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REGIOSELECTIVE GLYCOSYLATION OF UNPROTECTED METHYL HEXOPYRANOSIDE BY TRANSIENT MASKING WITH ARYLBORONIC ACID

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Abstract — Unprotected methyl α/β-D-galactopyranoside, α/β-D-glucopyranoside, α-L-fucopyranoside, and α-L-rhamnopyranoside were regioselectively glycosylated by treatment with per-*O*-pivaloyl-α-D-glycopyranosyl bromide to give glycosyl-β(1→3)-galactopyranoside, glycosyl-β(1→2/3)-glucopyranoside, glycosyl-β(1→2)-fucopyranoside, and glycosyl-β(1→4)-rhamnopyranoside, respectively. The reaction mainly occurred at the secondary hydroxy group, even in the presence of a primary hydroxy group, which was masked with arylboronic acid.

INTRODUCTION

Oligosaccharides are important target molecules in chemical and biological research. To ensure sufficient quantities of oligosaccharides available for studying their biological functions, suitable synthetic methods are required, especially when only limited quantities can be isolated from natural sources.[1] At present, many methods based on a conventional protection/deprotection strategy are available for synthesizing oligosaccharides,[2] but such methods typically require several steps for extensive manipulation of protecting groups, leading to a lengthy and impractical synthetic scheme. Regioselective glycosylation is a promising approach to overcoming these drawbacks because the reaction should be much more selective, rapid, and productive.

Although regioselective protection of hydroxy-free sugars has been frequently reported,[3] there are few precedents for regioselective glycosylation; in particular, stannylene-mediated[4-7] or boronate-mediated[8] regioselective glycosylation of unprotected hexopyranoside has been reported for one-pot assembly of certain oligosaccharides. However, these methods are limited to producing α/β-(1→6)-linked

disaccharides, except for 6-deoxyhexosides; in other words, glycosylation of the primary hydroxy group of a hexose is preferred. Furthermore, the yield of the glycosylation reaction is not always high.[4-8] Accordingly, a novel regioselective glycosylation method is needed that can be applied to secondary hydroxy groups, even in the presence of a primary hydroxy group.

A potential method for regio- and stereo-selective glycosylation of fully unprotected methyl hexopyranoside is in situ masking hydroxy groups with a suitable arylboronic acid.[9] Promoted by Ag(I) on silica alumina, glycosylation of unprotected methyl hexopyranoside by treatment with glycosyl bromide in a one-pot procedure is shown in this study to yield β-(1→3)- or β-(1→2)-linked disaccharides in good to moderate yields.

RESULTS AND DISCUSSION

We focused on arylboronic acids, which have been utilized in molecular recognition of sugar hydroxy groups since they can distinguish *cis*-1,2-diols and 1,3-diols to form five- and six-membered boronates, respectively. The preferred positions for boronate formation in various hexopyranosides are shown in Figure 1.

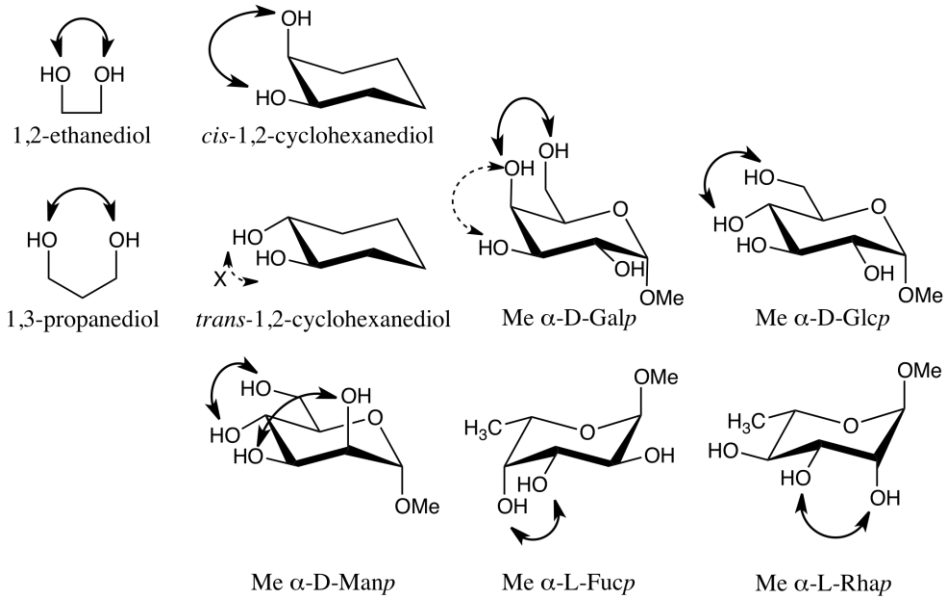
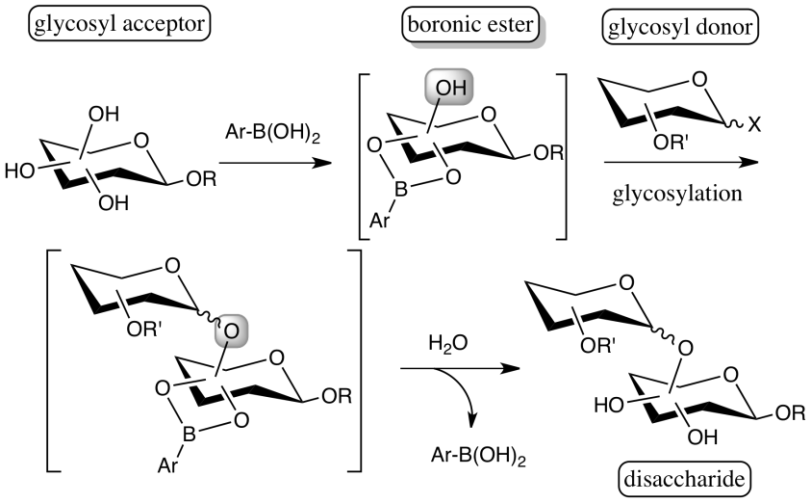


Figure 1. Preferable positions for boronic ester formation

Accordingly, our synthetic plan for regioselective glycosylation should proceed *via* intermediary boronate formation, followed by glycosylation and aqueous workup to provide a disaccharide through a one-pot procedure (Scheme 1). The regioselectivity should be controlled by boronate formation, in which the boron atom reduces the nucleophilicity of the neighboring oxygen atom; hence glycosylation will occur at only the free hydroxy group in the acceptor molecule to afford (1→3)- or (1→2)-linked disaccharide.

This selectivity would compliment the stannylene acetal method, which mainly provides (1→6)-linked disaccharides.



Scheme 1. Regioselective glycosylation of unprotected methyl glycopyranosides by transient masking with arylboronic acid

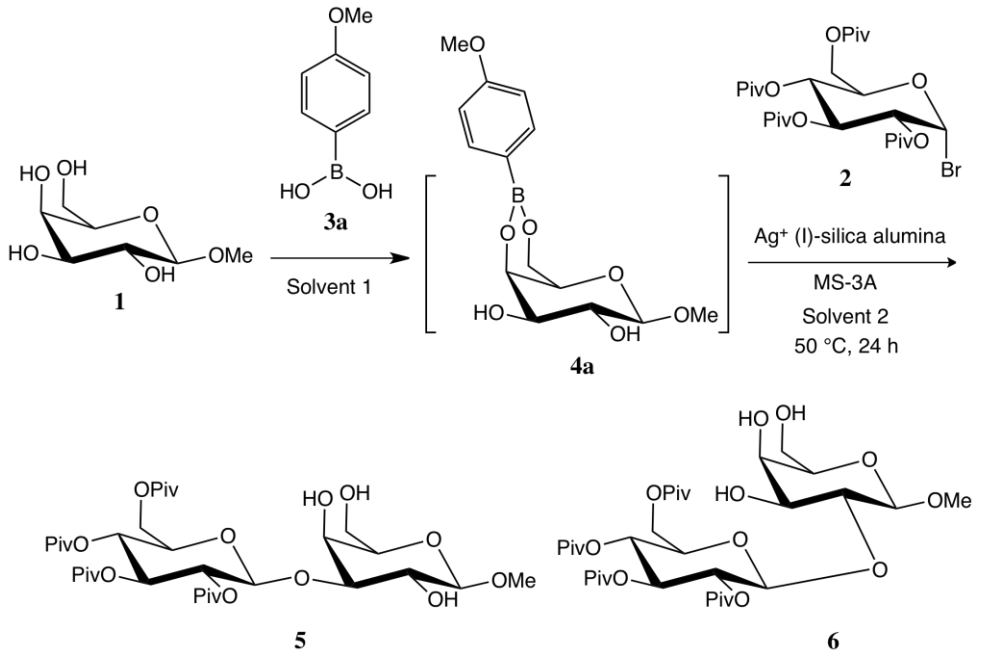
Since glycosyl β-(1→3)-linked D-galactopyranosides are the core disaccharide units of many immunologically relevant oligosaccharides,[10] we first examined our method by using unprotected methyl β-D-galactopyranoside (**1**) as the glycosyl acceptor. For β-selective glycosylation, we chose per-*O*-pivaloyl-α-D-glucopyranosyl bromide (**2**) as the glycosyl donor, because the stereoelectronic effects of the 2-*O*-pivaloyl group are suited to β selectivity. In addition, this donor hardly forms an orthoester under the glycosylation reaction conditions.[11]

As in the stannylene-activation method for regioselective glycosylation of methyl β-D-galactopyranoside (**1**) with per-*O*-benzoylated glycopyranosyl bromide, we selected Ag(I) on silica alumina[12] as a promoter, and screened the solvent, temperature, arylboronic acid substituent, and other reaction conditions.

