was also prepared employing **25b** (93.3 mg, 184 μmol), trifluoromethanesulfonic anhydride (268 mg, 951 μmol) and pyridine (157 mg, 1.98 mmol) in a similar manner as described in Section 4.28. 1H NMR (400 MHz, $CDCl_3$) δ 3.57 (3H, s, OCH_3), 4.29–4.39 (2H, m, C6H_2), 4.74 (1H, d, *J* = 7.9 Hz, C1*H*), 4.81 (1H, dd, *J* = 5.0, 10.3 Hz, C5*H*), 5.54 (1H, br d, *J* = 2.9 Hz, C4*H*), 5.58 (1H, dd, *J* = 2.9, 10.3 Hz, C3*H*), 5.74 (1H, dd, *J* = 7.9, 10.3 Hz, C2*H*), 7.35–7.42 (4H, *aromatic protons*), 7.45–7.58 (5H, *aromatic protons*), 7.61 (1H, br t, *J* = 7.6 Hz, *aromatic protons*), 7.96 (2H, br d, *J* = 7.5 Hz, *aromatic protons*), 8.01 (2H, br d, *J* = 7.3 Hz, *aromatic protons*), 8.05 (2H, br d, *J* = 8.3 Hz, *aromatic protons*). After **24** and **26b** thus obtained were dissolved in THF (0.5 mL), the mixture was treated with sodium hydride (washed with hexane, 4.4 mg, 184 μmol) in a similar manner as described in Section 4.29. Purification of the crude product by silica gel column chromatography (EtOAc/benzene = 20:80) gave **27b** (97.9 mg, 46% in two steps) as an oil, $[\alpha]_D^{23}$ +3.6 (*c* 0.82, $CHCl_3$); IR (film) 2925, 1750, 1230, 1070, 715 cm^{-1}; ^{1}H NMR (500 MH_Z, $CDCl_3$) δ 1.51, 1.96, 1.99, 2.01, 2.06, 2.08, 2.10 (each 3H, s, CH_3CO_2), 3.29 (1H, t, *J* = 11.0 Hz, C4*H*), 3.49 (3H, s, OCH_3), 3.63-3.71 (3H, m, C5′*H*, C4′*H*, C5″*H*), 3.95 (1H, dd, *J* = 5.7, 11.9 Hz, C6′*H*H), 4.04 (1H, dd, *J* = 2.2, 12.5 Hz, C6″*H*H), 4.16 (1H, ddd, *J* = 2.1, 4.3, 11.0 Hz, C5*H*), 4.34 (1H, dd, *J* = 4.5, 12.5 Hz, C6″*H*H), 4.48 (1H, d, *J* = 7.8 Hz, C1″*H*), 4.60 (1H, d, *J* = 7.9 Hz, C1*H*), 4.61 (1H, dd, *J* = 1.4, 11.9 Hz, C6′*H*H), 4.77 (1H, dd, *J* = 4.3, 12.0 Hz, C6*H*H), 4.83 (1H, dd, *J* = 9.2, 10.0 Hz, C2′*H*), 4.86 (1H, dd, *J* = 2.1, 12.0 Hz, C6*H*H), 4.93 (1H, dd, *J* = 7.8, 9.4 Hz, C2″*H*), 4.93 (1H, d, *J* = 10.0 Hz, C1′*H*), 5.06 (1H, t, *J* = 9.5 Hz, C4″*H*), 5.13-5.17 (2H, m, C3′*H*, C3″*H*), 5.41 (1H, dd, *J* = 7.9, 9.3 Hz, C2*H*), 5.67

