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Note

Synthesis of a tetrasaccharide fragment of mycobacterial arabinogalactan

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Abstract—The arabinogalactan of mycobacteria contains both monosaccharides in the furanose ring form, which are absent in mammals. We report here the first synthesis of the tetrasaccharide fragment α-D-Ara*f*-(1→5)-β-D-Gal*f*-(1→5)-β-D-Gal*f*-(1→6)-D-Gal*f*, conveniently derivatized for further elongation. The strategy relied on the use of suitably substituted D-galactono-1,4-lactones as precursors for the galactofuranose units. Reduction of lactone tetrasaccharide **9** with disiamylborane afforded the tetrasaccharide synthon **1**. The tetrasaccharide contains the linker unit of the arabinan to the galactan.

Keywords: Mycobacteria; Arabinogalactan; Galactofuranose; Arabinofuranose; Galactonolactone

Mycobacterium tuberculosis, the most studied species of mycobacteria, has received much attention in the last years.[1] The appearance of multidrug-resistant strains points to the search of new targets for chemotherapy.[2] The integrity of mycobacterial cell wall is essential for the viability of mycobacteria.[3] A major structure component of the cell wall is an arabinogalactan.[4] This polysaccharide, entirely formed by furanose residues, is a good candidate for carbohydrate-based vaccines, because the furanose constituents are absent in mammals. Also, synthesis of the oligosaccharides is an attractive challenge for carbohydrate chemists, considering the lability of the furanosidic as compared to pyranosidic linkages. All the galactofuranoses are β-linked in the galactan. However, the α-D-arabinan chains are substituted at nonreducing ends with units of β-D-Ara*f*. A domain of 22 Ara*f* residues has been recently synthesized by Lowary and co-workers.[5] Several reports from other and our laboratories described the chemical synthesis of the galactan fragments.[6–9] Few reports on the synthesis of oligosaccharides containing both units have been published. In this regard, we have recently synthesized the disaccharide linker unit of the arabinan to the galactan,[10] and glycosides of the disaccharide were also synthesized.[11] The synthesis of the branched trisaccharide α-D-Ara*f*-(1→5)-[β-D-Gal*f*-(1→6)]-D-Gal*f* was reported by two groups.[12,13] We now describe the preparation for the first time of tetrasaccharide α-D-arabinofuranosyl-(1→5)-β-D-galactofuranosyl-(1→5)-β-D-galactofuranosyl-(1→6)-D-galactofuranose **1** conveniently derivatized for further elongation of the chain. Synthetic oligosaccharide fragments of the mycobacterial cell wall are useful for studies on the biosynthetic pathways used for polysaccharide assembly. Thus, by using the galactofuranose trisaccharides containing β-(1→6) and β-(1→5) linkages the characterization of a bifunctional galactofuranosyl transferase was possible.[14] Very recently,[15] the galactofuranosyl transferase (GlfT1) responsible for attaching the first unit of Gal*f* to decaprenyl-P-P-GlcNAc-Rha was characterized using synthetic acceptors.

Our synthetic strategy relied on the glycosyl aldonolactone approach[6–8,16] for the introduction of the galactofuranose residues. Thus, after glycosylation, the lactone disaccharide is selectively reduced with diisoamylborane (DSB) followed by further activation of the anomeric