We first examined solvent effects in a two-stage one-pot procedure where the boronate intermediate was prepared in the first solvent (solvent 1), solvent 1 was removed, and the donor in a second solvent (solvent 2) was added, yielding disaccharides as shown in Scheme 2. Solvent effects are summarized in Table 1.

NMR spectra were consistent with the generation of the boronate intermediate (cf. Experimental). We found that 4,6-boronate **4a** formed by refluxing **1** (1 equiv) and **3a** (2 equiv) in MeOH for 3 h. With MeOH as solvent 1 and 1,2-dichloroethene (DCE) as solvent 2, β-(1→3)-glycoside **5** was obtained in 37% yield along with β-(1→2)- and β-(1→6)-linked disaccharides in 6% and 3% yields, respectively (Run 1). When THF (Run 2) or MeCN (Run 3) was used as solvent 2, regioselectivity was higher but the yield of **5** was lower in comparison with Run 1. Using dichloromethane (DCM) as solvent 1 and DCE as

solvent 2 improved the yield of **5**, but the selectivity became lower (Runs 4 and 5). Without boronic acid, the reaction became less effective, giving mainly β-(1→6)-linked disaccharide in only 13% yield (Run 6).



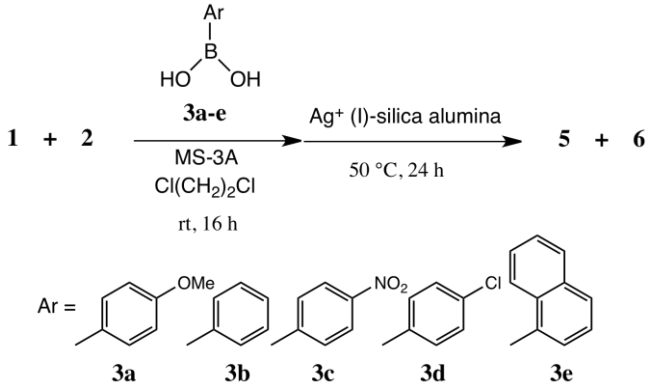
Scheme 2. Regioselective glycosylation of methyl β-D-galactopyranoside (**1**) by two-stage one-pot procedure

Table 1. Solvent effects on the regioselective glycosylation

Run[a)]	**3a** / **1** (eq)	solvent 1 (conditions)	solvent 2	product (%)		
				5 β(1→3)	**6** β(1→2)	β(1→6)
1	1.5	MeOH (reflux, 3 h)	$Cl(CH_2)_2Cl$	37	6	3
2	1.5	MeOH (reflux, 3 h)	THF	22	2	trace
3	1.5	MeOH (reflux, 3 h)	MeCN	10	trace	trace
4	1.0	CH_2Cl_2 (rt, 16 h)	$Cl(CH_2)_2Cl$	49	18	—
5[b)]	1.0	CH_2Cl_2 (rt, 16 h)	$Cl(CH_2)_2Cl$	33	14	—
6[c)]	—	—	$Cl(CH_2)_2Cl$	0.4	1.4	13

a) Two molar equivalents of **2** to **1** were employed.
b) Equimolar of **2** to **1** was used.
c) Glycosylation was performed without boronic acid.

On the basis of the above results, we changed the procedure into a one-stage one-pot procedure, where the all reagents (donor, acceptor, and boronic acid) were mixed simultaneously in DCE and stirred at room temperature for 16 h, followed by addition of the promoter (Ag (I) on silica alumina) and stirring at 50 °C for 24 h (Scheme 3). Compared with the results shown in Table 1 (two-stage one-pot), the yields of disaccharides through the one-stage procedure were substantially improved. The results are listed in Table 2.



Scheme 3. Effects of arylboronic acid on the regioselective glycosylation by one-stage one-pot procedure

Table 2. Effects of arylboronic acid on the regioselective glycosylation

Run[a)]	Arylboronic acid	product (%)		
		5 β(1→3)	**6** β(1→2)	β(1→6)
1	*p*-methoxyphenyl (**3a**)	56	20	—
2	phenyl (**3b**)	50	21	—
3	*p*-nitrophenyl (**3c**)	38	16	trace
4	*p*-chlorophenyl (**3d**)	57	14	—
5	1-naphthyl (**3e**)	41	29	—

a) Two molar equivalents of **2** and 1 molar equivalent of **3a-e** to **1** were employed, respectively.

In the one-stage one-pot procedure, the effects on the regioselective glycosylation of the arylboronic acid para substituent were investigated. All the substituents tested other than the NO_2 group (Run 3) resulted in increased reaction yields up to 70% (Runs 1–5), and the OMe group gave the best yield (Run 1). However, regioselectivity remained approximately 3.5 to 1 in favor of the (1→3) linkage over the (1→2) linkage.

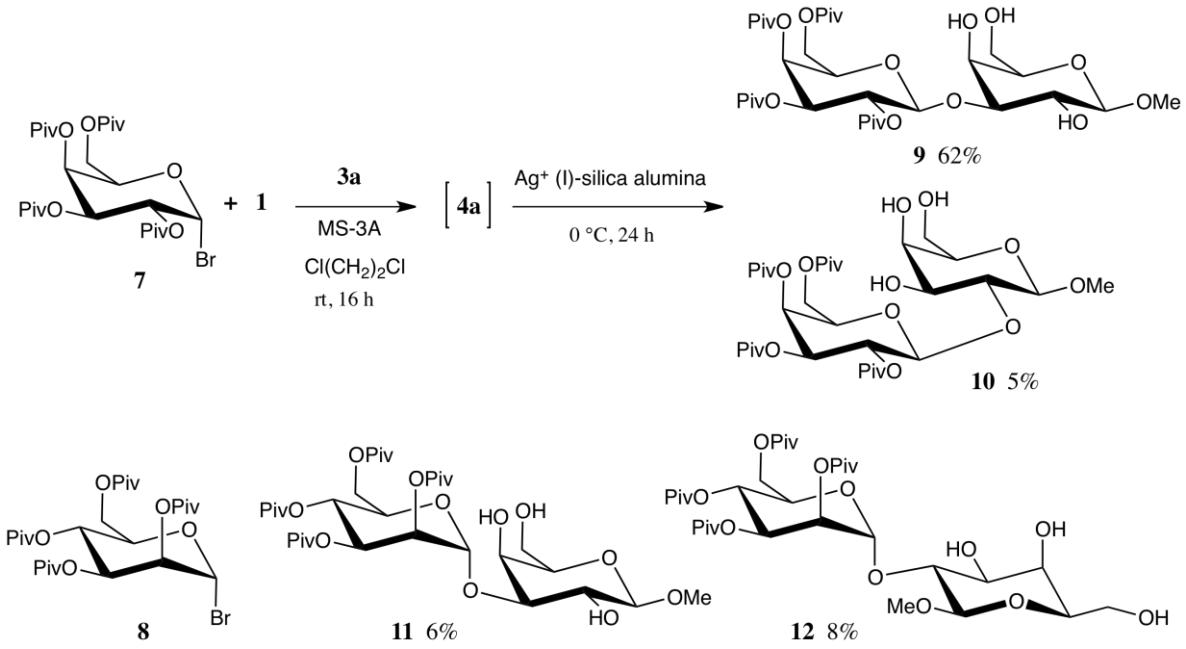
Then effects of reaction temperature on disaccharide yield as well as on regioselectivity were examined. The results are summarized in Table 3.

Table 3. Effects of temperature on the regioselective glycosylation

Run[a)]	temp (°C)	time (h)	product (%)	
			5 β(1→3)	**6** β(1→2)
1	50	24	56	20
2	rt	24	67	11
3	0	24	72	6
4	- 20	72	74	5

a) Two molar equivalents of **2** and 1 molar equivalent of **3a** to **1** were employed, respectively.

Temperatures between −20 to 50 °C were tested. The reaction conditions of 0 °C for 24 h provided the best yield (78%) of the disaccharides with good regioselectivity ((1→3)/(1→2) = 12/1). Subsequently, these conditions were extended to other glycosyl donors such as 2,3,4,6-tetra-*O*-pivaloyl-α-D-galactopyranosyl bromide (**7**) and 2,3,4,6-tetra-*O*-pivaloyl-α-D-mannopyranosyl bromide (**8**) (Scheme 4).



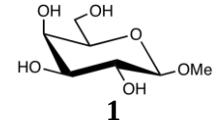
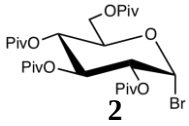
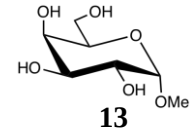
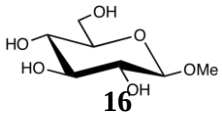
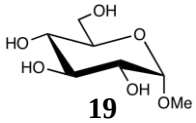
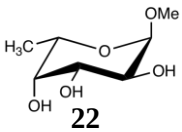
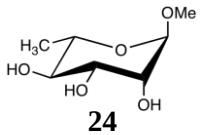
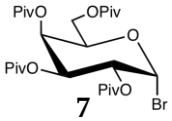
Scheme 4. Regioselective glycosylation with galactopyranosyl bromide (**7**) and mannopyranosyl bromide (**8**)

Glycosylation of galactoside **1** by treatment with galactosyl bromide **7** in the presence of boronic acid **3a** provided galactosyl-β-(1→3)-galactoside **9** and galactosyl-β-(1→2)-galactoside **10** in 62% and 5% yields, respectively, similar to the results for glucosyl donor **2**. Regioselectivity in this case was estimated to about 12/1. The structures of **9** and **10** were determined from their NMR spectra: the β-configuration was determined from a coupling constant, $J_{1',2'}$ = 8.0 Hz, and glycosylated carbons of **9** and **10** were identified from ^{13}C-NMR chemical shifts at δ 81.34 (C-3) and δ 80.24 (C-2), respectively. Furthermore, a second

order H/C-NMR spectra, i.e., ^{1}H-Detected Multiple-bond Heteronuclear Bond Coorelation (HMBC) showed a distinct coupling signal ($^{3}J_{C,H}$) between H-1' and C-3 of the compound **9**, which clearly provides the structure of (1→3)-linked disaccharide. On the other hand, HMBC spectra of **10** showed a coupling signal ($^{3}J_{C,H}$) between H-1' and C-2 designating a (1→2)-linked disaccharide.

