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Synthesis of (+)-sucrose via β-D-psicofuranosylation

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ABSTRACT

Despite the difficulty of direct β-furanosylation with D-fructose, the synthesis of β-D-fructofuranosyl α-D-glucopyranoside, (+)-sucrose **1**, has been achieved stepwise, via β-selective D-psicofuranosylation followed by stereo inversion of a hydroxy group at the C-3 position on the furanose ring. D-Psicofuranosyl donor **10** was prepared in eight steps from D-ribose monoacetonide **3** in excellent yield.

1. Introduction

(+)-Sucrose **1** is a natural sweetener and the most common disaccharide.[1] The structure consists of a glycoside linkage between the C-1 position of α-D-glucose and the C-2 position of β-D-fructose. Although many synthetic studies of disaccharides, as well as polysaccharides, have been reported,[2] the formation of glycosidic bond at both anomeric centers of two sugars is a difficult architectural element for the synthesis of dissacharides. Therefore, enzymatic glycosidation has been undertaken in such cases.[3]

Two approaches exist for the formation of a glycosidic bond for the synthesis of (+)-sucrose. They are (i) using D-glucose as a glycosyl donor and D-fructose as an acceptor or (ii) using D-glucose as a glycosyl acceptor and D-fructose as a donor (Fig. 1). Both approaches were reported. However, the D-glucopyranosylation of D-fructose[4] or the D-fructofuranosylation of D-glucose[5] predominantly or exclusively provided isosucrose **2**. The yield of desired sucrose was less than 20%. Among these synthetic approaches to (+)-sucrose,[3,4,6] one successful example for β-directing D-fructofuranosylation was reported by Oscarson et al.[7] in which two hydroxy groups at C-1 and C-4 were protected with cyclic silyl ether, blocking fructofuranosylation from the α-side on the furanose ring. In this synthesis, however, chromatographic separation of α- and β-*S*-ethyl fructofuranoside and use of an excess of specific promoter such as DMTST [dimethy(methylthio)sulfonium triflate] are required.

There exists a number of β-D-fructofuranosyl saccharides including sucrose in Nature.[8] The preparation of β-D-fructofuranoside is a subject of importance and highly desired in the synthesis of related disaccharides. Herein, we report a new synthetic approach focusing on the synthesis of (+)-sucrose **1**, which involves the formation of 2β-D-fructofuranoside via β-D-psicofuranoside.

2. Results and discussion

In the previous results for the synthesis of (+)-sucrose, the undesirable formation of α-D-fructofuranoside instead of β-D-

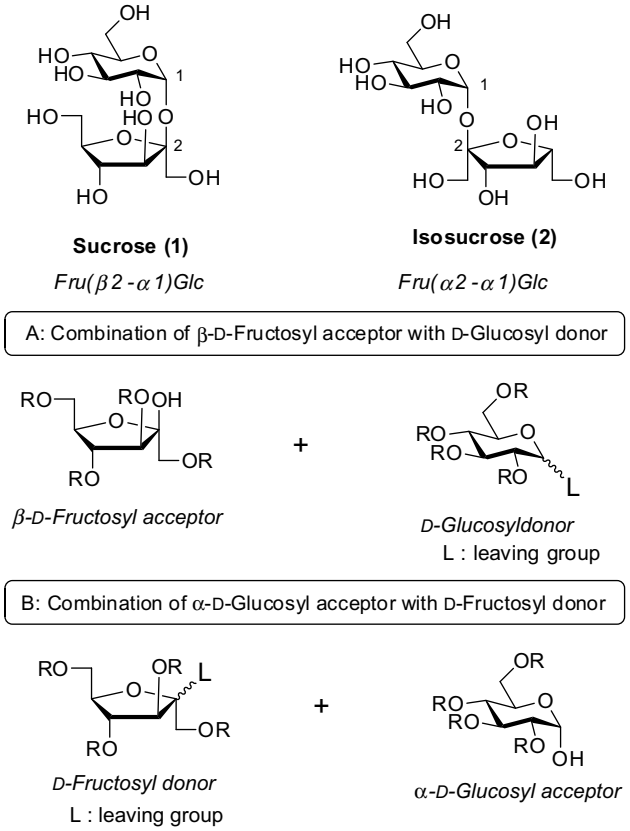

Figure 1.

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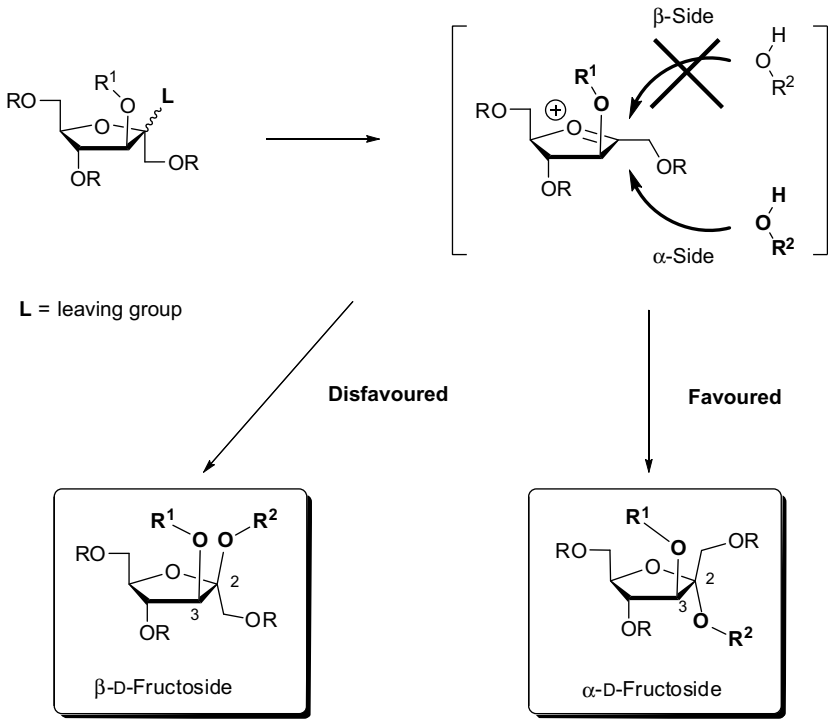
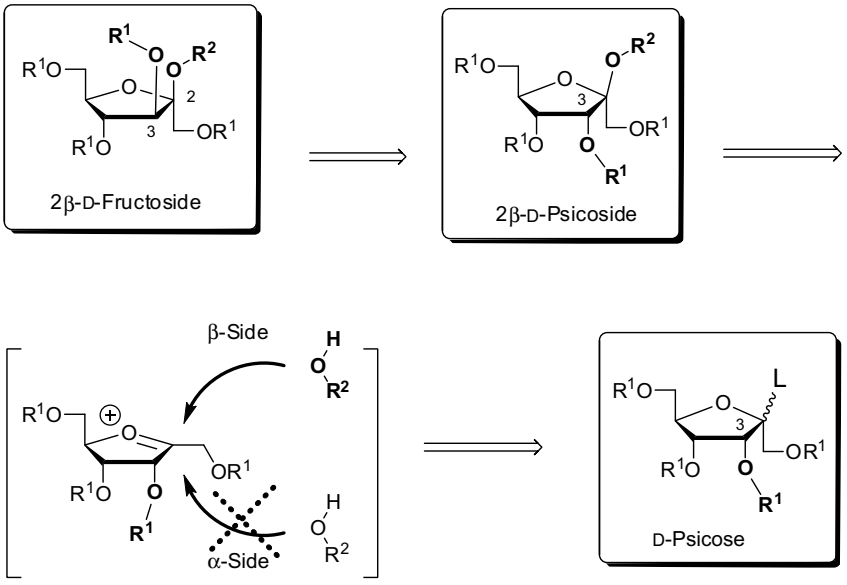


Figure 2.