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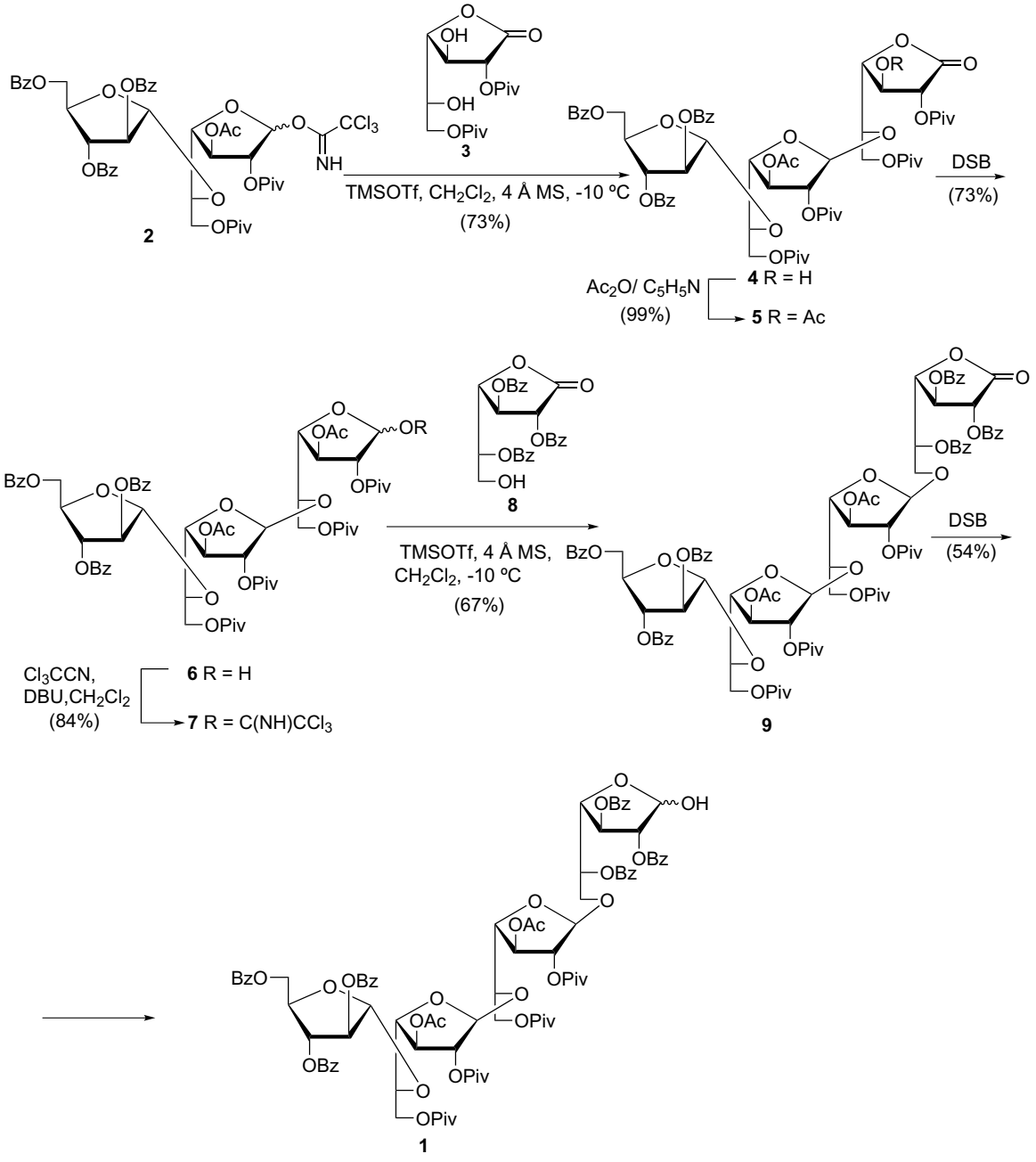
center. The synthesis began with disaccharide imidate **2**, which was recently described[10] (Scheme 1). For the introduction of the terminal nonreducing arabinofuranose in **2**, tin(IV) chloride-promoted glycosylation has been conveniently used.[10] Elongation of the chain with galactofuranoses was achieved using the milder trichloroacetimidate method.[8,17] D-Galactono-1,4-lactone, besides being a stable precursor for the reducing sugar, can be selectively substituted by acylation reactions.[18] Thus, 2,6-di-*O*-pivaloyl-D-galactono-1,4-lactone (**3**),[8] obtained in one step from D-galactono-1,4-lactone, was used for the introduction of the two internal galactose residues in **1** (Scheme 1). For the incorporation of the galactose in the reducing end, the easily obtained 2,3,5-tri-*O*-benzoyl-D-galactono-1,4-lactone (**8**)[16] was used as the precursor.

Selective glycosylation of the exocyclic OH-5 of lactone derivative **3** with **2** gave trisaccharide lactone **4** in 74% yield after purification by column chromatography. The same regioselectivity was found on glycosylation of the lactone with other imidates[8] or by using the perbenzoyl sugar and tin(IV) chloride as promoter.[10] The structure of **4** was confirmed by one- and two-dimensional NMR spectroscopy. The ^{13}C NMR spectrum



Scheme 1.