(1H, dd, *J* = 9.3, 11.0 Hz, C3*H*), 7.34–7.40 (4H, *aromatic protons*), 7.47–7.53 (4H, *aromatic protons*), 7.60 (1H, tt, *J* 8 1.3, 8.3 Hz, *aromatic protons*), 7.94–7.96 (4H, *aromatic protons*), 8.07 (br d, 2H, *J* = 1.3, 8.3 Hz, *aromatic protons*), ^{13}C NMR (125 MHz, $CDCl_3$) δ 19.90, 20.45, 20.52, 20.52, 20.52, 20.64, 20.67 (each CH_3CO_2), 46.46 (*C*4), 56.91 (OCH_3), 61.54 (*C*6″), 62.05 (*C*6′), 64.02 (*C*6), 67.77 (*C*4″), 69.88 (*C*3), 70.07 (*C*2′), 71.59 (*C*2″), 72.03 (*C*5″), 72.94 (*C*3″), 73.23 (*C*2), 73.28 (*C*3′), 74.27 (*C*5), 76.29 (*C*4′), 76.54 (*C*5′), 80.87 (*C*1′), 100.72 (*C*1″), 102.06 (*C*1), 128.35, 128.37, 128.51, 128.85, 129.29, 129.69, 129.81, 129.91, 129.94, 133.24, 133.24, 133.45 (*aromatic carbons*), 165.25, 165.59, 166.07, 168.98, 169.31, 169.51, 169.51, 169.97, 170.22, 170.49 (*C*═O); ESIMS (%, rel int.) *m/z*: 1163.3027 (34, calcd for $C_{54}H_{60}O_{25}SNa$ $[M+Na]^+$: 1163.3042).

4.31. Methyl β-D-glucopyranosyl-(1→4)-β-D-glucopyrano syl-(1→4)-α-D-4-thioglucopyranoside (3a)

A solution of **27a** (235 mg, 206 μmol) in a mixture of MeOH (5.0 mL) and 5% NaOH aqueous solution (0.5 mL) was stirred at room temperature for 1 h. After removing methanol in vacuo, the resulting aqueous solution was passed through an ion-exchange column (DOWEX 50 W, H^+ form). After the eluate was concentrated until the whole volume became 30 mL, the resulting aqueous solution was washed with EtOAc (20 mL). Lyophilization of the aqueous layer gave **3a** (109 mg, 99%) as an amorphous powder. $[\alpha]_D^{27}$ +16.6 (*c* 1.05, H_2O), The IR spectrum was not measured because this sample was only soluble in H_2O. ^{1}H NMR (500 MH_Z, D_2O) δ: 2.73 (1H, t, *J* = 10.8 Hz, C4*H*), 3.17 (1H, dd, *J* = 7.9, 9.2 Hz, C2″*H*), 3.25 (1H, dd, *J* = 8.9, 9.8 Hz, C2′*H*), 3.26 (3H,s, OCH_3), 3.27 (1H, m, C4″*H*), 3.32-3.38 (2H, C3″*H*, C5″*H*), 3.43-3.53 (4H, C2*H*, C3′*H*, C4′*H*, C5′*H*), 3.59 (1H, dd, *J* = 5.8, 12.3 Hz, C6″*H*H), 3.63 (1H, dd, *J* = 9.3, 10.8 Hz, C3*H*), 3.65 (1H, dd, *J* = 5.1, 12.5 Hz, C6′*H*H), 3.75-3.82 (3H, C5*H*, C6′*H*H, C6″*H*H), 3.83 (1H, dd, *J* = 4.5, 12.1 Hz, C6*H*H), 3.89 (1H, dd, *J* = 2.1, 12.1 Hz, C6*H*H), 4.36 (1H, d, *J* = 7.9 Hz, C1″*H*), 4.53 (1H, d, *J* = 9.8 Hz, C1′*H*), 4.71 (1H, d, *J* = 3.7 Hz, C1*H*); ^{13}C NMR (125 MHz, D_2O) δ 47.07 (*C*4), 55.19 (OCH_3), 60.23 (*C*6′), 60.74 (*C*6″), 61.46 (*C*6), 69.59 (*C*3), 69.61 (*C*4″), 72.07 (*C*5), 72.43 (*C*2′), 72.55 (*C*2), 73.31 (*C*2″), 75.65 (*C*3″), 75.76 (*C*4′), 76.16 (*C*5″), 78.40 (*C*3′), 78.84 (*C*5′), 83.61 (*C*1′), 99.47 (*C*1), 102.68 (*C*1″); ESIMS (%, rel int.) *m/z*: 557.1516 (100, calcd for $C_{19}H_{34}O_{15}SNa$ $[M+Na]^+$ 557.1516), 535.1698 (5.3, calcd for $C_{19}H_{35}O_{15}S$ $[M+H]^+$ $[M+H]^+$ 535.1697).