In contrast, the mannosyl donor **8** gave low yield and poor regioselectivity: mannosyl-α-(1→3)-galactoside **11** and mannosyl-α-(1→2)-galactoside **12** were obtained in only 6% and 8% yields, respectively. The α-D-manno configuration was determined by $J_{C1\text{-}H1}$ value (**11**: 171.0 Hz, **12**: 174.7 Hz) and the intersaccharide linkages were found to be similar to those in the galactosyl case described in the experimental section.

Table 4. Regioselective glycosylation of various unprotected glycosyl acceptors

Run	acceptor	donor	product (%)		
			β(1→2)	β(1→3)	β(1→4)
1	 **1**	 **2**	**6** (6)	**5** (72)	—
2	 **13**	**2**	**14** (8)	**15** (50)	—
3	 **16**	**2**	**17** (29)	**18** (17)	—
4	 **19**	**2**	**20** (37)	**21** (6)	—
5	 **22**	**2**	**23** (44)	—	—
6	 **24**	**2**	—	—	**25** (61)
7	**1**	 **7**	**10** (5)	**9** (62)	—

Finally, our method was applied to various unprotected acceptors (Table 4). Glycosylation of methyl α-D-galactopyranoside (**13**) afforded similar results as β-D-galactopyranoside (**1**) with moderate yield and regioselectivity (Run 2). Methyl α- and β-D-glucopyranosides had different selectivity: the methyl β-D-glucoside (**16**) gave low yield and poor regioselectivity (Run 3) . On the other hand, use of methyl α-D-glucopyranoside (**19**) resulted in a slightly better yield with reversed regioselectivity such that the β-(1→2)-disaccharide was favored over the β-(1→3)-disaccharide by about 6 to 1 (Run 4).

The regioselectivity appeared to arise from stereochemical factors. The good β-(1→3) selectivity of galactopyranosides (**1** and **13**) might attributable to the relative openness around the C-3 hydroxy group compared with the C-2 hydroxy group; this openness would allow for easier glycosylation. In the β-glucoside (**16**), there would be little difference in the stereochemical space around the C-3 and C-2 hydroxy groups, whereas in α-glucoside **19** the donor molecule might be accessible from the β-side of the C-2 hydroxy group, owing to the wider space in comparison with the C-3 hydroxy group, such that β-(1→2)-glucoside **20** is preferred (cf. Figure 2).

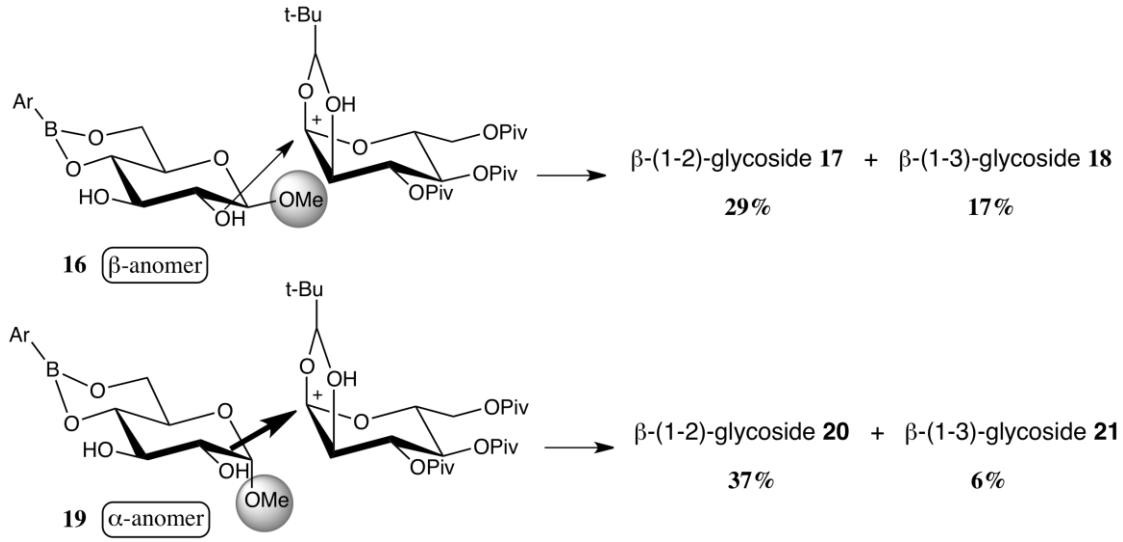


Figure 2. Regioselectivity of methyl anomeric D-glucopyranosides

6-Deoxyhexoside (e.g., methyl α-L-fucopyranoside (**22**) and methyl α-L-rhamnopyranoside (**24**)), afforded a single product since the intermediary boronate might mask the 1,2-*cis*-hydroxy group and leave only one hydroxyl group free, which could be regiospecifically glycosylated. In fact, glucosyl-β-(1→2)-fucopyranoside (**23**) and glucosyl-β-(1→4)-rhamnopyranoside (**25**) were obtained in 44% and 61% yields, respectively. The structures of the disaccharides were determined by NMR spectroscopy, mainly from the glycosylation shift of the glycosylated carbon in ^{13}C-NMR and HMBC spectra.

In summary, when promoted by Ag(I) on silica alumina, glycosylation of unprotected methyl β-D-galactopyranoside with per-*O*-pivaloyl-α-D-glucopyranosyl bromide in the presence of 4-methoxyphenyl boronic acid was found to give mainly β-(1→3)-linked disaccharide in 72% yield in a one-pot reaction. This regioselectivity was rationalized by generation of a 4,6-boronate intermediate, which might be formed in situ through the reaction between 4,6-hydroxy groups of methyl β-D-galactopyranoside and arylboronic acid. Thus, the intermediary boronate functions as a transient masking group present only in the reaction medium. Several unprotected sugars were regioselectively glycosylated at a secondary hydroxy group, even in the presence of primary hydroxy group, through this one-pot procedure. This method might be an alternative of the conventional protection/deprotection strategies. Further development and improvement of this methodology are in progress.

EXPERIMENTAL

General. Physical and spectral data were recorded on the following instruments; Mp: Yamato MP-1 apparatus and Yanagimoto micro melting-point apparatus (uncorrected); $[\alpha]_D$: JASCO DIP-150 digital polarimeter; MS: JEOL JMS-AX505HA and JMS-AX700 MStation mass spectrometer; ^{1}H and ^{13}C NMR: Varian VXR-300 and XL-400 spectrometers. TLC was carried out on silica-gel 60 F_{254} (Merk Art. 5735) developed with the same solvent systems as used for column chromatography in the individual experimental section. The spots were made visible by UV light (254 nm) or by charring with 10% aqueous H_2SO_4. Column chromatography was achieved on silica-gel 60 (Merck Art. 7734). Glycosyl acceptors employed were purchased from Tokyo Kasei Co., Wako Co., or Aldrich Co. Glycosyl donor **2**[11] was prepared according to the reported method. NMR data of boronate-masked methyl β-D-galactopyranoside **4a** was shown in this section. In general, chemical shifts of methyl group of the methoxy and pivaloyl group for methyl 2,3,4,6-tetra-*O*-pivaloylglycosides are as follows. OCH_3 : ^{1}Hδ = ca. 3.5 ; ^{13}C δ = ca. 57; Pivaloyl $(\underline{CH_3})_3CCO$: ^{1}H δ = 1.1-1.3; ^{13}C δ = 26.9-27.2; $(CH_3)_3\underline{C}CO$ ^{13}C δ =38.6-39.2; $(CH_3)_3C\underline{C}O$ ^{13}C δ =176-179.

General procedure for boronate-mediated glycosylation using glycosyl bromide donor: A mixture of unprotected methyl hexopyranoside (an acceptor, 0.25 mmol), arylboronic acid (0.25 mmol), per-*O*-pivaloyl-α-D-glycosyl bromide (0.50 mmol), and MS-3A (powder, 500 mg) in anhydrous $Cl(CH_2)_2Cl$ (5.0 mL) was stirred at room temperature for 16 h. To a resulting suspension including the boronate was added Ag (I)-silica alumina[12] (900 mg) in one portion. The mixture was stirred in the dark at 0 °C for 24 h. After dilution with $Cl(CH_2)_2Cl$ (30 mL), the mixture was filtered through Celite, and the filtrate was washed with 5% $NaHCO_3$ aq (30 mL) and water (3×30 mL), dried (Na_2SO_4), and evaporated. The residue was purified by silica-gel column chromatography ($CHCl_3$: MeOH, 20:1) to

give the disaccharide (products and yields: see Tables).