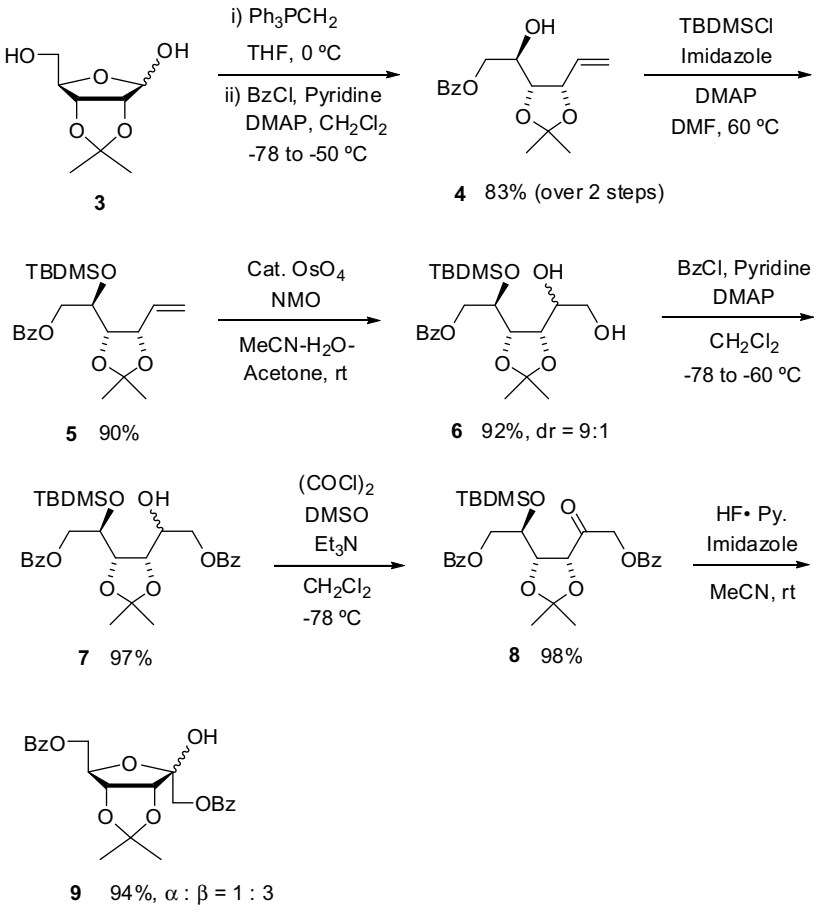
fructofuranoside is apparently due to the presence of a protected 3-β-hydroxy group-OR,[1] which sticks on the β-side of the ring. As shown in Figure 2, the R^1O group at the C-3 position facilitates nucleophilic attack of the glycosylic acceptor (R^2OH) from the α-side to the cyclic oxonium intermediate and results in the formation of α-fructofuranoside.

If the C-3 R^1O group locates itself at the α-side instead of the β-side, its glycosidation should occur through the intermediary cyclic oxonium cation from the β-side, as shown in Scheme 1. Based on this idea, we designed the synthesis of β-D-fructofuranoside using D-psicose, a diastereomeric isomer of D-fructose at the C-3 position, that would be expected as a glycosyl donor for β-glycosidation. After glycosidation, inversion of the stereocenter at C-3 would furnish the synthesis of β-D-fructoside.

Since D-psicose is an expensive rare sugar,[9–11] we have synthesized it from D-ribose, as shown in Scheme 2. Wittig methylenation of D-ribose acetonide **3**,[12] followed by selective benzoylation of the primary alcohol, gave **4** in 83% yield over two steps. Protection of the secondary hydroxy group with TBDMSCl and dihydroxylation of the terminal olefin by OsO_4 catalyzed oxidation gave diol **6** in 83% yield in two steps. The primary alcohol was protected selectively as a benzoate to give **7** in 97% yield. Transformation of the



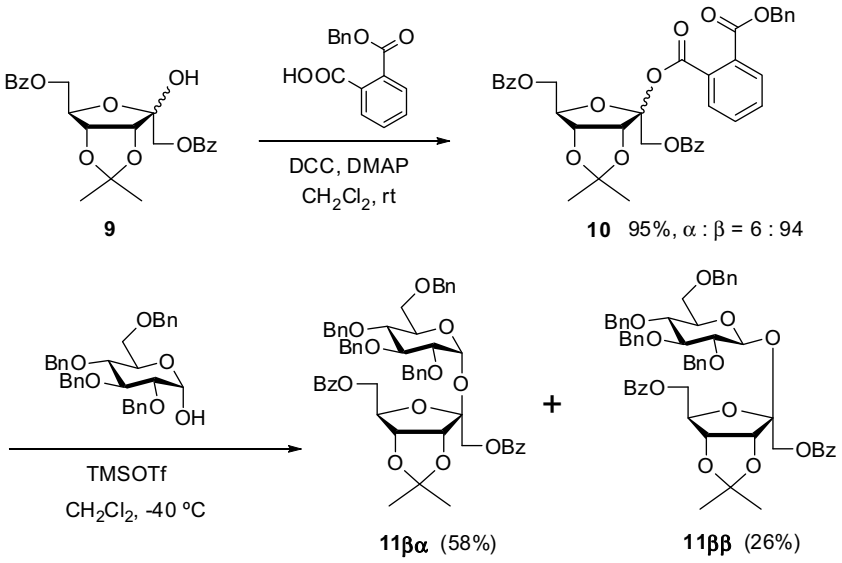
Scheme 1.



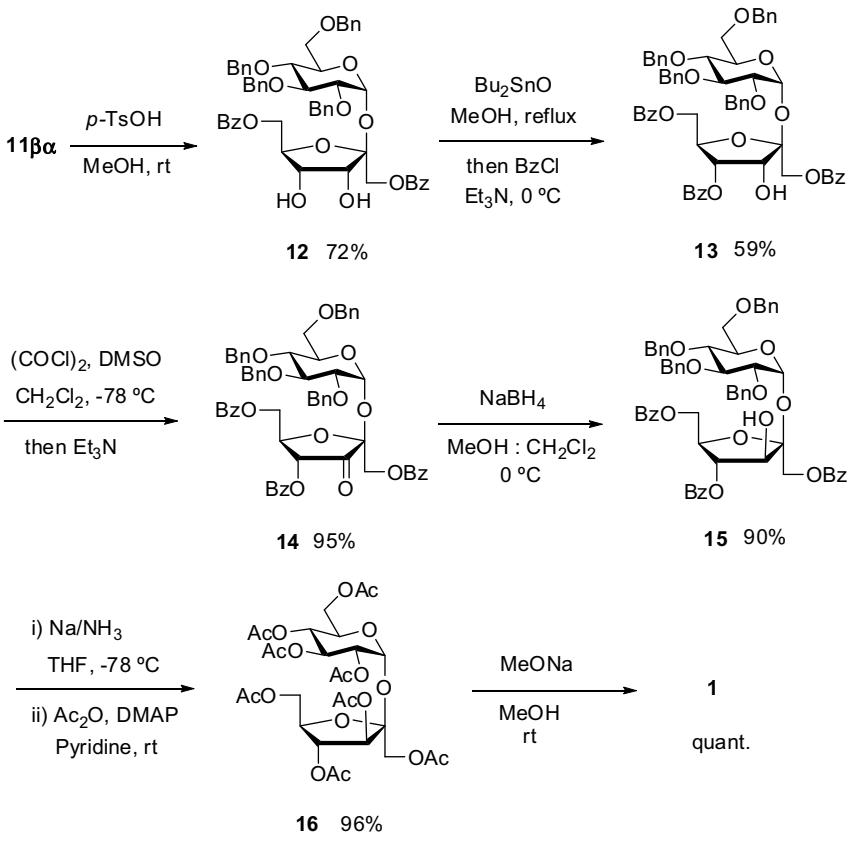
Scheme 2.

secondary alcohol to a ketone via Swern oxidation and deprotection of the silyl group with HF-pyridine gave D-psicofuranose **9** as an anomeric mixture in 92% yield in two steps.