showed C-1″ and C-1′ at 106.1 and 105.6 ppm, characteristic of α-D-arabinofuranosyl and β-D-galactofuranosyl linkages. In the ^{1}H NMR spectrum, H-1″ and H-1′ appeared as broad singlets at 5.64 and 5.21 ppm and H-2″ and H-2′ as doublets, with $J_{2,3} < 1.5$ Hz, at 5.38 and 5.13 ppm. Acetylation of compound **4** at OH-3 was performed before reduction of the lactone to sugar **6**. In the ^{1}H NMR spectrum of **5**, the signal of H-3 was shifted ≈1 ppm downfield with respect to **4**. Reduction of the trisaccharide lactone derivative **5** with DSB yielded the furanosidic derivative **6** as a 4.6:5.4 α:β anomeric mixture as indicated by the ^{1}H NMR spectrum. The anomeric protons appeared at 5.34 (H-1β) as a doublet ($J = 3.6$ Hz) and at 5.44 ppm as a doublet of doublets (H-1α, $J = 4.8$, 9.4 Hz). After D_2O exchange, the signal for H-1b appeared as a broad singlet and the signal for H-1a was simplified to a doublet ($J = 4.8$ Hz). The ^{13}C NMR spectrum showed all the anomeric signals for both anomers, and could be assigned with the aid of COSY and HSQC experiments. The anomeric carbons for the reducing unit appeared at 100.4 (C-1β) and 95.0 ppm (C-1α).

Activation of the anomeric center in **6** was performed by the trichloroacetimidate method.[19] Imidate **7** was obtained as a 1:9 α:β mixture in 84% yield, by treatment of **6** with Cl_3CCN and DBU. Glycosylation of **7** with the lactone derivative **8** afforded the tetrasaccharide lactone **9** in 73% yield. Formation of the new β-galactofuranoside linkage was indicated by the ^{1}H NMR spectrum of **9**. The H-1′ appeared as a singlet at 5.05 ppm and a doublet was observed at 6.08 ppm with $J_{2,3} = 5.8$ Hz characteristic of the H-2 for acylated D-galactono-1,4-lactone. Reduction of the tetrasaccharide lactone **9** afforded the furanose derivative **1** in 54% yield. The ^{13}C NMR spectrum of **1** showed the signals for the two anomers at 100.5 ppm (C-1β) and 95.3 ppm (C-1α).

In summary, we have constructed a synthon containing the two galactofuranosyl linkages present in the arabinogalactan, substituted at the nonreducing end by a D-arabinofuranose unit. Once again, we proved the efficiency of the glycosyl-lactone approach followed by DSB reduction. Synthon **1** is very appropriate for further coupling as subsequent deprotection could be achieved in one step.

1. Experimental

1.1. General methods

Melting points were determined with a Thomas-Hoover apparatus and are uncorrected. Optical rotations were measured with a Perkin–Elmer 343 polarimeter at 25 °C. TLC was performed on 0.2 mm Silica Gel 60 F254 (Merck) aluminum-supported plates. Detection was effected by exposure to UV light or by spraying with 5% (v/v) sulfuric acid in EtOH and charring. Column chromatography was performed on Silica Gel 60 (230–400 mesh, Merck). NMR spectra were recorded with a Bruker AVANCE II 500 spectrometer at 500 MHz (^{1}H) and 125.8 MHz (^{13}C), or with a Bruker AC 200 at 200 MHz (^{1}H) and 50.3 MHz (^{13}C). Chemical shifts are given relative to the signal of internal acetone standard at 2.16 ppm and 30.8 ppm for ^{1}H NMR and ^{13}C NMR spectra when recorded in D_2O. ^{1}H and ^{13}C assignments were supported by DEPT 135, homonuclear COSY and HSQC experiments. High resolution mass spectra (HRMS) were recorded on Agilent LCTOF (2006) equipped with a high resolution TOF analyzer with Windows XP based OS and APCI/ESI ionization.

1.2. 2,3,5-Tri-*O*-benzoyl-α-D-arabinofuranosyl-(1→5)-3-*O*-acetyl-2,6-di-*O*-pivaloyl-β-D-galactofuranosyl-(1→5)-2,6-di-*O*-pivaloyl-D-galactono-1,4-lactone (4)