1,2,3,4,6-Penta-*O*-pivaloyl-β-D-galactopyranose: A mixture of D-galactose (21.8 g, 0.12 mol), pivaloyl chloride (91.0 g, 0.75 mol), pyridine (90 mL), and $CHCl_3$ (150 mL) was stirred under reflux for 4 days. The reaction mixture was evaporated in vacuo and the residue was dissolved in Et_2O (300 mL), washed with 1 M H_2SO_4 (50 mL), 5% $NaHCO_3$ aq (5 x 250 mL), and water (2 x 250 mL). The organic phase was dried (Na_2SO_4) and evaporated to give the residue, which was crystallized from EtOH to afford 53.1 g (74% yield) of the title compound as colorless crystals. Mp 123~125 °C. $[\alpha]_D^{26.7}$ +8.12 (*c* 1.00, $CHCl_3$). MS (FAB) *m/z*: 623 $[M+Na]^+$. Anal. Calcd for $C_{31}H_{52}O_{11}$: C 61.98, H 8.72. Found: C 61.79, H 8.69. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: 3.99 (1H, dd, $J_{5,6a}$ = 6.5, $J_{6a,6b}$ = 10.0 Hz, H-6a), 4.09 (1H, ddd, $J_{4,5}$ = 1.0, $J_{5,6a}$ = 6.5, $J_{5,6b}$ = 6.5, H-5), 4.17 (1H, dd, $J_{5,6b}$ = 6.5, $J_{6a,6b}$ = 10.0 Hz, H-6b), 5.17 (1H, dd, $J_{2,3}$ = 10.0, $J_{3,4}$ = 3.5 Hz, H-3), 5.43 (1H, dd, $J_{3,4}$ = 3.5, $J_{4,5}$ = 1.0 Hz, H-4), 5.58 (1H, dd, $J_{1,2}$ = 8.0, $J_{2,3}$ = 10.0 Hz, H-2), 5.72 (1H, d, $J_{1,2}$ = 8.0 Hz, H-1). ^{13}C-NMR (75 MHz, $CDCl_3$) δ: 60.70 (C-6), 66.48 (C-4), 67.70 (C-2), 71.07 (C-3), 71.78 (C-5), 92.13 (C-1).

1,2,3,4,6-Penta-*O*-pivaloyl-α-D-mannopyranose: Prepared similarly as described above for per-*O*-pivaloyl-β-D-galactopyranose. Isolation of the anomeric isomers was performed by recrystallization from ethanol.

White powder (Yield 16%). Mp 154~161 °C. $[\alpha]_D^{29.1}$ +40.7 (*c* 1.00, $CHCl_3$). MS (FAB) *m/z*: 623 $[M+Na]^+$. Anal. Calcd for $C_{31}H_{52}O_{11}$: C 61.98, H 8.72. Found: C 61.95, H 8.67. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: 4.03 (1H, ddd, $J_{4,5}$ = 11.0, $J_{5,6a}$ = 2.0, $J_{5,6b}$ = 4.0 Hz, H-5), 4.12 (1H, dd, $J_{5,6a}$ = 2.0, $J_{6a,6b}$ = 12.0 Hz, H-6a), 4.18 (1H, dd, $J_{5,6b}$ = 4.0, $J_{6a,6b}$ = 12.0 Hz, H-6b), 5.28 (1H, dd, $J_{1,2}$ = 2.0, $J_{2,3}$ = 3.5 Hz, H-2), 5.38 (1H, dd, $J_{2,3}$ = 3.5, $J_{3,4}$ = 11.0 Hz, H-3), 5.54 (1H, t, $J_{3,4}$ = $J_{4,5}$ = 11.0 Hz, H-4), 6.01 (1H, d, $J_{1,2}$ = 2.0 Hz, H-1). ^{13}C-NMR (75 MHz, $CDCl_3$) δ: 61.70 (C-6), 64.51 (C-4), 68.21 (C-2), 69.36 (C-3), 71.17 (C-5), 90.72 ($J_{C\text{-}1,H\text{-}1}$ = 176.0 Hz, C-1).

1,2,3,4,6-Penta-*O*-pivaloyl-β-D-mannopyranose:

White powder (Yield 71%). Mp 125~127 °C. $[\alpha]_D^{28.5}$ –19.2 (*c* 1.00, $CHCl_3$). MS (FAB) *m/z*: 623 $[M+Na]^+$. Anal. Calcd for $C_{31}H_{52}O_{11}$: C 61.98, H 8.72. Found: C 61.86, H 8.80. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: 3.84 (1H, ddd, $J_{4,5}$ = 10.0, $J_{5,6a}$ = 2.0, $J_{5,6b}$ = 4.0 Hz, H-5), 4.16 (1H, dd, $J_{5,6a}$ = 2.0, $J_{6a,6b}$ = 12.0 Hz, H-6a), 4.21 (1H, dd, $J_{5,6b}$ = 4.0, $J_{6a,6b}$ = 12.0 Hz, H-6b), 5.16 (1H, dd, $J_{2,3}$ = 3.5, $J_{3,4}$ = 10.0 Hz, H-3), 5.46 (1H, dd, $J_{1,2}$ = 1.0, $J_{2,3}$ = 3.5 Hz, H-2), 5.47 (1H, t, $J_{3,4}$ = $J_{4,5}$ = 10.0 Hz, H-4), 5.83 (1H, d, $J_{1,2}$ = 1.0 Hz, H-1). ^{13}C-NMR (75 MHz, $CDCl_3$) δ: 61.49 (C-6), 64.69 (C-4), 68.13 (C-2), 70.98 (C-3), 73.15 (C-5), 90.67 ($J_{C\text{-}1,H\text{-}1}$ = 160.9 Hz, C-1).

Methyl β-D-galactopyranoside 4,6-(*p*-methoxyphenyl)boronic ester (4a): Although the intermediary boronates were not isolated under one-pot glycosylation, generation of the boronic ester (**4a**) was identified by its NMR spectra.

White amorphous powder. HRMS (FAB) *m/z*: Calcd for $C_{14}H_{19}BO_7Na$ $[M+Na]^+$ 333.1116; found 333.1108. ^{1}H-NMR (400MHz, CD_3OD) δ: 3.49 (1H, dd, $J_{1,2}$ = 7.5, $J_{2,3}$ = 9.5 Hz, H-2), 3.64 (1H, dd, $J_{2,3}$ = 9.5, $J_{3,4}$ = 3.5 Hz, H-3), 3.92 (1H, ddd, $J_{4,5}$ = 1.0, $J_{5,6a}$ = 2.0, $J_{5,6b}$ = 1.5 Hz, H-5), 4.16 (1H, dd, $J_{5,6a}$ = 2.0, $J_{6a,6b}$ = 12.0 Hz, H-6a), 4.24 (1H, d, $J_{1,2}$ = 7.5, H-1), 4.26 (1H, dd, $J_{5,6b}$ = 1.5, $J_{6a,6b}$ = 12.0 Hz, H-6b), 4.34 (1H, dd, $J_{3,4}$ = 3.5, $J_{4,5}$ = 1.0 Hz, H-4). ^{13}C-NMR (100MHz, CD_3OD) δ: 65.73 (C-6), 69.92 (C-5), 71.87 (C-2), 72.12 (C-4), 74.25 (C-3), 105.68 (C-1).

Methyl *O*-2,3,4,6-tetra-*O*-pivaloyl-β-D-glucopyranosyl-(1→3)-β-D-galactopyranoside (5):

Colorless syrup. $[\alpha]_D^{26.0}$ +2.44 (*c* 1.00, $CHCl_3$). HRMS (FAB) *m/z*: Calcd for $C_{33}H_{56}O_{15}Na$ $[M+Na]^+$ 715.3511; found 715.3550. ^{1}H-NMR (400 MHz, $CDCl_3$) δ: 3.53 (1H, ddd, $J_{4,5}$ = 1.0, $J_{5,6a}$ = 5.0, $J_{5,6b}$ = 6.5 Hz, H-5), 3.60 (1H, dd, $J_{2,3}$ = 9.5, $J_{3,4}$ = 3.5 Hz, H-3), 3.74 (1H, dd, $J_{1,2}$ = 7.5, $J_{2,3}$ = 9.5 Hz, H-2), 3.74 (1H, ddd, $J_{4',5'}$ = 10.0, $J_{5',6'a}$ = 2.0, $J_{5',6'b}$ = 5.5 Hz, H-5'), 3.82 (1H, dd, $J_{5,6a}$ = 5.0, $J_{6a,6b}$ = 12.0 Hz, H-6a), 3.96 (1H, dd, $J_{5',6'b}$ = 5.5, $J_{6'a,6'b}$ = 12.5 Hz, H-6'b), 3.98 (1H, dd, $J_{5,6b}$ = 6.5, $J_{6a,6b}$ = 12.0 Hz, H-6b), 4.02 (1H, dd, $J_{3,4}$ = 3.5, $J_{4,5}$ = 1.0 Hz, H-4), 4.16 (1H, d, $J_{1,2}$ = 7.5 Hz, H-1), 4.33 (1H, dd, $J_{5',6'a}$ = 2.0, $J_{6'a,6'b}$ = 12.5 Hz, H-6'a), 4.90 (1H, d, $J_{1',2'}$ = 8.0 Hz, H-1'), 5.04 (1H, dd, $J_{1',2'}$ = 8.0, $J_{2',3'}$ = 9.5 Hz, H-2'), 5.11 (1H, dd, $J_{3',4'}$ = 9.5, $J_{4',5'}$ = 10.0 Hz, H-4'), 5.35 (1H, t, $J_{2',3'}$ = $J_{3',4'}$ = 9.5 Hz, H-3'). ^{13}C-NMR (100 MHz, $CDCl_3$) δ: 61.64 (C-6'), 62.38 (C-6), 67.79 (C-4'), 68.65 (C-4), 70.73 (C-2), 71.42 (C-2'), 71.68 (C-3'), 72.49 (C-5'), 74.10 (C-5), 81.10 (C-3), 101.01 (C-1'), 103.73 (C-1).