The synthesis of β-D-psicosyl glucoside is shown in Scheme 3. The anomeric hydroxy group of **9** lead to the glycosidation donor possessing monobenzylphthalate.[13] Thus, the esterification of **9** with monobenzyl phthalate by DCC and DMAP in CH_2Cl_2 gave D-psicosyl phthalate **10** as a mixture of α- and β-isomers in a 6: 94 ratio in 95% yield. Glycosylation of **10** with 2,3,4,6-tetra-*O*-benzyl-α-D-glucose[14] was promoted by TMSOTf in CH_2Cl_2 at −40 °C. The reaction occurred exclusively on the β-side of D-psicofuranose and no α-isomer was produced. However, anomeric mixtures of glucosides **11βα** and **11ββ** were produced in 58% and 26% yields, because 2,3,4,6-tetra-*O*-benzyl-α-D-glucose was isomerized



Scheme 3.



Scheme 4.

to the β-D-glucose under the reaction conditions. The stereochemistry of the glycosidic bonds was determined by ^{1}H NMR. The coupling constant ($J_{1,2}$) of the anomeric proton for **11βα** is 3.5 Hz, which indicates a typical equatorial-axial relation for an α-glucoside, while the corresponding coupling constant of the anomeric proton of **11ββ** is 7.3 Hz, which is a typical axial-axial relation for β-glucoside. On the other hand, the β-glycosidic bond in psicosides **11βα** and **11ββ** was confirmed by NOE experiment.[15]

The structure of **11βα** possesses an identical glycosidic linkage to (+)-sucrose, and can be transformed into **1** by an inversion of the C-3 hydroxy group on the D-furanose ring (Scheme 4). Deprotection of acetonide of **11βα** by acidic methanol gave **12** in 72% yield, which underwent selective benzoylation of the C-4 hydroxy group via a stannylene acetal by treatment of the diol with dibutyltin oxide[16] to give **13** in 59% yield. Swern oxidation of the C-3 hydroxy group to ketone followed by a diastereoselective reduction with $NaBH_4$ produced **15** in 90% yield in two steps. Deprotection of four *O*-benzyl and three *O*-benzoyl groups under the Birch reduction conditions in one step and successive acetylation of the resulting product gave sucrose octaacetate **16** in 96% yield.[6b] Removal of all acetyl groups furnished the synthesis of (+)-sucrose **1**, which was identified in accordance with all physical and spectroscopic data of natural sucrose[6b] as well as by its sweet taste.

3. Conclusions

In conclusion, the stereoselective glycosidation of protected α-D-glucose with D-psicosyl phthalate **10** occurs to give β-D-psicosyl D-glucoside, which can be transformed to (+)-sucrose **1** in four steps including inversion of the C-3 hydroxy center. Since direct β-D-fructofuranosylation so far has been ineffective in the glycosidation reaction, this should provide a powerful methodology for the chemical synthesis of β-D-fructofuranoside.

4. Experimental

4.1. General

IR spectra were recorded on a JASCO FT/IR-410 spectrophotometer. ^{1}H NMR and ^{13}C NMR spectra were recorded at 300 or 400 MHz and at 75 or 100 MHz, respectively. Mass spectra were recorded using chemical ionization (CI) with isobutene gas or fast atom bombardment (FAB) ionization. Silica gel (230–400 mesh) was used for flash chromatography. Specific rotations were recorded on a JASCO DIP-360 polarimeter using $CHCl_3$ as a solvent. Analytical thin-layer chromatography (TLC) was performed on glass pre-coated with silica gel (0.25 mm thickness). High performance liquid chromatography (HPLC) was carried out on a UV spectrophotomeric detector (254 nm) to which a 20 × 250 mm size column packed with silica gel was attached. All experiments were carried out under an argon atmosphere. THF was dried over sodium/benzophenone ketyl, and CH_2Cl_2 was dried over P_2O_5, and they were distilled prior to use. The solvent extracts were dried over $MgSO_4$, and the solutions were evaporated under reduced pressure.

4.2. Preparation of D-psicose unit

4.2.1. (2*R*,3*S*,4*S*)-2-Hydroxy-3,4-*O*-isopropylidene-hex-5-enyl benzoate 4

To a suspension of methyltriphenylphosphonium bromide (69.6 g, 195 mmol) in anhydrous THF (230 mL) was added

potassium *tert*-butoxide (21.8 g, 195 mmol) in several portions at 0 °C. The mixture was stirred for 1 h at the same temperature and for an additional 1 h at room temperature. Then, a solution of 2,3-*O*-isopropylidene-D-ribose (10.6 g, 55.7 mmol) in THF (40 mL) was added dropwise at 0 °C. The reaction mixture was stirred overnight at room temperature and quenched with water (100 mL). The mixture was extracted with EtOAc (three times with 60 mL) and the extracts were dried over $MgSO_4$, and evaporated. The residual oil was dissolved in toluene and water was removed azeotropically. The resulting syrup was used directly for the next step. The crude product and 4-*N*,*N*-dimethylaminopyridine (679 mg, 5.57 mmol) were dissolved in a mixture of pyridine (11.3 mL, 111 mmol) and CH_2Cl_2 (100 mL), and benzoyl chloride (7.10 mL, 61.2 mmol) was carefully added at −78 °C. The mixture was warmed up to −50 °C during 30 min MeOH (5 mL) was added and the mixture was stirred for an additional 10 min at room temperature. Then, it was diluted with EtOAc, washed with 1 M HCl, saturated $NaHCO_3$, and brine, and dried over $MgSO_4$. After the extract was concentrated in vacuo, the residue was purified by column chromatography on silica gel eluted with 15% EtOAc in hexane to give **4** (13.5 g) in 83% yield over 2 steps. Colorless oil. R_f = 0.44 (30% EtOAc in hexane). $[\alpha]_D^{23} = +13.2$ (*c* 0.98, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$) δ: 8.06–8.03 (2H, m), 7.58–7.52 (1H, m), 7.45–7.39 (2H, m), 6.04 (1H, ddd, *J* = 17.2, 10.5, 6.8 Hz), 5.46 (1H, ddd, *J* = 17.2, 1.7, 1.3 Hz), 5.31 (1H, ddd, *J* = 10.5, 1.7, 1.1 Hz), 4.73 (1H, dd, *J* = 6.8, 6.2 Hz), 4.65 (1H, dd, *J* = 11.7, 2.4 Hz), 4.39 (1H, dd, *J* = 11.7, 6.4 Hz), 4.17 (1H, dd, *J* = 8.8, 6.2 Hz), 3.99 (1H, ddd, *J* = 8.8, 6.4, 2.4 Hz), 2.62 (1H, br s), 1.49 (3H, s), 1.37 (3H, s). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 167.0, 133.5, 133.1, 129.8, 129.6, 128.3, 118.2, 109.0, 78.4, 77.6, 68.8, 67.1, 27.7, 25.3. IR (film) cm^{-1}: 3473, 2987, 1721, 1452, 1380, 1276, 1070, 711. MS (CI) *m*/*z*: 293 $(M+H)^+$. HR-MS (CI) *m*/*z*: 293.1398 (calcd for $C_{16}H_{21}O_5$: 293.1389).