A vigorously stirred solution of dried trichloroacetimidate **2**[10] (1.07 g, 1.09 mmol), 2,6-di-*O*-pivaloyl-D-galactono-1,4-lactone (**3**,[8] 486 mg, 1.40 mmol), and activated 4 Å powdered molecular sieves (0.7 g) in anhyd CH_2Cl_2 (60 mL) was cooled to −10 °C, and TMSOTf (79 μL, 0.44 mmol) was slowly added. After 1 h of stirring, the mixture was filtered into satd aq $NaHCO_3$ (150 mL) and then extracted with CH_2Cl_2 (2 × 200 mL). The organic layer was washed with water (3 × 150 mL), dried (Na_2SO_4), filtered, and concentrated under reduced pressure. The residue was purified by column chromatography (15:1 toluene–EtOAc) affording 2,3,5-tri-*O*-benzoyl-α-D-arabinofuranosyl-(1→5)-3-*O*-acetyl-2,6-di-*O*-pivaloyl-β-D-galactofuranosyl-(1→5)-2,6-di-*O*-pivaloyl-D-galactono-1,4-lactone (**4**, 933 mg, 73%) as a syrup: $R_f = 0.37$ (5:1, toluene–EtOAc); $[\alpha]_D$ −29.7 (*c* 1.0, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 500 MHz): δ 8.08–8.04 (m, 15H, aromatic), 5.65 (dd, 1H, $J = 1.2$, 5.0 Hz, H-3″), 5.64 (br s, 1H, H-1″), 5.56 (d, 1H, $J = 8.7$ Hz, H-2), 5.38 (d, 1H, $J = 1.2$ Hz, H-2″), 5.21 (br s, 1H, H-1′), 5.18 (dd, 1H, $J = 1.3$, 4.2 Hz, H-3′), 5.13 (d, 1H, $J = 1.3$ Hz, H-2′), 4.83 (dt, 1H, $J = 4.2$, 8.2 Hz, H-3), 4.80 (dd, 1H, $J = 3.5$, 11.4 Hz, H-5a″), 4.77 (d, 1H, $J = 4.2$ Hz, OH), 4.75 (m, 1H, H-4″), 4.69 (dd, 1H, $J = 4.7$, 11.4 Hz, H-5b″), 4.49 (dd, 1H, $J = 5.6$, 14.0 Hz, H-6a′), 4.42 (dd, 1H, $J = 4.2$, 7.1 Hz, H-4′), 4.33 (dd, 1H, $J = 4.3$, 7.7 Hz, H-4), 4.32–4.30 (m, 2H, H-6a, H-6b), 4.19–4.13 (m, 3H, H-5, H-5′, H-6b′), 2.07 (s, 3H, CH_3), 1.19, 1.18, 1.17, 1.16 (4s, 36H, $(CH_3)_3CCO$); ^{13}C NMR ($CDCl_3$, 125.8 MHz): δ 178.2, 177.8, 177.4, 176.7 ($(CH_3)_3C\mathit{C}O$), 170.0 (C-1), 168.9–165.7 ($CH_3\mathit{C}O$ and $\mathit{C}O$Ph), 134.4–128.2 (aromatic), 106.1 (C-1″), 105.6 (C-1′), 84.9 (C-4′), 83.2 (C-2″), 80.9 (C-4″), 80.2 (C-2′), 79.2 (C-4), 77.4 (C-3″), 76.2 (C-3′), 75.5 (C-5′or C-5), 75.0 (C-2), 72.2 (C-5 or C-5′), 71.4 (C-3), 64.2 (C-6′), 63.5 (C-5″), 63.0 (C-6), 38.7

((CH_3)$_3$*C*CO × 4), 27.1, 27.0, 26.9, 26.8 ((CH_3)$_3$CCO), 20.6 (CH_3); HRMS (ESI/APCI) *m*/*z*: $[M+Na]^+$ calcd for $C_{60}H_{74}O_{23}Na$, 1185.4519; found, 1185.4495.

1.3. 2,3,5-Tri-*O*-benzoyl-α-D-arabinofuranosyl-(1→5)-3-*O*-acetyl-2,6-di-*O*-pivaloyl-β-D-galactofuranosyl-(1→5)-3-*O*-acetyl-2,6-di-*O*-pivaloyl-D-galactono-1,4-lactone (5)