4.32. Methyl β-D-glucopyranosyl-(1→4)-β-D-glucopyrano syl-(1→4)-β-D-4-thioglucopyranoside (3b)

In a similar manner as described in Section 4.31, **27b** (358 mg, 314 μmol) was treated employing MeOH (5.0 mL), 5% NaOH aqueous solution (1.0 mL). Following similar work-up gave **3b** (164.1 mg, 98%) as an amorphous powder. $[\alpha]_D^{23}$ −49 (*c* 0.93, H_2O). The IR spectrum was not measured because this sample was only soluble in H_2O. ^{1}H NMR (500 MH_Z, D_2O) δ 2.73 (1H, t, *J* = 10.6 Hz, C4*H*), 3.16 (1H, dd, *J* = 8.1, 9.0 Hz, C2*H*), 3.18 (1H, dd, *J* = 8.0, 9.2 Hz, C2″*H*), 3.25 (1H, dd, *J* = 8.8, 9.8 Hz, C2′*H*), 3.28 (1H, dd, *J* = 9.2, 9.7 Hz, C4″*H*), 3.35 (1H, ddd, *J* = 2.2, 5.7, 9.7 Hz, C5″*H*), 3.37 (1H, t, *J* = 9.2 Hz, C3″*H*), 3.43 (3H, s, OCH_3), 3.45 (1H, dd, *J* = 9.0, 10.6 Hz, C3*H*), 3.46 (1H, ddd, *J* = 2.2, 5.0, 9.5 Hz, C5′*H*), 3.49-3.54 (2H, C3′*H*, C4′*H*), 3.55 (ddd, 1H, *J* = 2.0, 5.3, 10.6 Hz, C5*H*), 3.60 (1H, dd, *J* = 5.7, 12.4 Hz, C6″*H*H), 3.66 (1H, dd, *J* = 5.0, 12.5 Hz, C6′*H*H), 3.78 (1H, dd, *J* = 2.2, 12.4 Hz, C6″*H*H), 3.79 (1H, dd, *J* = 5.3, 12.2 Hz, C6*H*H), 3.82 (1H, dd, *J* = 2.2, 12.5 Hz, C6′*H*H), 4.00 (1H, dd, *J* = 2.4, 12.2 Hz, C6*H*H), 4.22 (1H, d, *J* = 8.1 Hz, C1*H*), 4.37 (1H, d, *J* = 8.0 Hz, C1″*H*), 4.53 (1H, d, *J* = 9.8 Hz, C1′*H*), ^{13}C NMR (125 MHz, D_2O) δ 47.31 (*C*4), 57.29 (OCH_3), 60.25 (*C*6′), 60.77 (*C*6″), 61.56 (*C*6), 69.64 (*C*4″), 72.45 (*C*2′), 73.05 (*C*3), 73.34 (*C*2″), 74.48 (*C*2), 75.68 (*C*3″), 75.74 (*C*3′), 76.18 (*C*5″), 76.61 (*C*5), 78.39 (*C*4′), 78.73 (*C*5′), 83.84 (*C*1′), 102.70 (*C*1″), 103.13 (*C*1); ESIMS (%, rel int.) *m/z*: 557.1494 (100, calcd for $C_{19}H_{34}O_{15}SNa$ $[M+Na]^+$ 557.1516), 535.1674 (31, calcd for $C_{19}H_{35}O_{15}S$ $[M+H]^+$ $[M+H]^+$ 535.1697).