4.2.2. (2*R*,3*S*,4*S*)-2-*tert*-Butyldimethylsilyloxy-3,4-*O*-isopropylidene-hex-5-enyl benzoate 5

A stirred solution of **4** (11.6 g, 39.6 mmol), imidazole (10.8 g, 158 mmol), TBDMSCl (11.9 g, 79.2 mmol), and 4-*N*,*N*-dimethylaminopyridine (1.45 g, 11.9 mmol) in DMF (40 mL) was heated at 60 °C for 16 h. After cooling, water was added and the mixture extracted with EtOAc. The organic extract was washed with water and brine, dried over $MgSO_4$, and evaporated under vacuum. The crude product was purified by column chromatography on silica gel eluted with 7% EtOAc in hexane to give **5** (16.1 g) in 90% yield. Colorless oil. R_f = 0.55 (10% EtOAc in hexane). $[\alpha]_D^{23} = -2.3$ (*c* 1.03, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$) δ: 8.08–8.04 (2H, m), 7.58–7.53 (1H, m), 7.46–7.41 (2H, m), 6.02 (1H, ddd, *J* = 17.1, 10.3, 7.2 Hz), 5.41 (1H, ddd, *J* = 17.1, 1.7, 1.1 Hz), 5.28 (1H, ddd, *J* = 10.3, 1.7, 0.9 Hz), 4.67 (1H, dd, *J* = 7.2, 6.2 Hz), 4.52 (1H, dd, *J* = 11.8, 2.8 Hz), 4.39 (1H, dd, *J* = 11.8, 4.7 Hz), 4.28 (1H, dd, *J* = 7.2, 6.2 Hz), 4.11 (1H, ddd, *J* = 7.2, 4.7, 2.8 Hz), 1.48 (3H, s), 1.36 (3H, s), 0.86 (9H, s), 0.09 (3H, s), 0.07 (3H, s). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 166.4, 134.1, 132.9, 130.1, 129.6, 128.3, 118.4, 108.5, 78.6, 78.4, 69.6, 66.9, 27.6, 25.8, 25.8, 25.8, 25.3, 18.0, −3.9, −4.6. IR (film) cm^{-1}: 2931, 1724, 1602, 1454, 1379, 1274, 1112, 835, 777, 711. MS (CI) *m*/*z*: 407 $(M+H)^+$. HR-MS (CI) *m*/*z*: 407.2256 (calcd for $C_{22}H_{35}O_5Si$: 407.2254).

4.2.3. (2*R*,3*S*,4*S*)-2-*tert*-Butyldimethylsilyloxy-5,6-dihydroxy-3,4-*O*-isopropylidene-hexyl benzoate 6

To a solution of **5** (8.90 g, 21.9 mmol) in a 1:1:1 mixture of acetone–MeCN–H_2O (22 mL) were added 4% aqueous OsO_4 solution (1.34 mL, 0.219 mmol) and *N*-methylmorpholine *N*-oxide (3.85 g, 32.9 mmol). The mixture was vigorously stirred for 10 h at room temperature. The reaction mixture was quenched with saturated Na_2SO_3 solution and stirred for an additional 30 min. The mixture was extracted with EtOAc and washed with 1 M HCl, water, and brine and dried ($MgSO_4$). Concentration under reduced pressure and purification of the crude product by silica gel flash chromatography (elution: 30% EtOAc in hexane) gave **6** (8.83 g) in 92% yield (dr = 9:1). Colorless oil. R_f = 0.20 (30% EtOAc in hexane). ^{1}H NMR (300 MHz, $CDCl_3$) major isomer; δ: 8.07–8.03 (2H, m), 7.59–7.54 (1H, m), 7.47–7.41 (2H, m), 4.56–4.48 (3H, m), 4.26 (1H, ddd, *J* = 5.3, 2.6, 1.5 Hz), 4.16 (1H, d, *J* = 4.0 Hz), 4.09 (1H, dd, *J* = 9.5, 5.2 Hz), 3.90–3.82 (2H, m), 3.70–3.62 (1H, m), 2.44 (1H, t, *J* = 6.1 Hz), 1.42 (3H, s), 1.33 (3H, s), 0.90 (9H, s), 0.18 (3H, s), 0.15 (3H, s). Minor isomer; δ: 8.12–8.00 (2H, m), 7.61–7.55 (1H, m), 7.48–7.42 (2H, m), 4.60–3.67 (5H, m), 4.43 (1H, dd, *J* = 11.9, 4.6 Hz), 4.34 (1H, t, *J* = 6.9 Hz), 4.24 (1H, dd, *J* = 6.9, 1.5 Hz), 3.76 (1H, dd, *J* = 11.2, 6.2 Hz), 1.87 (1H, br s), 1.51 (3H, s), 1.35 (3H, s), 0.88 (9H, s), 0.18 (3H, s), 0.12 (3H, s). ^{13}C NMR (75 MHz, $CDCl_3$) major isomer; δ: 166.3, 133.2, 129.6, 128.4, 108.0, 77.3, 77.2, 69.9, 68.8, 65.9, 64.2, 27.9, 25.7, 25.6, 18.0, −4.4, −4.7. Minor isomer, δ: 166.3, 133.0, 129.5, 128.4, 108.5, 76.8, 69.6, 69.0, 66.6, 65.1, 26.4, 25.7, 24.7, −4.0, −5.1. IR (film) cm^{-1}: 3462, 2932, 2857, 1722, 1602, 1453, 1380, 1275, 1070, 837, 779, 712. MS (CI) *m*/*z*: 441 $(M+H)^+$. HR-MS (CI) *m*/*z*: 441.2300 (calcd for $C_{22}H_{37}O_7Si$: 441.2308).

4.2.4. (2*R*,3*S*,4*S*)-1-Benzoyloxy-2-*tert*-butyldimethylsilyloxy-5-hydroxy-3,4-*O*-isopropylidene-hexyl benzoate 7

To a stirred solution of **6** (8.66 g, 19.7 mmol), 4-*N*,*N*-dimethylaminopyridine (240 mg, 1.97 mmol) and pyridine (3.99 mL, 39.4 mmol) in CH_2Cl_2 (70 mL) was added BzCl (2.50 mL, 21.6 mmol) at −78 °C. The reaction mixture was gradually warmed up to −60 °C during 1 h. The reaction mixture was diluted with EtOAc, and washed with 1 M HCl, saturated $NaHCO_3$ solution, and brine. The extract was dried over $MgSO_4$ and condensed under reduced pressure. The residue was purified by flash chromatography on silica gel eluted with 10% EtOAc in hexane to afford **7** (10.4 g) in 97% yield (dr = 9:1). Colorless oil. R_f = 0.41 (20% EtOAc in hexane). ^{1}H NMR (300 MHz, $CDCl_3$) major isomer; δ: 8.09–8.03 (4H, m), 7.59–7.52 (2H, m), 7.47–7.40 (4H, m), 4.71 (1H, dd, *J* = 11.6, 1.7 Hz), 4.63–4.50 (3H, m), 4.48–4.28 (3H, m), 4.25–4.13 (2H, m), 4.08 (1H, d, *J* = 3.5 Hz), 1.46 (3H, s), 1.35 (3H, s), 0.91 (9H, s), 0.21 (3H, s), 0.16 (3H, s). Minor isomer; δ: 8.09–8.03 (4H, m), 7.59–7.52 (2H, m), 7.47–7.40 (4H, m), 4.73–4.08 (9H, m), 1.52 (3H, s), 1.37 (3H, s), 0.87 (9H, s), 0.19 (3H, s), 0.13 (3H, s). ^{13}C NMR (75 MHz, $CDCl_3$) major isomer; δ: 166.7, 166.3, 133.1, 132.8, 129.6, 129.6, 128.4, 128.2, 108.1, 77.3, 76.6, 69.9, 67.5, 66.3, 66.0, 27.9, 25.6, 25.6, 18.0, −4.5, −4.7. Minor isomer; δ: 166.3, 166.3, 133.0, 132.9, 130.2, 129.5, 128.3, 128.2, 108.5, 75.9, 69.6, 67.4, 66.6, 26.4, 25.7, 24.6, 18.1, −3.9, −4.8. IR (film) cm^{-1}: 3477, 2932, 2857, 1722, 1602, 1452, 1381, 1315, 1275, 1070, 1026, 837, 780, 711. MS (CI) *m*/*z*: 545 $(M+H)^+$. HR-MS (CI) *m*/*z*: 545.2578 (calcd for $C_{29}H_{41}O_8Si$: 545.2570).