To a solution of **4** (894 mg, 0.77 mmol) in dry pyridine (6.1 mL), cooled at 0 °C, was added Ac_2O (6.1 mL) dropwise and the mixture was stirred at room temperature for 30 min. After cooling to 0 °C, the reaction was quenched by the slow addition of MeOH (2.3 mL) and the stirring continued for 30 min at room temperature. The solution was diluted with CH_2Cl_2 (150 mL) and then sequentially washed with 10% HCl (2 × 150 mL), water (150 mL), satd aq $NaHCO_3$ (150 mL), water (2 × 150 mL), dried (Na_2SO_4), filtered, and then concentrated to give **5** (915 mg, 99%) as a chromatographically pure syrup; $R_f = 0.48$ (5:1, toluene–EtOAc); $[\alpha]_D$ −40.2 (*c* 1.0, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 500 MHz) *δ*: 8.07–7.16 (m, 15H, aromatic), 5.80 (t, 1H, *J* = 8.0 Hz, H-3), 5.67 (d, 1H, *J* = 8.0 Hz, H-2), 5.61 (s, 1H, H-1″), 5.58 (dd, 1H, *J* = 1.2, 4.7 Hz, H-3″), 5.51 (d, 1H, *J* = 1.2 Hz, H-2″), 5.22 (s, 1H, H-1′), 5.20 (dd, 1H, *J* = 1.7, 5.0 Hz, H-3′), 5.13 (d, 1H, *J* = 1.7 Hz, H-2′), 4.79 (dd, 1H, *J* = 3.0, 11.2 Hz, H-5a″), 4.71 (ddd, 1H, *J* = 3.0, 4.7, 5.0 Hz, H-4″), 4.68 (dd, 1H, *J* = 5.0, 11.2 Hz, H-5b″), 4.51 (dd, 1H, *J* = 3.5, 7.7 Hz, H-4), 4.48 (dd, 1H, *J* = 5.0, 7.0 Hz, H-4′), 4.40 (dd, 1H, *J* = 3.0, 11.7 Hz, H-6a′), 4.36 (dd, 1H, *J* = 3.7, 10.7 Hz, H-6a), 4.24 (m, 1H, H-5), 4.22 (dd, 1H, *J* = 6.1, 10.7 Hz, H-6b), 4.18 (ddd, 1H, *J* = 3.0, 6.2, 7.0 Hz, H-5′), 4.12 (dd, 1H, *J* = 6.2, 11.7 Hz, H-6b′); 2.10, 2.03 (2s, 6H, CH_3); 1.17, 1.16, 1.15, 1.14 (4s, 36H, (CH_3)$_3$CCO); ^{13}C NMR ($CDCl_3$, 125.8 MHz) *δ*: 178.0, 177.7, 177.0, 176.8 ((CH_3)$_3$C*C*O), 170.0 (C-1); 169.4, 168.0 (CH_3*C*O), 166.1–165.2 (*C*OPh), 137.8–128.2 (aromatic), 106.0 (C-1″), 104.4 (C-1′), 83.5 (C-4′), 82.0 (C-2″), 81.2 (C-4″), 80.0 (C-2′), 77.8 (C-3″), 77.0 (C-4), 76.5 (C-3′), 75.0 (C-5′), 72.2 (C-2), 72.0 (C-3), 71.2 (C-5), 64.2 (C-6′), 63.6 (C-5″), 62.2 (C-6); 38.7, 38.6, 38.5 ((CH_3)$_3$*C*CO); 27.1, 27.0, 26.9, 26.8 ((CH_3)$_3$CCO); 20.7, 20.4 (CH_3); HRMS (ESI/APCI) *m*/*z*: $[M+Na]^+$ calcd for $C_{62}H_{76}O_{24}Na$, 1227.4624; found, 1227.4597.

1.4. 2,3,5-Tri-*O*-benzoyl-α-D-arabinofuranosyl-(1→5)-3-*O*-acetyl-2,6-di-*O*-pivaloyl-β-D-galactofuranosyl-(1→5)-3-*O*-acetyl-2,6-di-*O*-pivaloyl-D-galactofuranose (6)

A solution of bis(2-butyl-3-methyl)borane (2.3 mmol) in anhyd THF (0.63 mL) cooled to 0 °C and under an argon atmosphere was added to a flask containing compound **5** (148 mg, 0.12 mmol) previously dried. The resulting solution was stirred for 22 h at room temperature and then processed as previously described.[20] The organic layer was washed with water, dried (Na_2SO_4), and concentrated. Boric acid was eliminated by coevaporation with MeOH (5 × 3 mL) at room temperature. The residue was purified by column chromatography (7:1, toluene–EtOAc) to give 107 mg (73%) of syrupy **6** as a 0.46:0.54 α/β anomeric mixture: $R_f = 0.43$ (3:1, toluene–EtOAc); $[\alpha]_D$ −17.3 (*c* 1.0, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 500 MHz), only the assigned *δ* are listed: 5.66 (br s, 0.46H, H-1″ α anomer), 5.64 (br s, 0.54H, H-1″ β anomer), 5.61 (dd, 0.54H, *J* = 1.4, 4.8 Hz, H-3″), 5.58 (dd, 0.46H, *J* = 1.2, 4.8 Hz, H-3″), 5.56 (d, 0.46H, *J* = 1.2 Hz, H-2″), 5.55 (d, 0.56H, *J* = 1.4 Hz, H-2″), 5.44 (dd, 0.46H, *J* = 4.8, 9.4 Hz, H-1 α anomer), 5.34 (d, 0.54H, *J* = 3.6 Hz, H-1 β anomer), 5.32 (br s, 0.46H, H-1′), 5.25 (m, 0.56H, H-3′), 5.23 (br s, 0.56H, H-1′), 5.21 (dd, 0.46H, *J* = 2.0, 6.5 Hz, H-3′), 3.86 (d, 1H, *J* = 9.4 Hz, OH), 3.81 (d, 1H, *J* = 3.6 Hz, OH); ^{13}C NMR ($CDCl_3$, 125.8 MHz): *δ* 178.2, 177.9, 177.6, 176.9 ((CH_3)$_3$C*C*O), 170.0, 169.9, 169.8, 169.7 (CH_3*C*O), 166.1–165.6 (*C*OPh), 133.6–129.0 (aromatic), 106.1 (C-1″ α anomer), 106.0 (C-1″ β anomer), 105.2 (C-1′ β anomer), 105.1 (C-1′ α anomer), 100.4 (C-1 β anomer), 95.0 (C-1 α anomer), 82.9, 82.2, 82.3, 81.6, 81.5, 81.4, 81.2, 81.0, 79.7, 77.9, 77.8, 77.7, 76.8, 76.5, 76.0, 75.1, 74.9, 74.8, 73.5, 64.4, 64.2, 63.7, 63.6, 63.5, 63.3, 38.7, 38.6 ((CH_3)$_3$*C*CO); 27.1, 27.0, 26.9 ((CH_3)$_3$CCO); 20.7, 20.6 (CH_3); HRMS (ESI/APCI) *m*/*z*: $[M+Na]^+$ calcd for $C_{62}H_{78}O_{24}Na$, 1229.4781; found, 1229.4758.