Methyl *O*-2,3,4,6-tetra-*O*-pivaloyl-β-D-glucopyranosyl-(1→2)-β-D-galactopyranoside (6):

Colorless syrup. $[\alpha]_D^{27.5}$ +6.65 (*c* 1.00, $CHCl_3$). HRMS (FAB) *m/z*: Calcd for $C_{33}H_{56}O_{15}Na$ $[M+Na]^+$ 715.3511; found 715.3535. ^{1}H-NMR (400 MHz, $CDCl_3$) δ: 3.52 (1H, ddd, $J_{4,5}$ = 1.5, $J_{5,6a}$ = 4.5, $J_{5,6b}$ = 6.0 Hz, H-5), 3.60 (1H, dd, $J_{1,2}$ = 7.0, $J_{2,3}$ = 9.0 Hz, H-2), 3.63 (1H, dd, $J_{2,3}$ = 9.0, $J_{3,4}$ = 3.0 Hz, H-3), 3.74 (1H, ddd, $J_{4',5'}$ = 10.0, $J_{5',6'a}$ = 2.0, $J_{5',6'b}$ =3.5 Hz, H-5'), 3.85 (1H, dd, $J_{5',6'a}$ = 2.0, $J_{6'a,6'b}$ = 12.5 Hz, H-6a), 3.96 (1H, dd, $J_{5,6b}$ = 6.0, $J_{6a,6b}$ = 12.0 Hz, H-6b), 3.98 (1H, dd, $J_{3,4}$ = 3.0, $J_{4,5}$ = 1.5 Hz, H-4), 4.10 (1H, dd, $J_{5',6'b}$ =3.5, $J_{6'a,6'b}$ = 12.5 Hz, H-6'b), 4.25 (1H, dd, $J_{5',6'a}$ = 2.0, $J_{6'a,6'b}$ = 12.5 Hz, H-6'a), 4.31 (1H, d, $J_{1,2}$ = 7.0 Hz, H-1), 4.90 (1H, d, $J_{1',2'}$ = 8.0 Hz, H-1'), 5.00 (1H, dd, $J_{1',2'}$ = 8.0, $J_{2',3'}$ = 9.5 Hz, H-2'), 5.18 (1H, dd, $J_{3',4'}$ = 9.5, $J_{4',5'}$ = 10.0 Hz, H-4'), 5.35 (1H, t, $J_{2',3'}$ = $J_{3',4'}$ = 9.5 Hz, H-3'). ^{13}C-NMR (100 MHz, $CDCl_3$) δ: 61.58 (C-6'), 62.61 (C-6), 67.48 (C-4'), 69.14 (C-4), 72.14 (C-3'), 72.17 (C-5'), 72.56 (C-2'), 72.59 (C-3), 73.90 (C-5), 79.70 (C-2), 101.08 (C-1'), 103.04 (C-1).

2,3,4,6-Tetra-*O*-pivaloyl-α-D-galactopyranosyl bromide (7): To a stirred solution of penta-*O*-pivaloyl-β-D-galactopyranose (13.5 g, 22.5 mmol) was added dropwise 30% hydrogen bromide in AcOH (25 mL) under ice-cooling. The resulting mixture was stirred at ambient temperature for 1 day, and then evaporated in vacuo azeotropically with toluene (3 x 250 mL). The residue was dissolved in Et_2O (300 mL) followed by washing with 5% $NaHCO_3$ aq (250 mL) and water (2 x 250 mL). The organic phase was dried (Na_2SO_4) and evaporated to give the residue, which was crystallized from Et_2O-hexane to afford 10.3 g (78% yield) of **7** as colorless crystals. Mp 56~58 °C. $[\alpha]_D^{24.2}$ +143.6 (*c* 1.00, $CHCl_3$). MS (FAB) *m/z*: 579, 581 $[M+H]^+$, 601, 603 $[M+Na]^+$. Anal. Calcd for $C_{26}H_{43}O_9Br$: C 53.89, H 7.48, Br 13.79. Found: C 53.80, H 7.43, Br 13.70. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: 4.06 (1H, dd, $J_{5,6a}$ = 7.0, $J_{6a,6b}$ = 11.0 Hz, H-6a), 4.14 (1H, dd, $J_{5,6b}$ = 7.0 Hz, $J_{6a,6b}$ = 11.0 Hz, H-6b), 4.52 (1H, br dt, $J_{4,5}$ = 1.0, $J_{5,6a}$ = $J_{5,6b}$ = 7.0 Hz, H-5), 5.03 (1H, dd, $J_{1,2}$ = 4.0, $J_{2,3}$ = 10.5 Hz, H-2), 5.50 (1H, dd, $J_{2,3}$ = 10.5, $J_{3,4}$ = 3.0 Hz, H-3), 5.54 (1H, dd, $J_{3,4}$ = 3.0, $J_{4,5}$ = 1.0 Hz, H-4), 6.69 (1H, d, $J_{1,2}$ = 4.0 Hz, H-1). ^{13}C-NMR (75 MHz, $CDCl_3$) δ: 60.51 (C-6), 66.60 (C-2), 67.82 (C-4), 68.10 (C-3), 71.55 (C-5), 88.37 (C-1).

2,3,4,6-Tetra-O-pivaloyl-α-D-mannopyranosyl bromide (8): Prepared similarly as described above for galactosyl bromide **7**.

Colorless crystals. Mp 113~115 °C. $[\alpha]_D^{23.4}$ +75.9 (*c* 1.00, $CHCl_3$). MS (FAB) *m/z*: 579, 581 $[M+H]^+$, 601, 603 $[M+Na]^+$. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: 4.15 (1H, dd, $J_{5,6a}$ = 4.0, $J_{6a,6b}$ = 11.0 Hz, H-6a), 4.25 (1H, ddd, $J_{5,6a}$ = $J_{5,6b}$ = 4.0, $J_{6a,6b}$ = 11.0 Hz, H-5), 4.27 (1H, dd, $J_{5,6b}$ = 4.0 Hz, $J_{6a,6b}$ = 11.0 Hz, H-6b), 5.45 (1H, dd, $J_{1,2}$ = 1.5, $J_{2,3}$ = 3.5 Hz, H-2), 5.57 (1H, t, $J_{3,4}$ = $J_{4,5}$ = 10.0 Hz, H-4), 5.75 (1H, dd, $J_{2,3}$ = 3.5, $J_{3,4}$ = 10.0 Hz, H-3), 6.26 (1H, d, $J_{1,2}$ = 1.5 Hz, H-1). ^{13}C-NMR (75 MHz, $CDCl_3$) δ: 60.95 (C-6), 64.30 (C-4), 68.32 (C-3), 72.06 (C-2), 73.18 (C-5), 83.73 ($J_{C\text{-}1,H\text{-}1}$ = 185.1 Hz, C-1).

Methyl *O*-2,3,4,6-tetra-*O*-pivaloyl-β-D-galactopyranosyl-(1→3)-β-D-galactopyranoside (9):

Colorless syrup. $[\alpha]_D^{22.1}$ –0.72 (*c* 1.00, $CHCl_3$). HRMS (FAB) *m/z*: Calcd for $C_{33}H_{56}O_{15}Na$ $[M+Na]^+$ 715.3511; found 715.3503. ^{1}H-NMR (400 MHz, $CDCl_3$) δ: 3.54 (1H, ddd, $J_{4,5}$ = 1.0, $J_{5,6a}$ = 4.5, $J_{5,6b}$ = 6.5 Hz, H-5), 3.61 (1H, dd, $J_{2,3}$ = 10.5, $J_{3,4}$ = 3.5 Hz, H-3), 3.76 (1H, dd, $J_{1,2}$ = 8.0, $J_{2,3}$ = 9.5 Hz, H-2), 3.80 (1H, dd, $J_{5,6a}$ = 4.5, $J_{6a,6b}$ = 11.5 Hz, H-6a), 3.98 (1H, dd, $J_{5,6b}$ = 6.5, $J_{6a,6b}$ = 11.5 Hz, H-6b), 4.01 (1H, ddd, $J_{4',5'}$ = 1.0, $J_{5',6'a}$ = 5.5, $J_{5',6'b}$ = 6.0 Hz, H-5'), 4.02 (1H, dd, $J_{5',6'b}$ = 6.0, $J_{6'a,6'b}$ = 9.5 Hz, H-6'b), 4.02 (1H, dd, $J_{3,4}$ = 3.5, $J_{4,5}$ = 1.0 Hz, H-4), 4.12 (1H, dd, $J_{5',6'a}$ = 5.5, $J_{6'a,6'b}$ = 9.5 Hz, H-6'a), 4.16 (1H, d, $J_{1,2}$ = 8.0 Hz, H-1), 4.88 (1H, d, $J_{1',2'}$ = 8.0 Hz, H-1'), 5.14 (1H, dd, $J_{2',3'}$ = 10.5, $J_{3',4'}$ = 3.5 Hz, H-3'), 5.22 (1H, dd, $J_{1',2'}$ = 8.0, $J_{2',3'}$ = 10.5 Hz, H-2'), 5.40 (1H, dd, $J_{3',4'}$ = 3.5, $J_{4',5'}$ = 1.0 Hz, H-4'). ^{13}C-NMR (75 MHz, $CDCl_3$) δ: 61.46 (C-6'), 62.41 (C-6), 66.67 (C-4'), 68.63 (C-4), 68.91 (C-2'), 70.48 (C-3'), 70.63

(C-2), 71.40 (C-5'), 74.12 (C-5), 81.34 (C-3), 101.32 (C-1'), 103.76 (C-1).