4.2.5. 1,6-Di-*O*-benzoyl-5-*O*-*tert*-butyldimethylsilyl-3,4-*O*-isopropylidene-D-psicose 8

To a solution of oxalyl chloride (2.00 mL, 22.9 mmol) in CH_2Cl_2 (50 mL), was slowly added DMSO (3.38 mL, 47.7 mmol) in CH_2Cl_2 (25 mL) at −78 °C, and the mixture was stirred for 15 min at the same temperature. A solution of **7** (10.4 g, 19.1 mmol) in CH_2Cl_2 (50 mL) was added to the mixture over a period of 15 min at −78 °C and the reaction was continued for 1 h at the same temperature. After the addition of triethylamine (13.3 mL, 95.5 mmol), the mixture was allowed to warm up to room temperature over 15 min, and then quenched with saturated ammonium chloride solution. The organic phase was separated and the aqueous phase was extracted with EtOAc. The combined organic extract was washed with brine, dried over $MgSO_4$, and concentrated under reduced pressure. The crude product was purified by flash chromatography on silica gel eluted with 10% EtOAc in hexane to give **8**

(10.1 g) in 98% yield. Colorless oil. R_f = 0.52 (20% EtOAc in hexane). $[\alpha]_D^{22} = +21.0$ (*c* 1.05, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$) δ: 8.10–8.03 (4H, m), 7.60–7.54 (2H, m), 7.47–7.42 (4H, m), 5.47 (1H, d, *J* = 17.8 Hz), 5.07 (1H, d, *J* = 17.8 Hz), 4.71 (1H, d, *J* = 8.1 Hz), 4.64 (1H, dd, *J* = 8.1, 3.1 Hz), 4.58–4.50 (1H, m), 4.43–4.39 (2H, m), 1.64 (3H, s), 1.40 (3H, s), 0.91 (9H, s), 0.16 (3H, s), 0.12 (3H, s). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 202.6, 166.1, 165.7, 133.1, 133.0, 129.8, 129.5, 129.4, 128.3, 128.2, 109.5, 80.0, 79.4, 70.0, 68.2, 65.7, 26.1, 25.8, 25.8, 25.8, 23.9, 18.2, −4.2, −5.0. IR (film) cm^{-1}: 2931, 1725, 1602, 1584, 1453, 1384, 1275, 1115, 836, 710. MS (CI) *m*/*z*: 543 (M+H)$^+$. HR-MS (CI) *m*/*z*: 543.2422 (calcd for $C_{29}H_{39}O_8Si$: 543.2414).

4.2.6. 1,6-Di-*O*-benzoyl-3,4-*O*-isopropylidene-D-psicofuranose 9

To a mixture of **8** (10.1 g, 18.6 mmol) and imidazole (12.6 g, 186 mmol) in MeCN (100 mL), was added HF·pyridine complex (70% HF, 4.83 mL, 186 mmol) at 0 °C and the mixture was stirred for 24 h at room temperature. Aqueous KH_2PO_4 solution was added and the mixture extracted with Et_2O. The extract was washed with water and brine, dried over $MgSO_4$, and condensed under vacuum. Purification by silica gel flash chromatography (eluent: 12.5% EtOAc in hexane) gave **9** (7.54 g) in 94% yield as a 1:3 ratio of α- and β-anomers. Colorless syrup. R_f = 0.45 (30% EtOAc in hexane). ^{1}H NMR (300 MHz, $CDCl_3$) β-anomer, δ: 8.08–8.01 (4H, m), 7.59–7.53 (2H, m), 7.46–7.35 (4H, m), 4.89 (1H, dd, $J_{3,4}$ = 5.9, $J_{4,5}$ = 1.4 Hz, H-4), 4.83–4.71 (2H, m, H-3,6a), 4.64 (1H, d, $J_{1a,1b}$ = 11.6 Hz, H-1a), 4.56–4.47 (1H, m, H-5), 4.54 (1H, d, $J_{1a,1b}$ = 11.6 Hz, H-1b), 4.35 (1H, dd, $J_{6a,6b}$ = 11.3, $J_{5,6b}$ = 6.1 Hz, H-6b), 4.14 (1H, br s, O*H*), 1.53 (3H, s), 1.37 (3H, s); α-anomer, δ: 8.08–8.01 (4H, m), 7.59–7.53 (2H, m), 7.46–7.35 (4H, m), 4.90–4.39 (8H, m), 1.66 (3H, s), 1.43 (3H, s). ^{13}C NMR (75 MHz, $CDCl_3$) β-anomer, δ: 166.7, 166.5, 133.2, 133.1, 129.7, 129.7, 128.3, 128.3, 113.4, 106.0, 85.3, 84.6, 82.3, 65.7, 65.6, 26.5, 25.1; α-anomer, δ: 166.1, 165.9, 133.1, 129.6, 129.5, 128.2, 116.3, 101.2, 81.2, 81.0, 79.9, 66.2, 64.1, 26.4, 25.0. IR (film) cm^{-1}: 3443, 2989, 1729, 1602, 1452, 1280, 871, 709, 681. MS (FAB) *m*/*z*: 451 (M+Na)$^+$. HR-MS (FAB) *m*/*z*: 451.1378 (calcd for $C_{23}H_{24}O_8Na$: 451.1369).

4.3. Glycosidation

4.3.1. (1,6-Di-*O*-benzoyl-3,4-*O*-isopropylidene-β-D-psicofuranosyl) benzyl phthalate 10β and (1,6-di-*O*-benzoyl-3,4-*O*-isopropylidene-α-D-psicofuranosyl) benzyl phthalate 10α

To a mixture of **9** (4.00 g, 9.34 mmol) and benzyl hydrogen phthalate (9.56 g, 37.4 mmol) in CH_2Cl_2 (100 mL), were added *N*,*N*′-dicyclohexylcarbodiimide (5.77 g, 28.0 mmol) and 4-*N*,*N*-dimethylaminopyridine (1.14 g, 9.34 mmol) at 0 °C and the whole mixture was stirred for 20 h at room temperature. After CH_2Cl_2 was added, the precipitate was filtered off through a Celite pad and then washed with CH_2Cl_2. The filtrate was washed with 5% aqueous Na_2CO_3 solution and water, dried over $MgSO_4$, and concentrated to dryness. The residual oil was purified by flash chromatography on silica gel eluted with 20% EtOAc in hexane to afford **10** (5.93 g) in 95% yield as a syrupy anomeric mixture (β:α = 94:6). The isomers could be separated by HPLC. Compound **10β:** R_f = 0.72 (10% Et_2O in chloroform). $[\alpha]_D^{25} = -11.1$ (*c* 0.89, $CHCl_3$). ^{1}H NMR (300 MHz, C_6D_6) δ: 8.25–8.22 (2H, m), 8.04–8.01 (2H, m), 7.64–7.62 (1H, m), 7.57–7.55 (1H, m), 7.25–7.23 (2H, m), 7.13–7.08 (2H, m), 7.07–7.02 (3H, m), 6.99–6.92 (4H, m), 6.87 (1H, m), 6.78 (1H, m), 5.73 (1H, d, $J_{3,4}$ = 6.0 Hz, H-3), 5.71 (1H, d, $J_{1a,1b}$ = 12.1 Hz, H-1a), 5.33 (1 H, d, $J_{1a,1b}$ = 12.1 Hz, H-1b), 5.25 (1H, d, *J* = 12.5 Hz, C*H*$_2$Ph), 5.20 (1H, d, *J* = 12.5 Hz, C*H*$_2$Ph), 4.95 (1H, dd, $J_{3,4}$ = 6.0, $J_{4,5}$ = 1.8 Hz, H-4), 4.75 (1H, ddd, $J_{5,6a}$ = 7.3, $J_{5,6b}$ = 6.6, $J_{4,5}$ = 1.8 Hz, H-5), 4.49 (1H, dd, $J_{6a,6b}$ = 11.4, $J_{5,6a}$ = 7.3 Hz, H-6a), 4.42 (1H, dd, $J_{6a,6b}$ = 11.4, $J_{5,6b}$ = 6.6 Hz, H-6b), 1.40 (3H, s, (C*H*$_3$)$_2$C), 1.13 (3H, s, (C*H*$_3$)$_2$C). δ: 166.4, 166.1, 165.8, 165.7, 135.3, 133.0, 132.9, 131.6, 130.8, 130.2, 129.8, 129.7, 129.5, 129.4, 129.3, 128.4, 128.2, 128.1, 113.7, 112.3, 85.6, 84.7, 82.1, 67.3, 64.3, 63.1, 26.4, 25.0. IR (film) cm^{-1}: 2957, 1729, 1601, 1452, 1376, 1273, 1117, 869, 710. MS (FAB) *m*/*z*: 689 (M+Na)$^+$. HR-MS (FAB) *m*/*z*: 689.1992 (calcd for $C_{38}H_{34}O_{11}Na$: 689.1999). Compound **10α:** R_f = 0.63 (10% Et_2O in chloroform). $[\alpha]_D^{23} = +6.5$ (*c* 1.06, $CHCl_3$). ^{1}H NMR (300 MHz, C_6D_6) δ: 8.15–8.13 (2H, m), 8.10–8.07 (2H, m), 7.88–7.86 (1H, m), 7.52–7.49 (1H, m), 7.28–6.80 (13H, m), 5.46 (1H, d, $J_{1a,1b}$ = 11.7 Hz, H-1a), 5.32 (1H, d, *J* = 12.3 Hz, C*H*$_2$Ph), 5.24 (1H, d, *J* = 12.3 Hz, C*H*$_2$Ph), 5.12 (1H, d, $J_{1a,1b}$ = 11.7 Hz, H-1b), 4.88 (1H, d, $J_{3,4}$ = 6.9 Hz, H-3), 4.81 (1H, ddd, $J_{5,6b}$ = 5.6, $J_{4,5}$ = 4.9, $J_{5,6a}$ = 4.3 Hz, H-5), 4.47 (1H, dd, $J_{3,4}$ = 6.9, $J_{4,5}$ = 4.9 Hz, H-4), 4.37 (1H, dd, $J_{6a,6b}$ = 12.0, $J_{5,6a}$ = 4.3 Hz, H-6a), 4.27 (1H, dd, $J_{6a,6b}$ = 12.0, $J_{5,6b}$ = 5.6 Hz, H-6b), 1.35 (3H, s, (C*H*$_3$)$_2$C), 1.09 (3H, s, (C*H*$_3$)$_2$C). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 167.0, 166.1, 165.5, 164.9, 135.4, 133.1, 132.0, 131.9, 131.2, 131.0, 129.6, 129.6, 129.4, 129.4, 129.1, 128.9, 128.5, 128.4, 128.4, 128.3, 128.2, 116.0, 108.0, 82.7, 81.9, 80.7, 67.5, 64.1, 63.9, 26.3, 25.6. IR (film) cm^{-1}: 2955, 1730, 1601, 1453, 1379, 1272, 1114, 864, 709. MS (FAB) *m*/*z*: 689 (M+Na)$^+$. HR-MS (FAB) *m*/*z*: 689.2004 (calcd for $C_{38}H_{34}O_{11}Na$: 689.1999).