1.5. 2,3,5-Tri-*O*-benzoyl-α-D-arabinofuranosyl-(1→5)-3-*O*-acetyl-2,6-di-*O*-pivaloyl-β-D-galactofuranosyl-(1→5)-3-*O*-acetyl-2,6-di-*O*-pivaloyl-β-D-galactofuranosyl-(1→6)-2,3,5-tri-*O*-benzoyl-D-galactono-1,4-lactone (9)

To a stirred solution of **6** (86 mg, 0.071 mmol) and trichloroacetonitrile (0.036 mL, 0.36 mmol) in CH_2Cl_2 (5 mL), cooled to 0 °C, DBU (5 mL, 0.036 mmol) was slowly added. After 1 h, TLC monitoring showed the consumption of the starting material. The solution was concentrated at room temperature under reduced pressure, and the residue was purified by column chromatography (20:1:0.21, toluene–EtOAc–TEA) to give *O*-(2,3,5-tri-*O*-benzoyl-α-D-arabinofuranosyl-(1→5)-3-*O*-acetyl-2,6-di-*O*-pivaloyl-β-D-galactofuranosyl-(1→5)-3-*O*-acetyl-2,6-di-*O*-pivaloyl-β-D-galactofuranosyl) trichloroacetimidate (**7**, 80.2 mg, 84%) as a syrup. Compound **7** was stable for 1 day at −20 °C: $R_f = 0.60$ (β-anomer), 0.50 (α-anomer) (5:1:0.06, toluene–EtOAc–TEA); ^{1}H NMR ($CDCl_3$, 200 MHz) *δ* for the β anomer: 8.72 (s, 0.1H, N*H* α anomer), 8.59 (s, 0.9H, N*H*), 8.08–7.15 (m, 15H, aromatic), 6.51 (d, 0.1H, *J* = 4.0 Hz, H-1 α anomer), 6.25 (s, 0.9H, H-1 β anomer), 5.62 (br s, 0.9H, H-1″), 5.60 (m, 0.9H, H-3″), 5.52 (d, 0.9H, *J* = 1.2 Hz, H-2″), 5.36–5.31 (m, 1.8H,

H-3′, H-1′), 5.26–5.24 (m, 1.8H, H-2, H-3), 5.15 (d, 0.9H, $J = 1.6$ Hz, H-2″), 4.84–4.64 (m, 3H, H-4″, H-5a″, H-5b″), 4.50–4.13 (m, 8H, H-4, H-4′, H-5, H-5′, H-6a, H-6b, H-6a′, H-6b′); 2.06, 2.02 (2s, 6H, CH_3); 1.26, 1.23, 1.18, 1.17 (4s, 36H, $(CH_3)_3CCO$); ^{13}C NMR ($CDCl_3$, 50.3 MHz) δ for the β anomer: 178.0, 176.9 ($(CH_3)_3CCO$); 170.0, 169.6 (CH_3CO), 166.1–165.1 (*C*OPh), 160.1 ($NHCOCl_3$), 133.5–125.2 (aromatic), 105.6 (C-1″ β anomer), 104.6 (C-1′ β anomer), 102.7 (C-1 β anomer), 90.8 (C-1 α anomer), 84.8, 83.3, 82.1, 81.5, 81.4, 81.3, 81.1, 80.4, 77.8, 76.7, 75.5, 74.0, 72.0, 64.2, 63.6, 63.5, 28.7, 38.6, 38.5 ($(CH_3)_3$-*C*CO); 27.1, 27.0, 26.9, 26.8 ($(CH_3)_3CCO$); 20.7, 20.5 (CH_3).