Methyl *O*-2,3,4,6-tetra-*O*-pivaloyl-β-D-galactopyranosyl-(1→2)-β-D-galactopyranoside (10):

Colorless syrup. $[\alpha]_D^{22.1}$ –4.44 (*c* 0.50, $CHCl_3$). HRMS (FAB) *m/z*: Calcd for $C_{33}H_{56}O_{15}Na$ $[M+Na]^+$ 715.3511; found 715.3544. ^{1}H-NMR (400 MHz, $CDCl_3$) δ: 3.52 (1H, ddd, $J_{4,5}$ = 1.0, $J_{5,6a}$ = 4.5, $J_{5,6b}$ = 6.0 Hz, H-5), 3.59 (1H, dd, $J_{1,2}$ = 7.5, $J_{2,3}$ = 9.0 Hz, H-2), 3.68 (1H, dd, $J_{2,3}$ = 9.0, $J_{3,4}$ = 3.5 Hz, H-3), 3.84 (1H, dd, $J_{5,6a}$ = 4.5, $J_{6a,6b}$ = 12.0 Hz, H-6a), 3.96 (1H, dd, $J_{5,6b}$ = 6.0, $J_{6a,6b}$ = 12.0 Hz, H-6b), 3.99 (1H, dd, $J_{3,4}$ = 3.5, $J_{4,5}$ = 1.0 Hz, H-4), 4.00 (1H, dd, $J_{5',6'a}$ = 8.5, $J_{6'a,6'b}$ = 15.0 Hz, H-6'a), 4.01 (1H, ddd, $J_{4',5'}$ = 1.0, $J_{5',6'a}$ = 8.5, $J_{5',6'b}$ = 10.0 Hz, H-5'), 4.21 (1H, dd, $J_{5',6'b}$ = 10.0, $J_{6'a,6'b}$ = 15.0 Hz, H-6'b), 4.32 (1H, d, $J_{1,2}$ = 7.5 Hz, H-1), 4.87 (1H, d, $J_{1',2'}$ = 7.5 Hz, H-1'), 5.13 (1H, dd, $J_{1',2'}$ = 7.5, $J_{2',3'}$ = 10.5 Hz, H-2'), 5.18 (1H, dd, $J_{2',3'}$ = 10.5, $J_{3',4'}$ = 3.0 Hz, H-3'), 5.42 (1H, dd, $J_{3',4'}$ = 3.0, $J_{4',5'}$ = 1.0 Hz, H-4'). ^{13}C-NMR (75 MHz, $CDCl_3$) δ: 60.68 (C-6'), 62.51 (C-6), 66.21 (C-4'), 68.95 (C-4), 70.39 (C-2'), 70.65 (C-5'), 70.12 (C-3'), 72.28 (C-3), 74.01 (C-5), 80.24 (C-2), 101.55 (C-1'), 103.39 (C-1).

Methyl *O*-2,3,4,6-tetra-*O*-pivaloyl-α-D-mannopyranosyl-(1→3)-β-D-galactopyranoside (11):

Colorless syrup. $[\alpha]_D^{19.1}$ +33.4 (*c* 1.00, $CHCl_3$). HRMS (FAB) *m/z*: Calcd for $C_{33}H_{56}O_{15}Na$ $[M+Na]^+$ 715.3511; found 715.3517. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: 3.48 (1H, ddd, $J_{4,5}$ = 1.0, $J_{5,6a}$ = 5.0, $J_{5,6b}$ = 6.0 Hz, H-5), 3.71 (1H, dd, $J_{2,3}$ = 9.5, $J_{3,4}$ = 3.0 Hz, H-3), 3.82 (1H, dd, $J_{1,2}$ = 7.5, $J_{2,3}$ = 9.5 Hz, H-2), 3.84 (1H, dd, $J_{5,6a}$ = 5.0, $J_{6a,6b}$ = 11.5 Hz, H-6a), 3.94 (1H, dd, $J_{5,6b}$ = 6.0, $J_{6a,6b}$ = 11.5 Hz, H-6b), 4.07 (1H, dd, $J_{3,4}$ = 3.0, $J_{4,5}$ = 1.0 Hz, H-4), 4.14 (1H, dd, $J_{5',6'a}$ = 2.5, $J_{6'a,6'b}$ = 10.5 Hz, H-6'a), 4.15 (1H, dd, $J_{5',6'b}$ = 2.5, $J_{6'a,6'b}$ = 10.5 Hz, H-6'b), 4.16 (1H, d, $J_{1,2}$ = 7.5 Hz, H-1), 4.54 (1H, dt, $J_{4',5'}$ = 10.0, $J_{5',6'a}$ = $J_{5',6'b}$ = 2.5 Hz, H-5'), 4.95 (1H, d, $J_{1',2'}$ = 1.5 Hz, H-1'), 5.30 (1H, dd, $J_{1',2'}$ = 1.5, $J_{2',3'}$ = 3.0 Hz, H-2'), 5.42 (1H, dd, $J_{2',3'}$ = 3.0, $J_{3',4'}$ = 10.0 Hz, H-3'), 5.52 (1H, t, $J_{3',4'}$ = $J_{4',5'}$ = 10.0 Hz, H-4'). ^{13}C-NMR (75 MHz, $CDCl_3$) δ: 61.80 (C-6'), 62.07 (C-6), 64.85 (C-4'), 65.98 (C-4), 68.95 (C-5'), 69.56 (C-2, 3'), 69.66 (C-2'), 74.14 (C-5), 77.66 (C-3), 94.87 ($J_{C\text{-}1,H\text{-}1}$ = 171.0 Hz, C-1'), 104.56 (C-1).

Methyl *O*-2,3,4,6-tetra-*O*-pivaloyl-α-D-mannopyranosyl-(1→2)-β-D-galactopyranoside (12):

Colorless syrup. $[\alpha]_D^{22.3}$ +35.8 (*c* 0.65, $CHCl_3$). HRMS (FAB) *m/z*: Calcd for $C_{33}H_{56}O_{15}Na$ $[M+Na]^+$ 715.3511; found 715.3526. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: 3.50 (1H, ddd, $J_{4,5}$ = 1.0, $J_{5,6a}$ = 4.5, $J_{5,6b}$ = 5.0 Hz, H-5), 3.60 (1H, dd, $J_{2,3}$ = 10.0, $J_{3,4}$ = 3.0 Hz, H-3), 3.62 (1H, dd, $J_{1,2}$ = 7.0, $J_{2,3}$ = 10.0 Hz, H-2), 3.92 (1H, dd, $J_{5,6a}$ = 4.5, $J_{6a,6b}$ = 12.0 Hz, H-6a), 3.96 (1H, dd, $J_{5,6b}$ = 5.0, $J_{6a,6b}$ = 12.0 Hz, H-6b), 4.03 (1H, dd, $J_{3,4}$ = 3.0, $J_{4,5}$ = 1.0 Hz, H-4), 4.13 (1H, dd, $J_{5',6'a}$ = 2.5, $J_{6'a,6'b}$ = 12.5 Hz, H-6'a), 4.16 (1H, dd, $J_{5',6'b}$ = 3.0, $J_{6'a,6'b}$ = 12.5 Hz, H-6'b), 4.26 (1H, d, $J_{1,2}$ = 7.0 Hz, H-1), 4.51 (1H, ddd, $J_{4',5'}$ = 10., $J_{5',6'a}$ = 2.5, $J_{5',6'b}$ = 3.0 Hz, H-5'), 5.09 (1H, d, $J_{1',2'}$ = 2.0 Hz, H-1'), 5.28 (1H, dd, $J_{1',2'}$ = 2.0, $J_{2',3'}$ = 3.5 Hz, H-2'), 5.39 (1H,

dd, $J_{2',3'}$ = 3.5, $J_{3',4'}$ = 10.5 Hz, H-3'), 5.51 (1H, t, $J_{3',4'}$ = $J_{4',5'}$ = 10.5 Hz, H-4'). ^{13}C-NMR (75 MHz, $CDCl_3$) δ: 62.14 (C-6'), 62.78 (C-6), 65.16 (C-4'), 68.97 (C-5'), 69.44 (C-2'), 69.50 (C-3'), 70.23 (C-4), 72.39 (C-3), 73.52 (C-5), 78.30 (C-2), 98.31 ($J_{C\text{-}1,H\text{-}1}$ = 174.7 Hz, C-1'), 104.33 (C-1).

Methyl *O*-2,3,4,6-tetra-*O*-pivaloyl-β-D-glucopyranosyl-(1→2)-α-D-galactopyranoside (14):

Colorless syrup. $[\langle]_D^{21.5}$ +54.9 (*c* 0.84, $CHCl_3$). HRMS (FAB) *m/z*: Calcd for $C_{33}H_{56}O_{15}Na$ $[M+Na]^+$ 715.3511; found 715.3500. ^{1}H-NMR (300 MHz, $CDCl_3$) ™: 3.74 (1H, ddd, $J_{4',5'}$ = 10.0, $J_{5',6'a}$ = 1.5, $J_{5',6'b}$ = 5.5 Hz, H-5'), 3.82 (1H, ddd, $J_{4,5}$ = 1.5, $J_{5,6a}$ = 4.0, $J_{5,6b}$ = 6.0 Hz, H-5), 3.83 (1H, dd, $J_{5,6a}$ = 4.0, $J_{6a,6b}$ = 12.5 Hz, H-6a), 3.88 (1H, dd, $J_{1,2}$ = 3.5, $J_{2,3}$ = 9.5 Hz, H-2), 3.92 (1H, dd, $J_{5,6b}$ = 6.0, $J_{6a,6b}$ = 12.5 Hz, H-6b), 3.99 (1H, dd, $J_{2,3}$ = 9.5, $J_{3,4}$ = 3.5 Hz, H-3), 4.01 (1H, dd, $J_{5',6'b}$ = 5.5, $J_{6'a,6'b}$ = 12.0 Hz, H-6'b), 4.09 (1H, dd, $J_{3,4}$ = 3.5, $J_{4,5}$ = 1.5 Hz, H-4), 4.28 (1H, dd, $J_{5',6'a}$ = 1.5, $J_{6'a,6'b}$ = 12.0 Hz, H-6'a), 4.83 (1H, d, $J_{1',2'}$ = 8.0 Hz, H-1'), 4.91 (1H, d, $J_{1,2}$ = 3.5 Hz, H-1), 5.09 (1H, dd, $J_{1',2'}$ = 8.0, $J_{2',3'}$ = 9.5 Hz, H-2'), 5.12 (1H, dd, $J_{3',4'}$ = 9.5, $J_{4',5'}$ = 10.0 Hz, H-4'), 5.34 (1H, t, $J_{2',3'}$ = $J_{3',4'}$ = 9.5 Hz, H-3'). ^{13}C-NMR (75 MHz, $CDCl_3$) δ: 61.78 (C-6'), 63.15 (C-6), 67.58 (C-4'), 67.95 (C-3), 68.93 (C-5), 70.72 (C-4), 71.57 (C-2'), 72.14 (C-3'), 72.55 (C-5'), 78.01 (C-2), 99.44 (C-1), 101.49 (C-1').