4.3.2. (1,6-Di-*O*-benzoyl-3,4-*O*-isopropylidene-β-D-psicofuranosyl) 2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside 11βα and (1,6-di-*O*-benzoyl-3,4-*O*-isopropylidene-β-D-psicofuranosyl) 2,3,4,6-tetra-*O*-benzyl-β-D-glucopyranoside 11ββ

A mixture of **10** (200 mg, 0.3 mmol) and 2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranose (243 mg, 0.45 mmol) was predried azeotropically with toluene three times and the residual oily material was dried further over P_2O_5 at 1–2 mmHg for 2 h. To this mixture, CH_2Cl_2 (6 mL) was added and cooled to −40 °C. Then TMSOTf (81 mL, 0.45 mmol) was added dropwise and the mixture was stirred for 30 min at the same temperature. The mixture was quenched with satd $NaHCO_3$ solution, extracted with CH_2Cl_2, washed with water, dried over $MgSO_4$, and evaporated under reduced pressure. The residue was purified by silica gel flash chromatography eluted with 15% EtOAc in hexane to give **11βα** (165 mg) in 58% yield and **11ββ** (73 mg) in 26% yield. Compound **11βα:** Colorless syrup. R_f = 0.57 (30% EtOAc in hexane). $[\alpha]_D^{23} = +29.0$ (*c* 1.08, $CHCl_3$). ^{1}H NMR (300 MHz, C_6D_6) δ: 8.29–8.26 (2H, m), 8.13–8.09 (2H, m), 7.40–6.95 (26H, m), 5.42 (1H, d, $J_{1,2}$ = 3.5 Hz, H-1), 5.08–4.95 (5H, m), 4.85 (1H, d, $J_{3',4'}$ = 6.1 Hz, H-3′), 4.68–4.28 (11H, m), 3.84 (1H, t, *J* = 9.5 Hz), 3.72 (1H, dd, $J_{6a,6b}$ = 11.0, $J_{5,6a}$ = 3.5 Hz, H-6a), 3.68 (1H, dd, $J_{6a,6b}$ = 11.0, $J_{5,6b}$ = 2.2 Hz, H-6b), 3.47 (1H, dd, $J_{2,3}$ = 9.7, $J_{1,2}$ = 3.5 Hz, H-2), 1.38 (3H, s), 1.11 (3H, s). ^{13}C NMR (75 MHz, $CDCl_3$) d: 165.9, 165.9, 138.6, 138.1, 137.8, 133.0, 132.8, 130.2, 129.7, 128.3, 128.2, 128.0, 127.8, 127.7, 127.6, 127.5, 127.4, 113.6, 109.1, 91.8, 84.7, 84.2, 82.0, 81.9, 78.9, 77.4, 75.5, 75.0, 73.5, 73.3, 71.4, 68.0, 64.7, 64.1, 26.5, 24.9. IR (film) cm^{-1}: 3030, 2931, 1716, 1602, 1496, 1454, 1374, 1272, 1096, 698. MS (FAB) *m*/*z*: 973 (M+Na)$^+$. HR-MS (FAB) *m*/*z*: 973.3770 (calcd for $C_{57}H_{58}O_{13}Na$: 973.3775). Compound **11ββ:** Colorless syrup. R_f = 0.63 (30% EtOAc in hexane). $[\alpha]_D^{23} = -13.8$ (*c* 1.00, $CHCl_3$). ^{1}H NMR (300 MHz, C_6D_6) δ: 8.32–8.29 (2H, m), 8.18–8.15 (2H, m), 7.36–7.33 (2H, m), 7.25–7.21 (2H, m), 7.14–6.97 (22H, m), 5.29 (1H, d, $J_{1'a,1'b}$ = 11.4 Hz, H-1′a), 5.14 (1H, d, $J_{1,2}$ = 7.3 Hz, H-1), 4.97 (1H, d, $J_{1'a,1'b}$ = 11.4 Hz, H-1′b), 4.95 (1H, d, $J_{3',4'}$ = 5.9 Hz, H-3′), 4.86–4.67 (7H, m), 4.62 (1H, dd, $J_{3',4'}$ = 5.9, $J_{4',5'}$ = 1.7 Hz, H-4′), 4.52 (1H, d, *J* = 11.6 Hz, C*H*HPh), 4.44 (1H, dd, *J* = 9.0, 5.0 Hz), 4.38 (1H, d, *J* = 11.9 Hz, C*H*HPh), 4.23 (1H, d, *J* = 11.9 Hz, C*H*HPh), 3.76–3.70 (1H, m), 3.65–3.56 (4H, m), 3.22 (1H, ddd, $J_{4,5}$ = 9.7, $J_{5,6a}$ = 2.9, $J_{5,6b}$ = 2.2 Hz, H-5), 1.36 (3H, s), 1.15 (3H, s). ^{13}C NMR (75 MHz, $CDCl_3$) d: 166.0, 165.7, 138.4,

138.1, 133.0, 132.6, 130.4, 129.8, 129.7, 128.3, 128.3, 128.2, 128.2, 128.1, 128.0, 127.9, 127.8, 127.7, 127.6, 127.5, 127.5, 127.4, 127.1, 113.4, 109.4, 95.3, 85.6, 85.5, 85.1, 82.0, 82.0, 77.6, 75.6, 75.3, 75.0, 74.7, 73.2, 68.6, 64.6, 63.5, 26.6, 25.3. IR (film) cm^{-1}: 2870, 1723, 1602, 1496, 1453, 1383, 1273, 1070, 1027, 871, 752, 711. MS (FAB) *m*/*z*: 973 $(M+Na)^+$. HR-MS (FAB) *m*/*z*: 973.3771 (calcd for $C_{57}H_{58}O_{13}Na$: 973.3775).