A vigorously stirred suspension of dried trichloroacetimidate **7** (55 mg, 0.040 mmol), 2,3,5-tri-*O*-benzoyl-D-galactono-1,4-lactone (**8**,[16] 24 mg, 0.048 mmol), and dried 4 Å powdered molecular sieves (0.2 g) in anhyd CH_2Cl_2 (4 mL) was cooled to −15 °C. After 10 min of stirring, TMSOTf (3 μL, 0.016 mmol) was slowly added. After 1 h, TLC monitoring showed the consumption of imidate **7**, the mixture was rapidly filtered into satd aq $NaHCO_3$ (25 mL) and then extracted with CH_2Cl_2 (2 × 25 mL). The organic phase was separated and washed with water (3 × 50 mL), dried ($MgSO_4$), and concentrated. The oily residue was purified by column chromatography (12:1, toluene–EtOAc) to give 44 mg of **9** (67% yield) as an amorphous solid: $R_f = 0.69$ (4:1, toluene–EtOAc); $[\alpha]_D$ −27.2 (*c* 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$, 500 MHz): δ 8.02–7.16 (m, 30H, aromatic), 6.08 (d, 1H, $J = 5.8$ Hz, H-2), 5.82 (t, 1H, $J = 5.5$ Hz, H-3), 5.76 (ddd, 1H, $J = 2.2$, 6.2, 7.7 Hz, H-5), 5.64 (s, 1H, H-1‴), 5.60 (dd, 1H, $J = 1.2$, 4.8 Hz, H-3‴), 5.52 (d, 1H, $J = 1.2$ Hz, H-2‴), 5.31–5.29 (m, 2H, H-3″, H-1″), 5.26 (dd, 1H, $J = 1.6$, 5.5 Hz, H-3′), 5.17 (d, 1H, $J = 1.6$ Hz, H-2′), 5.06 (dd, 1H, $J = 2.2$, 5.5 Hz, H-4), 5.05 (br s, 1H, H-1′), 5.02 (d, 1H, $J = 2.1$ Hz, H-2″), 4.80 (dd, 1H, $J = 3.4$, 11.5 Hz, H-5a‴), 4.72 (m, 1H, H-4‴), 4.67 (dd, 1H, $J = 4.7$, 11.5 Hz, H-5b‴), 4.42 (t, 1H, $J = 5.5$ Hz, H-4′), 4.40–4.33 (m, 2H, H-6a′, H-6a″), 4.30 (dd, 1H, $J = 3.7$, 6.1 Hz, H-4″), 4.27 (m, 1H, H-5″), 4.25–4.17 (m, 3H, H-5′, H-6b′, H-6b″), 4.03 (dd, 1H, $J = 7.7$, 10.3 Hz, H-6a), 3.92 (dd, 1H, $J = 6.2$, 10.3 Hz, H-6b); 2.03, 1.94 (2s, CH_3); 1.16, 1.13, 1.12 (4s, 36H, $(CH_3)_3CCO$); ^{13}C NMR ($CDCl_3$, 125.8 MHz) δ: 177.8, 177.3 ($(CH_3)_3CCO$); 170.0, 169.7 (CH_3CO), 168.9 (C-1), 165.7–165.1 (*C*OPh), 137.8–128.3 (aromatic), 106.1 (C-1‴), 105.4 (C-1″), 104.5 (C-1′), 82.1 (C-2‴), 82.0 (C-4′), 81.5 (C-2″), 81.4 (C-2′), 81.2 (C-4″), 81.1 (C-4‴), 78.9 (C-4), 77.8 (C-3‴), 76.8 (C-3′), 75.8 (C-3″), 74.5 (C-5″), 74.1 (C-3), 72.4 (C-2), 71.4 (C-5′), 70.1 (C-5), 64.2, 63.8 (C-6′, C-6″), 63.6 (C-5‴, C-6); 38.6, 38.5 ($(CH_3)_3CCO$); 27.1, 27.0, 26.9, 26.8 ($(CH_3)_3CCO$); 20.7, 20.5 (CH_3); HRMS (ESI/APCI) *m*/*z*: $[M+Na]^+$ calcd for $C_{89}H_{98}O_{32}Na$, 1701.5939; found, 1701.5944.