4.33. Methyl β-D-glucopyranosyl-(1→4)-β-D-glucopyrano syl-(1→4)-β-D-4-thioglucopyranosyl-(1→4)-β-D-glucopyranoside (4)

A solution of thioacetate **23** (92.7 mg, 142 μmol) was stirred with NaOMe (23.0 mg, 426 μmol) in a mixture of CH_2Cl_2 (2.0 mL) and MeOH (8.0 mL) at 0 °C. After 5 min at 0 °C, the solution was poured into H_2O (50 mL) and extracted with EtOAc (30 mL). The combined extracts were washed with brine, dried over $MgSO_4$ and then cocncentrated in vacuo to give thiol **24**, which was immediately mixed with triflate **20** (150 mg, 124 μmol) and diluted with THF (700 μL). Sodium hydride (3.4 mg, 142 μmol) was added to the mixture at 0 °C and it was allowed to warm to room temperature. After 2 h, the resulting suspension was poured into H_2O (50 mL) and extracted with EtOAc (30 mL). The combined extracts were washed with brine, dried over $MgSO_4$ and then concentrated in vacuo. Purification by silica gel column chromatography with Hexan: EtOAc = 1:1 afforded the adduct (140.5 mg, 82 μmol, 57% in two steps). $[\alpha]_D^{27}$+3.3 (c 0.5, $CHCl_3$); IR (film) 2935, 1750, 1610, 1510, 1245 cm^{-1}; ^{1}H NMR (500 MHz, C_6D_6) δ 1.67, 1.68, 1.69, 1.78, 1.80, 1.88, 1.94 (each 3H, s, $COCH_3$ ×7), 3.06 (1H, ddd, *J* = 1.8, 6.7, 9.9 Hz, C5″*H*), 3.21 (1H, ddd, *J* = 2.0, 4.0, 10.1 Hz, C5‴*H*), 3.29, 3.30, 3.31 (each 3H, s, $ArOCH_3$ ×3), 3.38-3.44 (5H, C5*H*, C′3*H*, C4′*H*, C5′*H*, C4″*H*), 3.40, 3.41 (each 3H, s, $ArOCH_3$ ×2), 3.41 (3H, s, $C1OCH_3$), 3.43 (3H, s, $ArOCH_3$), 3.53 (1H, m, C2′*H*), 3.67 (1H, dd, *J* = 7.7, 9.0 Hz, C2*H*), 3.78 (1H, t, *J* = 9.0 Hz, C3*H*), 3.81 (1H, dd, *J* = 1.5, 11.0 Hz, C6*H*H), 3.86 (1H, dd, *J* = 2.0, 11.5 Hz, C6‴*H*H), 3.88 (1H, dd, *J* = 1.8, 10.5 Hz, C6′*H*H), 3.96 (1H, dd, *J* = 6.7, 11.8 Hz, C6″*H*H), 4.02 (1H, dd, *J* = 3.1, 10.5 Hz, C6′*H*H), 4.15 (1H, dd, *J* = 3.5, 11.0 Hz, C6*H*H), 4.19 (1H, d, *J* = 8.0 Hz, C1‴*H*), 4.32 (1H, d, *J* = 7.7 Hz, C1*H*), 4.32 (1H, t, *J* = 9.0 Hz, C4*H*), 4.34 – 4.39 (2H, C6″*H*H, C6‴*H*H), 4.37 (1H, d, *J* = 11.2 Hz, ArC*H*HO), 4.41 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.53 (1H, d, *J* = 11.2 Hz, ArC*H*HO), 4.62 (1H, d, *J* = 11.6 Hz, ArC*H*HO), 4.73 (1H, d, *J* = 8.0 Hz, C1′*H*), 4.75 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 4.82 (1H, d, *J* = 10.2 Hz, C1″*H*), 4.83 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 4.86 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 4.96 (1H, d, *J* = 11.2 Hz, ArC*H*HO), 4.97 (1H, d, *J* = 10.3 Hz, ArC*H*HO), 5.01 (1H, d, *J* = 10.9 Hz, ArC*H*HO), 5.09 (1H, dd, *J* = 8.0, 9.3 Hz, C2‴*H*), 5.12 (1H, d, *J* = 10.3 Hz, ArC*H*HO), 5.18 (1H, dd, *J* = 9.3, 10.1 Hz, C4‴*H*), 5.20 (1H, dd, *J* = 9.2, 10.2 Hz, C2″*H*), 5.30 (1H, t, *J* = 9.3 Hz, C3‴*H*), 5.33 (1H, t, *J* = 9.2 Hz, C3″*H*), 5.40 (1H, d, *J* = 11.2 Hz, ArC*H*HO), 6.79 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 6.82 (2H, br d, *J* = 8.5 Hz, *aromatic protons*), 6.87 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 6.90 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 6.92 (2H, br d, *J* = 8.7 Hz, *aromatic protons*), 7.26 (2H, br d, *J* = 8.6 Hz, aromatic protons), 7.31–7.37 (6H, *aromatic protons*), 7.52 (2H, br d, *J* = 8.6 Hz, *aromatic protons*), 7.56 (2H, br d, *J* = 8.6 Hz, *aromatic protons*); ^{13}C NMR (125 MHz, C_6D_6) δ 20.06, 20.13, 20.16, 20.24, 20.43, 20.44, 20.44 ($COCH_3$ ×7), 48.18 (C4′), 54.66, 54.72, 54.72, 54.80, 54.90, 54.92 ($ArOCH_3$ ×6), 56.53 ($C1OCH_3$), 61.32 (*C*6‴), 62.88 (*C*6″), 68.04 (*C*4‴), 68.34 (*C*6), 69.70 (*C*6′), 71.35 (*C*2″), 72.13 (*C*2‴), 72.25 (C5‴), 73.39, 73.44 ($ArCH_2O$ *2*), 73.51 (*C*3‴), 74.26 (*C*3″), 74.70, 74.99, 75.02, 75.41 ($ArCH_2O$ ×4), 75.76 (*C*5), 76.55 (*C*5″), 76.80 (*C*5′), 77.38, 77.44 (*C*4, *C*4″), 81.08 (*C*3′), 82.08 (*C*2), 82.82 (*C*3), 83.14 (*C*1″), 83.67 (*C*2′), 101.51 (*C*1‴), 102.99 (*C*1′), 105.25 (*C*1), 113.89, 113.89, 113.91, 114.06, 114.18, 114.27, 129.38, 129.66, 129.79, 129.87, 129.88, 129.88, 130.77, 130.81, 131.22, 131.66, 131.75, 132.38, 159.53, 159.61, 159.71, 159.80, 159.80, 159.89, (*aromatic carbons*), 168.91, 168.99, 169.18, 169.48, 169.92, 169.97, 170.24 ($COCH_3$ ×7); ESIMS (%, rel int.) *m/z*: 1728.6684 (92, calcd for $C_{87}H_{110}NO_{33}S$