4.4. Synthesis of (+)-sucrose

4.4.1. (1,6-Di-*O*-benzoyl-β-D-psicofuranosyl) 2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside 12

A methanol (6 mL) solution of **11βα** (152 mg, 159 μmol) and *p*-toluenesulfonic acid monohydrate (90.6 mg, 477 μmol) was stirred for 42 h at room temperature. Satd aqueous $NaHCO_3$ solution was added and it was extracted with $CHCl_3$, and washed with water. The organic extracts were dried over $MgSO_4$ and concentrated to dryness, and then purified by silica gel flash chromatography eluted with 35% EtOAc in hexane to give **12** (104 mg) in 72% yield. Colorless syrup. R_f = 0.29 (40% EtOAc in hexane). $[\alpha]_D^{22} = +55.5$ (*c* 1.03, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$) δ: 8.08–8.02 (4H, m), 7.60–7.11 (26H, m), 5.52 (1H, d, $J_{1,2}$ = 3.5 Hz, H-1), 4.84–4.79 (3H, m), 4.69–4.58 (4H, m), 4.55 (1H, d, *J* = 11.9 Hz), 4.53 (1H, d, *J* = 11.6 Hz), 4.46 (1H, d, *J* = 11.9 Hz), 4.45 (1H, d, *J* = 11.0 Hz), 4.41–4.33 (3H, m), 4.30–4.25 (2H, m), 4.05 (1H, ddd, $J_{4,5}$ = 10.1, $J_{5,6b}$ = 6.2, $J_{5,6a}$ = 1.7 Hz, H-5), 3.93 (1H, t, *J* = 9.3 Hz), 3.70 (1H, dd, $J_{6a,6b}$ = 10.1, $J_{5,6a}$ = 1.7 Hz, H-6a), 3.53 (1H, dd, $J_{6a,6b}$ = 10.1, $J_{5,6b}$ = 6.2 Hz, H-6b), 3.50 (1H, dd, $J_{2,3}$ = 9.7, $J_{1,2}$ = 3.5 Hz, H-2), 3.42 (1H, dd, *J* = 10.0, 8.9 Hz), 2.60 (1H, d, *J* = 6.6 Hz, OH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 167.0, 166.3, 138.5, 137.9, 137.7, 137.4, 133.0, 129.9, 129.8, 129.6, 128.3, 128.3, 128.2, 128.1, 128.0, 127.9, 127.8, 127.8, 127.7, 127.6, 127.5, 107.3, 89.6, 81.9, 81.5, 79.0, 77.7, 75.5, 74.9, 73.7, 73.4, 72.5, 71.4, 70.9, 69.0, 65.7, 63.6. IR (film) cm^{-1}: 3458, 2922, 1715, 1601, 1495, 1453, 1275, 1068. MS (FAB) *m*/*z*: 933 $(M+Na)^+$. HR-MS (FAB) *m*/*z*: 933.3456 (calcd for $C_{54}H_{54}O_{13}Na$: 933.3462).

4.4.2. (1,4,6-Tri-*O*-benzoyl-β-D-psicofuranosyl) 2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside 13

A stirred solution of **12** (94.2 mg, 103 μmol) and di-*n*-butyltin (IV) oxide (25.6 mg, 103 μmol) in MeOH (6.9 mL) was heated at reflux temperature for 45 min. Then, BzCl (119 μL, 1.03 mmol) and triethylamine (143 μL, 1.03 mmol) were added to the mixture at 0 °C successively, and stirred for 10 min at the same temperature, then evaporated under vacuum. The residual solid was dissolved in a minimum amount of chloroform and purified by silica gel flash chromatography, eluted with 15% EtOAc in hexane to yield **13** (61.5 mg) in 59% yield. Colorless syrup. R_f = 0.61 (40% EtOAc in hexane). $[\alpha]_D^{23} = +37.5$ (*c* 0.99, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$) δ: 8.10-8.06 (4H, m), 8.02–7.98 (2H, m), 7.61–7.42 (6H, m), 7.34–7.12 (23H, m), 5.55 (1H, d, $J_{1,2}$ = 3.5 Hz, H-1), 5.49 (1H, dd, $J_{3',4'}$ = 5.4, $J_{4',5'}$ = 4.7 Hz, H-4′), 4.90 (1H, dd, $J_{3',OH}$ = 5.5, $J_{3',4'}$ = 5.4 Hz, H-3′), 4.84–4.79 (3H, m), 4.74–4.44 (10H, m), 4.20 (1H, ddd, $J_{4,5}$ = 9.8, $J_{5,6b}$ = 6.8, $J_{5,6a}$ = 1.5 Hz, H-5), 3.99 (1H, dd, $J_{2,3}$ = 9.8, $J_{3,4}$ = 9.2 Hz, H-3), 3.93 (1H, d, $J_{3',OH}$ = 5.5 Hz, O*H*), 3.74 (1H, dd, $J_{6a,6b}$ = 9.8, $J_{5,6a}$ = 1.5 Hz, H-6a), 3.50 (1H, dd, $J_{6a,6b}$ = 9.8, $J_{5,6b}$ = 6.8 Hz, H-6b), 3.48 (1H, dd, $J_{2,3}$ = 9.8, $J_{1,2}$ = 3.5 Hz, H-2), 3.38 (1H, dd, $J_{4,5}$ = 9.8, $J_{3,4}$ = 9.2 Hz, H-4). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 166.8, 166.1, 165.7, 138.5, 137.9, 137.8, 137.2, 133.4, 133.0, 132.8, 130.0, 129.9, 129.8, 129.7, 129.4, 129.2, 128.5, 128.4, 128.3, 128.2, 128.0, 127.9, 127.9, 127.9, 127.8, 127.7, 127.5, 107.8, 89.6, 82.0, 79.2, 78.8, 77.7, 75.5, 74.9, 73.4, 73.4, 72.5, 72.2, 70.9, 69.0, 65.2, 63.5. IR (film) cm^{-1}: 3440, 3030, 2923, 1723, 1601, 1495, 1452, 1315, 1271, 1070, 1026, 750, 710. MS (FAB) *m*/*z*: 1037 $(M+Na)^+$. HR-MS (FAB) *m*/*z*: 1037.3716 (calcd for $C_{61}H_{58}O_{14}Na$: 1037.3724).

4.4.3. (1,4,6-Tri-*O*-benzoyl-β-D-*erythro*-2,3-hexodiulofuranosyl) 2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside 14

To a solution of oxalyl chloride (15.9 μL, 182 μmol) in CH_2Cl_2 (1.5 mL) was dropped DMSO (25.8 μL, 364 μmol) in CH_2Cl_2 (0.2 mL) at −78 °C, and the mixture was stirred for 15 min at the same temperature. Then, a solution of **13** (61.5 mg, 60.6 μmol) in CH_2Cl_2 (1.0 mL) was added dropwise and the whole mixture was stirred for 1 h at −78 °C prior to addition of triethylamine (101 μL, 727 μmol). Satd. aqueous NH_4Cl solution was added and the mixture was extracted with EtOAc, washed with water, brine, dried over $MgSO_4$, and concentrated in vacuo. The residue was purified by flash chromatography on silica gel eluted with 15% EtOAc in hexane to give **14** (58.5 mg) in 95% yield. Colorless syrup. R_f = 0.50 (30% EtOAc in hexane). $[\alpha]_D^{23} = +98.5$ (*c* 0.68, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$) δ: 8.06–8.00 (6H, m), 7.65–7.56 (2H, m), 7.48–7.16 (27H, m), 6.33 (1H, d, $J_{4',5'}$ = 8.3 Hz, H-4), 5.69 (1H, d, $J_{1,2}$ = 3.9 Hz, H-1), 4.95 (1H, d, *J* = 10.6 Hz), 4.89–4.53 (10H, m), 4.46 (1H, d, *J* = 11.7 Hz), 4.46 (1H, d, *J* = 11.9 Hz), 3.94 (1H, dd, $J_{2,3} = J_{3,4}$ = 9.7 Hz, H-3), 3.82 (1H, dd, $J_{3,4}$ = 9.7, $J_{4,5}$ = 9.2 Hz, H-4), 3.79 (1H, dd, $J_{6a,6b}$ = 11.0, $J_{5,6a}$ = 2.0 Hz, H-6a), 3.63 (1H, ddd, $J_{4,5}$ = 9.2, $J_{5,6a}$ = 2.0, $J_{5,6b}$ = 1.8 Hz, H-5), 3.52 (1H, dd, $J_{6a,6b}$ = 11.0, $J_{5,6b}$ = 1.8 Hz, H-6b), 3.39 (1H, dd, $J_{2,3}$ = 9.7, $J_{1,2}$ = 3.9 Hz, H-2). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 205.3, 166.0, 165.0, 164.8, 138.5, 138.2, 137.5, 133.8, 133.3, 133.2, 129.9, 129.7, 129.6, 129.3, 129.1, 128.5, 128.4, 128.4, 128.3, 128.2, 128.2, 128.1, 127.9, 127.8, 127.7, 127.4, 97.7, 90.1, 81.1, 78.4, 75.9, 75.6, 75.2, 73.4, 73.4, 72.8, 71.6, 69.4, 67.4, 66.7, 63.2. IR (film) cm^{-1}: 2925, 1784, 1730, 1601, 1495, 1453, 1268, 1091, 709. MS (FAB) *m*/*z*: 1035 $(M+Na)^+$. HR-MS (FAB) *m*/*z*: 1035.3564 (calcd for $C_{61}H_{56}O_{14}Na$: 1035.3568).