Methyl *O*-2,3,4,6-tetra-*O*-pivaloyl-β-D-glucopyranosyl-(1→3)-α-D-galactopyranoside (15):

Colorless syrup. $[\langle]_D^{24.4}$ +63.7 (*c* 1.0, $CHCl_3$). HRMS (FAB) *m/z*: Calcd for $C_{33}H_{56}O_{15}Na$ $[M+Na]^+$ 715.3511; found 715.3523. ^{1}H-NMR (300 MHz, $CDCl_3$) ™: 3.72 (1H, ddd, $J_{4',5'}$ = 10.0, $J_{5',6'a}$ = 2.0, $J_{5',6'b}$ = 5.5 Hz, H-5'), 3.77 (1H, ddd, $J_{4,5}$ = 1.0, $J_{5,6a}$ = 4.0, $J_{5,6b}$ = 7.0 Hz, H-5), 3.78 (1H, dd, $J_{5,6a}$ = 4.0, $J_{6a,6b}$ = 12.5 Hz, H-6a), 3.78 (1H, dd, $J_{2,3}$ = 10.0, $J_{3,4}$ = 3.5 Hz, H-3), 3.92 (1H, dd, $J_{5,6b}$ = 7.0, $J_{6a,6b}$ = 12.5 Hz, H-6b), 3.94 (1H, dd, $J_{1,2}$ = 4.0, $J_{2,3}$ = 10.0 Hz, H-2), 3.95 (1H, dd, $J_{5',6'b}$ = 5.5, $J_{6'a,6'b}$ = 12.0 Hz, H-6'b), 4.07 (1H, dd, $J_{3,4}$ = 3.5, $J_{4,5}$ = 1.0 Hz, H-4), 4.30 (1H, dd, $J_{5',6'a}$ = 2.0, $J_{6'a,6'b}$ = 12.0 Hz, H-6'a), 4.81 (1H, d, $J_{1,2}$ = 4.0 Hz, H-1), 4.90 (1H, d, $J_{1',2'}$ = 8.0 Hz, H-1'), 5.02 (1H, dd, $J_{1',2'}$ = 8.0, $J_{2',3'}$ = 9.5 Hz, H-2'), 5.08 (1H, dd, $J_{3',4'}$ = 9.5, $J_{4',5'}$ = 10.0 Hz, H-4'), 5.34 (1H, t, $J_{2',3'}$ = $J_{3',4'}$ = 9.5 Hz, H-3'). ^{13}C-NMR (75 MHz, $CDCl_3$) ™: 61.67 (C-6'), 62.75 (C-6), 67.82 (C-4'), 68.19 (C-2), 69.23 (C-5), 69.80 (C-4), 71.45 (C-2'), 71.69 (C-3'), 72.41 (C-5'), 78.99 (C-3), 99.42 (C-1), 101.12 (C-1').

Methyl *O*-2,3,4,6-tetra-*O*-pivaloyl-β-D-glucopyranosyl-(1→2)-β-D-glucopyranoside (17):

Colorless syrup: $[\alpha]_D^{21.9}$ +3.73 (*c* 1.00, $CHCl_3$). HRMS (FAB) *m/z*: Calcd for $C_{33}H_{56}O_{15}Na$ $[M+Na]^+$ 715.3511; found 715.3514. ^{1}H-NMR (400 MHz, $CDCl_3$) δ: 3.26 (1H, dd, $J_{1,2}$ = 8.0, $J_{2,3}$ = 9.0 Hz, H-2), 3.34 (1H, ddd, $J_{4,5}$ = 9.0, $J_{5,6a}$ = 3.5, $J_{5,6b}$ = 4.5 Hz, H-5), 3.52 (1H, t, $J_{3,4}$ = $J_{4,5}$ = 9.0 Hz, H-4), 3.56 (1H, t, $J_{2,3}$ = $J_{3,4}$ = 9.0 Hz, H-3), 3.73 (1H, ddd, $J_{4',5'}$ = 10.0, $J_{5',6'a}$ = 1.5, $J_{5',6'b}$ = 3.5 Hz, H-5'), 3.80 (1H, dd, $J_{5,6b}$

= 4.5, $J_{6a,6b}$ = 12.0 Hz, H-6b), 3.90 (1H, dd, $J_{5,6a}$ = 3.5, $J_{6a,6b}$ = 12.0 Hz, H-6a), 4.09 (1H, dd, $J_{5',6'b}$ = 3.5, $J_{6'a,6'b}$ = 12.5 Hz, H-6'b), 4.25 (1H, dd, $J_{5',6'a}$ = 1.5, $J_{6'a,6'b}$ = 12.5 Hz, H-6'a), 4.36 (1H, d, $J_{1,2}$ = 8.0 Hz, H-1), 4.85 (1H, d, $J_{1',2'}$ = 8.0 Hz, H-1'), 5.00(1H, dd, $J_{1',2'}$ = 8.0, $J_{2',3'}$ = 9.5 Hz, H-2'), 5.19 (1H, dd, $J_{3',4'}$ = 9.5, $J_{4',5'}$ = 10.0 Hz, H-4'), 5.34 (1H, t, $J_{2',3'}$ = $J_{3',4'}$ = 9.5 Hz, H-3'). ^{13}C-NMR (100 MHz, $CDCl_3$) δ: 61.50 (C-6'), 62.32 (C-6), 67.46 (C-4'), 69.96 (C-4), 72.14 (C-3'), 72.18 (C-5'), 72.42 (C-2'), 74.99 (C-5), 75.51 (C-3), 81.52 (C-2), 100.91 (C-1'), 102.93 (C-1).

Methyl *O*-2,3,4,6-tetra-*O*-pivaloyl-β-D-glucopyranosyl-(1→3)-β-D-glucopyranoside (18):

Colorless syrup: $[\alpha]_D^{19.7}$ –2.94 (*c* 1.00, $CHCl_3$). HRMS (FAB) *m/z*: Calcd for $C_{33}H_{56}O_{15}Na$ $[M+Na]^+$ 715.3511; found 715.3540. ^{1}H-NMR (400 MHz, $CDCl_3$) δ: 3.33 (1H, ddd, $J_{4,5}$ = 9.0, $J_{5,6a}$ = 3.5, $J_{5,6b}$ = 5.0 Hz, H-5), 3.36 (1H, dd, $J_{1,2}$ = 8.0, $J_{2,3}$ = 9.0 Hz, H-2), 3.45 (1H, t, $J_{2,3}$ = $J_{3,4}$ = 9.0 Hz, H-3), 3.49 (1H, t, $J_{3,4}$ = $J_{4,5}$ = 9.0 Hz, H-4), 3.76 (1H, dd, $J_{5,6b}$ = 5.0, $J_{6a,6b}$ = 12.0 Hz, H-6b), 3.79 (1H, ddd, $J_{4',5'}$ = 10.0, $J_{5',6'a}$ = 2.0, $J_{5',6'b}$ = 6.0 Hz, H-5'), 3.92 (1H, dd, $J_{5,6a}$ = 2.0, $J_{6a,6b}$ = 12.0 Hz, H-6a), 3.99 (1H, dd, $J_{5',6'b}$ = 6.0, $J_{6'a,6'b}$ = 12.0 Hz, H-6'b), 4.18 (1H, d, $J_{1,2}$ = 8.0 Hz, H-1), 4.25 (1H, dd, $J_{5',6'a}$ = 2.0, $J_{6'a,6'b}$ = 12.0 Hz, H-6'a), 4.79 (1H, d, $J_{1',2'}$ = 8.0 Hz, H-1'), 5.05 (1H, dd, $J_{1',2'}$ = 8.0, $J_{2',3'}$ = 9.5 Hz, H-2'), 5.09 (1H, dd, $J_{3',4'}$ = 9.5, $J_{4',5'}$ = 10.0 Hz, H-4'), 5.35 (1H, t, $J_{2',3'}$ = $J_{3',4'}$ = 9.5 Hz, H-3'). ^{13}C-NMR (100 MHz, $CDCl_3$) δ: 61.78 (C-6'), 62.83 (C-6), 67.86 (C-4'), 69.32 (C-4), 71.36 (C-2'), 71.92 (C-3'), 72.43 (C-5'), 72.96 (C-2), 75.49 (C-5), 85.99 (C-3), 101.38 (C-1'), 103.62 (C-1).