$[M+NH^4]^+$: 1728.6681). The obtained adduct (580 mg, 339 μmol) in mixture of CH_2Cl_2 (10 mL) and H_2O (1.0 mL) was stirred with DDQ (629 mg, 3.04 mmol) at room temperature. After 1 h, the solution was poured into H_2O (200 ml), washed with EtOAc (100 mL × 3), and then concentrated in vacuo. Purification of ODS silica gel column chromatography H_2O/MeOH = 65: 35 afforded the hepta-acetate (271 mg, 273 μmol). $[\alpha]_D^{27}$ −20.5 (c 0.25, H_2O); ^{1}H NMR (500 MHz, D_2O) δ 2.00, 2.04, 2.067, 2.074, 2.09, 2.10, 2.15 (each 3H, COCH_3 ×7), 2.84 (1H, t, J = 10.8 Hz, C4′H), 3.26 (1H, dd, J = 8.0, 9.1 Hz, C2H), 3.30 (1H, dd, J = 8.0, 9.0 Hz, C2′H), 3.53 (3H, s, C1OCH_3), 3.54 (1H, dd, J = 9.0, 10.8 Hz, C3′H), 3.55-3.62 (3H, C3H, C4H, C5H), 3.63 (1H, ddd, J = 2.1, 4.9, 10.8 Hz, C5′H), 3.78 (1H, dd, J = 4.3, 12.4 Hz, C6HH), 3.86 (1H, ddd, J = 1.8, 5.6, 9.8 Hz, C5″H), 3.88 (1H, dd, J = 4.9, 12.1 Hz, C6′HH), 3.94 (1H, dd, J = 1.9, 12.4 Hz, C6HH), 3.97 (1H, ddd, J = 2.1, 3.8, 10.0 Hz, C5‴H), 3.98 (1H, dd, J = 2.1, 12.1 Hz, C6′HH), 4.04 (1H, dd, J = 9.3, 9.8 Hz, C4″H), 4.11 (1H, dd, J = 2.1, 12.7 Hz, C6‴HH), 4.12 (1H, dd, J = 5.6, 12.2 Hz, C6″HH), 4.36 (1H, d, J = 8.0 Hz, C1H), 4.40 (1H, dd, J = 3.8, 12.7 Hz, C6‴HH), 4.45 (1H, d, J = 8.0 Hz, C1′H), 4.49 (1H, dd, J = 1.8, 12.2 Hz, C6″HH), 4.78 (1H, d, J = 7.9 Hz, C1‴H), 4.88 (1H, dd, J = 7.9, 9.4 Hz, C2‴H), 4.89 (1H, dd, J = 8.2, 9.9 Hz, C2″H), 4.92 (1H, d, J = 9.9 Hz, C1″H), 5.05 (1H, dd, J = 9.4, 10.0 Hz, C4‴H), 5.21 (1H, dd, J = 8.2, 9.3 Hz, C3″H), 5.26 (1H, t, J = 9.4 Hz, C3‴H); ^{13}C NMR (125 MHz, D_2O, Assignments for some signals were not complete, thus only the chemical shifts are described for these signals.) δ 20.06, 20.08, 20.14, 20.17, 20.24, 20.35, 20.35 (OCOCH_3 ×7), 47.77 (C4′), 57.27 (C1OCH_3), 60.08 (C6), 61.15 (C6′), 61.88 (C6‴), 62.57 (C6″), 68.02 (C4‴), 70.83 (C2″), 71.20, 71.90, 72.42 (C3′), 72.96 (C2), 73.29 (C3‴), 74.40, 74.43, 74.64, 74.80, 76.00, 76.02, 76.20, 78.71, 81.59 (C1″), 100.28 (C1‴), 102.38 (C1′), 103.17 (C1), 172.55, 172.79, 173.12, 173.19, 173.73, 173.76, 173.76 (each OCOCH_3 ×7); ESIMS (%, rel int.) m/z: 1008.3221 (100, calcd for $C_{39}H_{62}NO_{27}S$ $[M+NH^4]^+$: 1008.3230), 1013.2755 (65, calcd for $C_{39}H_{58}O_{27}SNa$ $[M+Na]^+$: 1013.2784). The product (271 mg, 273 μmol) was stirred in mixture of MeOH (5 mL) and H_2O (10 mL), and 1.0 M aqueous NaOH (3.0 mL) at room temperature. After stirring for 30 min, the mixture was poured into H_2O (50 mL) and washed with EtOAc (30 mL × 3). The aqueous solution was passed through an ion-exchange column (DOWEX 50 W, H^+ form), and afforded 2 (197 mg 283 μmol, in two steps 83%) after lyophilization. $[\alpha]_D^{27}$ −20.5 (c 0.50, H_2O); ^{1}H NMR (500 MHz, D_2O) δ 2.75 (1H, t, J = 10.8 Hz, C4′H), 3.14 (1H, dd, J = 8.0, 9.4 Hz, C2H), 3.15 (1H, dd, J = 7.9, 9.2 Hz, C2‴H), 3.20 (1H, dd, J = 8.0, 9.0 Hz, C2′H), 3.24 (1H, dd, J = 9.2, 9.9 Hz, C2″H), 3.25 (1H, dd, J = 9.2, 9.8 Hz, C4‴H), 3.33 (1H, ddd, J = 2.0, 5.8, 9.8 Hz, C5‴H), 3.35 (1H, t, J = 9.2 Hz, C3‴8H), 3.42 (3H, s, C1OCH_3), 3.43-3.53 (7H, C3H, C4H, C5H, C3′H, C3″H, C4″H, C5″H), 3.56 (1H, ddd, J = 2.2, 5.1, 10.8 Hz, C5′H), 3.58 (1H, dd, J = 5.8, 12.5 Hz, C6‴HH), 3.63 (1H, dd, J = 4.8, 12.4 Hz, C6HH), 3.66 (1H, dd, J = 4.7, 12.4 Hz, C6″HH), 3.76 (1H, dd, J = 2.0, 12.5 Hz, C6‴HH), 3.79 (1H, dd, J = 5.1, 12.3 Hz, C6′HH), 3.80 (1H, dd, J = 2.1, 12.4 Hz, C6HH), 3.83 (1H, dd, J = 2.1, 12.4 Hz, C6″HH), 3.95 (1H, dd, J = 2.2, 12.3 Hz, C6′HH), 4.25 (1H, d, J = 8.0 Hz, C1H), 4.34 (1H, d, J = 8.0 Hz, C1′H), 4.35 (1H, d, J = 7.9 Hz, C1‴H), 4.50 (1H, d, J = 9.9 Hz, C1″H); ^{13}C NMR (125 MHz, D_2O, assignments for some signals were not complete, thus only the chemical shifts are described for these signals.) δ 47.08 (C4′), 57.41 (C1OCH_3), 60.17 (C6″), 60.23 (C6), 60.75 (C6‴), 61.41 (C6′), 69.62 (C4‴), 72.44 (C2″), 72.76 (C3′), 73.04 (C2), 73.33 (C2‴), 74.50 (C3 or C5 or C5″), 74.55 (C2′), 74.92 (C3 or C5 or C5″), 75.66 (C3‴), 75.72 (C3″), 76.17 (C5‴), 76.66 (C5′), 78.38 (C4″), 78.73, 78.77, 83.81 (C1″), 102.47 (C1′), 102.69 (C1‴), 103.26 (C1); ESIMS (%, rel int.) m/z: 719.2053 (100, calcd for $C_{25}H_{44}NO_{20}SNa$ $[M+Na]^+$: 719.2044).