1.6. 2,3,5-Tri-*O*-benzoyl-α-D-arabinofuranosyl-(1→5)-3-*O*-acetyl-2,6-di-*O*-pivaloyl-β-D-galactofuranosyl-(1→5)-3-*O*-acetyl-2,6-di-*O*-pivaloyl-β-D-galactofuranosyl-(1→6)-2,3,5-tri-*O*-benzoyl-D-galactose (1)

Lactone **9** (26 mg, 0.015 mmol) was reduced with a solution of bis(2-butyl-3-methyl)borane (2.16 mmol) in anhyd THF (0.63 mL) as described for compound **5**. Purification by column chromatography (3:1, hexane–EtOAc) gave 14 mg (54%) of syrupy **1** as a 0.1:0.9 α/β anomeric mixture: $R_f = 0.63$ (4:1, toluene–EtOAc); $[\alpha]_D$ −30.6 (*c* 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$, 500 MHz) δ for the β anomer: 8.06–7.21 (m, 30H, aromatic), 5.78–5.71 (m, 1H, H-5, H-1 α anomer), 5.72 (d, 0.9H, $J = 4.6$ Hz, H-1 β anomer), 5.66 (br s, 0.9H, H-1‴), 5.59 (dd, 0.9H, $J = 1.4$, 5.0 Hz, H-3‴), 5.54 (d, 0.9H, $J = 1.2$ Hz, H-2), 5.51 (dd, 0.9H, $J = 1.2$, 5.5 Hz, H-3), 5.48 (d, 0.9H, $J = 1.4$ Hz, H-2‴), 5.38 (br s, 0.9H, H-1″), 5.25 (dd, 0.9H, $J = 1.9$, 6.0 Hz, H-3″), 5.23 (dd, 0.9H, $J = 1.9$, 6.0 Hz, H-3′), 5.18 (d, 0.9H, $J = 1.9$ Hz, H-2′), 5.04 (d, 0.9H, $J = 1.9$ Hz, H-2″), 4.98 (s, 0.9H, H-1′), 4.91 (d, 0.9H, $J = 4.6$ Hz, OH), 4.82 (dd, 0.9H, $J = 3.4$, 11.5 Hz, H-5a‴), 4.79 (dd, 0.9H, $J = 1.9$, 5.5 Hz, H-4), 4.74–4.67 (m, 1.8H, H-4‴, H-6a′ or H-6a″), 4.68 (dd, 0.9H, $J = 4.6$, 11.5 Hz, H-5b‴), 4.46 (t, 0.9H, $J = 5.7$ Hz, H-4′), 4.41 (dd, 0.9H, $J = 3.4$, 6.0 Hz, H-4″), 4.33–4.27 (m, 2.7H, H-5′, H-5″, H-6a″ or H-6a′), 4.21–4.15 (m, 1.8H, H-6b′, H-6b″), 4.07 (t, 0.9H, $J = 8.4$ Hz, H-6a), 4.78 (dd, 0.9H, $J = 5.6$, 8.3 Hz, H-6b); 2.04, 1.83 (2s, 5.4H, CH_3); 1.18, 1.17, 1.13, 1.11 (4s, 32.4H, $(CH_3)_3CCO$); ^{13}C NMR ($CDCl_3$, 125.8 MHz) δ for the β anomer: 178.2, 177.0 ($(CH_3)_3CCO$), 169.8 ($CH_3CO \times 2$), 168.9 (C-1), 166.7–164,1 (*C*OPh), 137.8–128.3 (aromatic), 105.9 (C-1‴), 104.0 (C-1′, C-1″), 100.5 (C-1), 95.3 (C-1α anomer), 83.4 (C-2‴), 82.1 (C-2), 81.9, 81.8 (C-4′, C-4″), 81.6 (C-2′, C-2″, C-4‴), 80.5 (C-4), 78.0 (C-3‴), 77.6 (C-3), 76.9 (C-3″), 75.7 (C-3′), 74.4, 70.2 (C-5′, C-5″), 69.5 (C-5); 66.9, 64.0 (C-6′, C6″); 63.6 (C-5‴), 62.4 (C-6), 38.7, 38.6 ($(CH_3)_3CCO$); 27.1, 27.0, 26.9 (×2) ($(CH_3)_3CCO$); 20.7, 20.4 (CH_3); HRMS (ESI/APCI) *m*/*z*: $[M+Na]^+$ calcd for $C_{89}H_{100}O_{32}Na$, 1703.6095, found, 1703.6091.

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