Methyl *O*-2,3,4,6-tetra-*O*-pivaloyl-β-D-glucopyranosyl-(1→2)-α-D-glucopyranoside (20):

Colorless syrup. $[\alpha]_D^{22.5}$ +54.7 (*c* 1.00, $CHCl_3$). HRMS (FAB) *m/z*: Calcd for $C_{33}H_{56}O_{15}Na$ $[M+Na]^+$ 715.3511; found 715.3521. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: 3.45 (1H, dd, $J_{1,2}$ = 3.5, $J_{2,3}$ = 10.0 Hz, H-2), 3.53 (1H, dd, $J_{3,4}$ = 9.0, $J_{4,5}$ = 9.5 Hz, H-4), 3.63 (1H, dt, $J_{4,5}$ = 9.5, $J_{5,6a}$ = $J_{5,6b}$ = 3.5 Hz, H-5), 3.74 (1H, ddd, $J_{4',5'}$ = 10.0, $J_{5',6'a}$ = 1.5, $J_{5',6'b}$ = 5.5 Hz, H-5'), 3.79 (1H, dd, $J_{5,6a}$ = 3.5, $J_{6a,6b}$ = 11.5 Hz, H-6a), 3.84 (1H, dd, $J_{5,6b}$ = 3.5, $J_{6a,6b}$ = 11.5 Hz, H-6b), 3.90 (1H, dd, $J_{2,3}$ = 10.0, $J_{3,4}$ = 9.0 Hz, H-3), 3.99 (1H, dd, $J_{5',6'b}$ = 5.5, $J_{6'a,6'b}$ = 12.5 Hz, H-6'b), 4.30 (1H, dd, $J_{5',6'b}$ = 5.5 Hz, $J_{6'a,6'b}$ = 12.5 Hz, H-6'a), 4.81 (1H, d, $J_{1,2}$ = 3.5 Hz, H-1), 4.85 (1H, d, $J_{1',2'}$ = 8.0 Hz, H-1'), 5.08 (1H, dd, $J_{1',2'}$ = 8.0 Hz, $J_{2',3'}$ = 9.5 Hz, H-2'), 5.11 (1H, dd, $J_{3',4'}$ = 9.5 Hz, $J_{4',5'}$ = 10.0 Hz, H-4'), 5.33 (1H, t, $J_{2',3'}$ = $J_{3',4'}$ = 9.5 Hz, H-3'). ^{13}C-NMR (75 MHz, $CDCl_3$) δ: 61.77 (C-6'), 62.22 (C-6), 67.62 (C-4'), 70.55 (C-5), 70.70 (C-4), 71.57 (C-2'), 71.78 (C-3), 72.13 (C-3'), 72.48 (C-5'), 80.48 (C-2), 99.30 (C-1), 101.24 (C-1').

Methyl *O*-2,3,4,6-tetra-*O*-pivaloyl-β-D-glucopyranosyl-(1→3)-α-D-glucopyranoside (21):

Colorless syrup. $[\alpha]_D^{23.0}$ +62.2 (*c* 1.00, $CHCl_3$). HRMS (FAB) *m/z*: Calcd for $C_{33}H_{56}O_{15}Na$ $[M+Na]^+$

715.3511; found 715.3506. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: 3.44 (1H, dd, $J_{3,4}$ = 8.0, $J_{4,5}$ = 9.5 Hz, H-4), 3.54 (1H, dd, $J_{1,2}$ = 4.0, $J_{2,3}$ = 9.5 Hz, H-2), 3.58 (1H, ddd, $J_{4,5}$ = 9.5, $J_{5,6a}$ = 3.5, $J_{5,6b}$ = 5.0 Hz, H-5), 3.59 (1H, dd, $J_{3,4}$ = 8.0, $J_{4,5}$ = 9.5 Hz, H-3), 3.75 (1H, dd, $J_{5,6b}$ = 5.0, $J_{6a,6b}$ = 11.5 Hz, H-6b), 3.77 (1H, ddd, $J_{4',5'}$ = 10.0, $J_{5',6'a}$ = 2.0, $J_{5',6'b}$ = 6.0 Hz, H-5'), 3.86 (1H, dd, $J_{5,6a}$ = 3.5, $J_{6a,6b}$ = 11.5 Hz, H-6a), 3.99 (1H, dd, $J_{5',6'b}$ = 6.0, $J_{6'a,6'b}$ = 12.5 Hz, H-6'b), 4.24 (1H, dd, $J_{5',6'a}$ = 2.0, $J_{6'a,6'b}$ = 12.5 Hz, H-6'a), 4.73 (1H, d, $J_{1,2}$ = 4.0 Hz, H-1), 4.76 (1H, d, $J_{1',2'}$ = 8.0 Hz, H-1'), 5.05 (1H, dd, $J_{1',2'}$ = 8.0, $J_{2',3'}$ = 9.5 Hz, H-2'), 5.09 (1H, dd, $J_{3',4'}$ = 9.5, $J_{4',5'}$ = 10.0 Hz, H-4'), 5.34 (1H, t, $J_{2',3'}$ = $J_{3',4'}$ = 9.5 Hz, H-3'). ^{13}C-NMR (75 MHz, $CDCl_3$) δ: 61.72 (C-6'), 62.74 (C-6), 67.85 (C-4'), 69.14 (C-4), 71.05 (C-2), 71.12 (C-5), 71.39 (C-2'), 71.94 (C-3'), 72.38 (C-5'), 85.23 (C-3), 99.05 (C-1), 101.54 (C-1').

Methyl *O*-2,3,4,6-tetra-*O*-pivaloyl-β-D-glucopyranosyl-(1→2)-α-L-fucopyranoside (23):

Colorless crystals. Mp 210~212 °C. $[\alpha]_D^{22.5}$ –38.6 (*c* 0.97, $CHCl_3$). HRMS (FAB) *m/z*: Calcd for $C_{33}H_{56}O_{14}Na$ [M+Na]+ 699.3568; found 699.3560. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: 1.28 (3H, d, $J_{5,6}$ = 6.0 Hz, H-6), 3.78 (1H, ddd, $J_{4',5'}$ = 10.0, $J_{5',6'a}$ = 2.0, $J_{5',6'b}$ = 6.0 Hz, H-5'), 3.79 (1H, dd, $J_{1,2}$ = 4.0, $J_{2,3}$ = 9.5 Hz, H-2), 3.82 (1H, dd, $J_{3,4}$ = 3.5, $J_{4,5}$ = 1.0 Hz, H-4), 3.90 (1H, dq, $J_{4,5}$ = 1.0, $J_{5,6}$ = 6.0 Hz, H-5), 3.94 (1H, dd, $J_{2,3}$ = 9.5, $J_{3,4}$ = 3.5 Hz, H-3), 3.95 (1H, dd, $J_{5',6'b}$ = 6.0, $J_{6'a,6'b}$ = 12.5 Hz, H-6'b), 4.33 (1H, dd, $J_{5',6'a}$ = 2.0, $J_{6'a,6'b}$ = 12.5 Hz, H-6'a), 4.60 (1H, d, $J_{1',2'}$ = 8.0 Hz, H-1'), 4.66 (1H, d, $J_{1,2}$ = 4.0 Hz, H-1), 5.06 (1H, dd, $J_{1',2'}$ = 8.0, $J_{2',3'}$ = 9.5 Hz, H-2'), 5.10 (1H, dd, $J_{3',4'}$ = 9.5, $J_{4',5'}$ = 10.0 Hz, H-4'), 5.32 (1H, t, $J_{2',3'}$ = $J_{3',4'}$ = 9.5 Hz, H-3'). ^{13}C-NMR (75 MHz, $CDCl_3$) δ: 15.93 (C-6), 61.49 (C-6'), 65.11 (C-5), 67.46 (C-4'), 68.20 (C-3), 71.07 (C-2'), 71.19 (C-4), 71.90 (C-3'), 72.75 (C-5'), 80.35 (C-2), 97.99 (C-1), 101.54 (C-1').

Methyl *O*-2,3,4,6-tetra-*O*-pivaloyl-β-D-glucopyranosyl-(1→4)-α-L-rhamnopyranoside (25):

Colorless syrup. $[\alpha]_D^{22.0}$ –28.3 (*c* 1.00, $CHCl_3$). HRMS (FAB) *m/z*: Calcd for $C_{33}H_{56}O_{14}Na$ $[M+Na]^+$ 699.3562; found 699.3571 $[M+Na]^+$. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: 1.27 (3H, d, $J_{5,6}$ = 6.0 Hz, H-6), 3.50 (1H, dd, $J_{3,4}$ = 9.0 $J_{4,5}$ = 9.5 Hz, H-4), 3.61 (1H, dq, $J_{4,5}$ = 9.5, $J_{5,6}$ = 6.0 Hz, H-5), 3.70 (1H, ddd, $J_{4',5'}$ = 10.0, $J_{5',6'a}$ = 2.0, $J_{5',6'b}$ = 5.0 Hz, H-5'), 3.76 (1H, dd, $J_{2,3}$ = 3.5, $J_{3,4}$ = 9.0 Hz, H-3), 3.85 (1H, dd, $J_{1,2}$ = 1.5, $J_{2,3}$ = 3.5 Hz, H-2), 3.98 (1H, dd, $J_{5',6'b}$ = 5.0, $J_{6'a,6'b}$ = 12.0 Hz, H-6'b), 4.25 (1H, dd, $J_{5',6'a}$ = 2.0, $J_{6'a,6'b}$ = 12.0 Hz, H-6'a), 4.63 (1H, d, $J_{1,2}$ = 1.5 Hz, H-1), 4.95-5.02 (2H, m, $J_{1',2'}$ = 7.0 Hz, H-1', 2'), 5.12 (1H, dd, $J_{3',4'}$ = 9.5, $J_{4',5'}$ = 10.0 Hz, H-4'), 5.32 (1H, t, $J_{2',3'}$ = $J_{3',4'}$ = 9.5 Hz, H-3'). ^{13}C-NMR (75 MHz, $CDCl_3$) δ: 17.57 (C-6), 61.71 (C-6'), 66.02 (C-5), 67.98 (C-4'), 71.17 (C-2), 71.39 (C-3), 71.83 (C-2'), 71.98 (C-5'), 72.30 (C-3'), 79.32 (C-4), 100.25 (C-1), 100.59 (C-1').

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