Evaluation of dissociation constants: Endoglucanase, NCE5, from *H. insolens*, a homologous protein with EG IV from *H. grisea*[13], was generously given by Meiji Seika Kaisha, Ltd., Japan and it was used after further purification by an ultra-filtration system. The 20 mM glycine buffer, pH 3.0, was used for the preparation of both the enzyme and the inhibitor solution. The concentration of the protein was determined by monitoring the absorbance with a spectrophotometer, using an extinction coefficient of 65.5 cm^{-1} mM^{-1} at 280 nm and a molecular mass of 22,100 Da.[15] The enzyme concentration of this study was set to about 10 μM. The solutions of inhibitors were prepared by dissolving them into the buffer solution. The concentration of the inhibitor was adjusted considering its dissociation constants; 20 mM for compounds **1a** and **1b**, 1.7 mM for compound **2**, 20 mM for compounds **3a** and **3b**, and 9.8 mM for compound **4**.

DSC experiments were performed at 1.0 K/min scanning rate. The thermal transition of the enzyme was fully reversible judging from the results of the re-heating and cooling down of the sample to 10 °C just after the completion of the thermal denaturation. The observed heat capacity function was analyzed with an equilibrium two-state transition model to obtain the thermodynamic parameters of the thermal transition, such as mid point temperature (T_m), the enthalpy of the transition at the temperature (ΔH_{unf}), and others by non-linear least squares fitting with an in-house program.

Dissociation constant K_I of enzyme–inhibitor complex was evaluated using the following equation:

$$\frac{\Delta T_m}{T_m} = \frac{RT_m}{\Delta H_{unf,0}} \ln(1 + \frac{[I]}{K_I})$$

(0.1)where, (ΔT_m) is the difference between the transition temperatures of the enzyme with and without the inhibitor, (T_m) is the mean temperature between the transition temperatures, [I] is the concentration of the inhibitor, and ($\Delta H_{unf,0}$) is the transition enthalpy. In this study the common transition enthalpy, 379 kJ/mol was used in order to reduce the estimation error for the dissociation constant from the experimental error of the transition enthalpy. Consequently the constant can be calculated from the transition temperature of the enzyme-inhibitor complex because the transition temperature of the enzyme is common for all the experiments.

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Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.bmc.2011.04.048.

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