4.4.4. (1,4,6-Tri-*O*-benzoyl-β-D-fructofuranosyl) 2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranoside 15

To a stirred solution of **14** (58.5 mg, 57.7 μmol) in MeOH and CH_2Cl_2 (1:1, 3.0 mL) was added $NaBH_4$ (4.4 mg, 115 μmol) at 0 °C and the mixture was stirred for 30 min at the same temperature. The mixture was diluted with water and extracted with EtOAc. Organic extract was washed with water and brine and dried over $MgSO_4$. The residue was purified by flash chromatography on silica gel (eluent: 15% EtOAc in hexane) to give **15** (55.6 mg) in 95% yield. Colorless syrup. R_f = 0.44 (30% EtOAc in hexane). $[\alpha]_D^{21} = +39.2$ (*c* 1.00, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$) δ: 8.05–7.92 (6H, m), 7.56–7.48 (2H, m), 7.45–7.31 (7H, m), 7.28–7.09 (20H, m), 5.64 (1H, d, $J_{1,2}$ = 3.9 Hz, H-1), 5.59 (1H, d, $J_{4',5'}$ = 7.2 Hz, H-4′), 4.84 (1H, d, *J* = 10.8 Hz), 4.81–4.73 (2H, m), 4.69–4.34 (11H, m), 4.13 (1H, ddd, $J_{4,5}$ = 9.9, $J_{5,6b}$ = 4.4, $J_{5,6a}$ = 2.1 Hz, H-5), 3.95 (1H, dd, $J_{2,3}$ = 9.4, $J_{3,4}$ = 9.2 Hz, H-3), 3.79 (1H, d, $J_{3',OH}$ = 9.4 Hz, OH), 3.64 (1H, dd, $J_{6a,6b}$ = 10.7, $J_{5,6a}$ = 2.1 Hz, H-6a), 3.60 (1H, dd, $J_{6a,6b}$ = 10.7, $J_{5,6b}$ = 4.4 Hz, H-6b), 3.55 (1H, dd, $J_{4,5}$ = 9.9, $J_{3,4}$ = 9.2 Hz, H-4), 3.51 (1H, dd, $J_{2,3}$ = 9.9, $J_{1,2}$ = 3.9 Hz, H-2). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 166.0, 165.9, 165.7, 138.4, 138.0, 137.6, 137.4, 133.4, 133.2, 132.9, 129.8, 129.7, 129.7, 129.6, 129.5, 129.0, 128.4, 128.4, 128.3, 128.2, 128.1, 127.9, 127.9, 127.8, 127.7, 127.6, 104.4, 91.2, 81.7, 78.6, 77.9, 77.9, 77.5, 77.1, 75.6, 75.0, 73.4, 73.2, 71.5, 68.3, 64.8, 64.1. IR (film) cm^{-1}: 3459, 2925, 1730, 1602, 1495, 1453, 1272, 1070, 698. MS (FAB) *m*/*z*: 1037 $(M+Na)^+$. HR-MS (FAB) *m*/*z*: 1037.3733 (calcd for $C_{61}H_{58}O_{14}Na$: 1037.3724).

4.4.5. (1,3,4,6-Tetra-*O*-acetyl-β-D-fructofuranosyl) 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranoside 16

Metal Na (approximately 60 mg) was added to liquid ammonia (2 mL) at −78 °C. To the resultant dark blue solution was added **15** (54.2 mg, 53.3 mmol) in THF (2 mL) solution and stirred for 30 min at the same temperature. The reaction was quenched with acetic acid (0.5 mL) and MeOH (2 mL) at −78 °C and evaporated. The residue obtained after removal of the solvent was dissolved in

pyridine (10 mL), and acetic anhydride (3 mL) and DMAP (10 mg) were added. The reaction was stirred overnight and evaporated under reduced pressure. The crude product was purified by flash chromatography on silica gel eluted with 50% EtOAc in hexane to give **16** (34.9 mg) in 96% yield. Colorless syrup. $R_f = 0.53$ (60% EtOAc in hexane). $[\alpha]_D^{23} = +58$ (*c* 2.36, $CHCl_3$) lit.[6b] $[\alpha]_D^{23} = +60$ (*c* 1.0, $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$) δ: 5.67 (1H, d, $J_{1,2} = 3.7$ Hz, H-1), 5.44 (1H, d, $J_{3',4'} = 5.7$ Hz, H-3′), 5.43 (1H, dd, $J_{2,3} = 10.5$, $J_{3,4} = 9.5$ Hz, H-3), 5.36 (1H, dd, $J_{4',5'} = 5.9$, $J_{3',4'} = 5.7$ Hz, H-4′), 5.06 (1H, dd, $J_{4,5} = 10.1$, $J_{3,4} = 9.5$ Hz, H-4), 4.86 (1H, dd, $J_{2,3} = 10.5$, $J_{1,2} = 3.7$ Hz, H-2), 4.37–4.07 (8H, m), 2.16 (3H, s), 2.10 (3H, s), 2.10 (3H, s), 2.10 (3H, s), 2.09 (3H, s), 2.09 (3H, s), 2.03 (3H, s), 2.01 (3H, s). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 170.5, 170.3, 169.9 (2C), 169.8, 169.7, 169.5, 169.3, 103.8, 89.7, 78.9, 75.5, 74.8, 70.1, 69.4, 68.3, 68.0, 63.5, 62.7, 61.6, 20.5–20.4 (8C). The spectroscopic data described above show the same value as those reported in the literature.[6]

4.4.6. Sucrose 1

To a stirred solution of **16** (34.9 mg, 51.4 mmol) in MeOH (1.0 mL) was dropped a solution of NaOMe in MeOH (1.0 M, 10 mL). The reaction mixture was stirred for 3 h at rt. Amberlite IRC-50 was added and the mixture was stirred for 10 min. Then, water was added and resin was removed by filtration. The filtrate was lyophilized to afford **1** (15.8 mg) in 90% yield as a white powder. $[\alpha]_D^{23} = +64.5$ (*c* 1.1, H_2O) lit.[4a] $[\alpha]_D^{23} = +66.7$ (*c* 1.0, H_2O).

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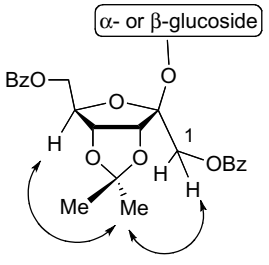
15. As described below, NOEs were observed between one of the CH_2 protons at C-1 and one of the Me groups located inside



11βα or **11ββ**

the ring and also between the CH proton at C-5 and the same Me group in the proton NMR of **11βα** and **11ββ**.
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