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Published on Web 08/22/2006

Practical Approach for the Stereoselective Introduction of β-Arabinofuranosides

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Abstract: A practical approach for the stereoselective introduction of β-arabinofuranosides has been developed on the basis of locking an arabinosyl donor in a conformation in which nucleophilic attack from the β face is favored. The new glycosyl donor was designed by analyzing optimized geometries of low-energy conformers of the arabinofuranosyl oxacarbenium ion. The Newman projection of the E_3 conformer indicated that nucleophilic attack from the α face is disfavored because an eclipsed H-2 will be encountered. On the other hand, an approach from the β face was expected to be more favorable, because it will experience only staggered substituents. The arabinofuranosyl oxacarbenium ion could be locked in the E_3 conformation by employing a 3,5-*O*-di-*tert*-butylsilane protecting group, which places C-5 and O-3 in a pseudoequatorial orientation, resulting in a perfect chair conformation of the protecting group. The new glycosyl donor gave excellent β selectivities in a range of glycosylations with glycosyl acceptors having primary and secondary alcohols. The attractiveness of the new methodology was demonstrated by the chemical synthesis of a fragment of arabinogalactan, which is an important constituent of the primary plant cell wall.

Introduction

The stereoselective introduction of glycosidic linkages presents the principal challenge to the chemical synthesis of complex oligosaccharides of biological importance.[1−4] In general, 1,2-*trans*-glycosides can be obtained by neighboring group participation of a 2-*O*-acyl protecting group of a glycosyl donor. In these reactions, a promoter activates an anomeric leaving group, resulting in its departure and the formation of an oxacarbenium ion. Subsequent neighboring group participation of the 2-*O*-acyl protecting group will give a more stable 1,2-*cis*-acyloxonium ion. Nucleophilic attack at the anomeric center of the acyloxonium ion by an alcohol will give a 1,2-*trans*-glycoside. Recently, the stereoselective introduction of 1,2-*cis*-pyranosyl glycosidic linkages, such as α-glucopyranosides and α-galactopyranosides, has been accomplished by employing a participating (*S*)-phenylthiomethylbenzyl group at C-2 of a glycosyl donor.[5] In this glycosylation, an intermediate anomeric β-sulfonium ion is formed, which upon displacement by a sugar hydroxyl gives only α-glycopyranosides. Several elegant methods have been reported for the introduction of β-mannopyranosides.[6,7] In particular, the displacement of an α-triflate of a 4,6-*O*-benzylidine-protected mannoside, which can be formed in situ from various glycosyl donors, has found general use.[8]

Unfortunately, methods for the stereoselective introduction of furanosides are not as well developed as for pyranosides.[9] These glycosides are, however, important constituents of microbial and plant polysaccharides.[10−12] For example, the mycobacterium cell wall contains galactans and lipomannnans, which are substituted by α- and β-D-arabinofuranosides. Interestingly, while the primary cell walls of plants also contain galactans, they are modified by β-L-arabinofuranosides. There is evidence that these highly complex polysaccharides are involved in plant cell differentiation.[13]

In general, 1,2-*trans*-furanosides can be obtained in a straightforward manner by neighboring group participation of an acyl ester at C-2 of a furanosyl donor. On the other hand, furanosyl donors having a nonparticipating protecting group at C-2 give in general glycosides with poor anomeric selectivity. The stereoselective introduction of 1,2-*cis*-furanosides, such as β-arabinofuranosyl glycosides, has only been accomplished by indirect protocols. For example, Lowary's method employs a 2,3-anhydrofuranosyl donor, which can be stereoselectively glycosylated to give β-glycosides.[14,15] The oxirane of the

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10.1021/ja0629817 CCC: $33.50

resulting product can then be opened in a regioselective manner using lithium benzyl alkoxide in the presence of (−)-sparteine to give a β-arabinofuranoside. In another approach, β-Araf residues have been installed using an intramolecular aglycon delivery approach whereby a glycosyl acceptor is first tethered to the C-2 hydroxyl of an arabinofuranosyl donor followed by glycosylation.[16,17] β-Arabinofuranoside selectivity has also been improved by deactivation of the glycosyl donor and acceptor.[18]

We report here a practical approach for the stereoselective introduction of β-arabinofuranosides by locking a donor in a conformation in which attack from the β face is favored. As a result, a range of glycosylations of the novel arabinofuranosyl donor with primary and secondary glycosyl acceptors gave the corresponding glycosides with excellent β selectivities. The new glycosyl donor was designed by analyzing optimized geometries of low-energy conformers of the arabinofuranosyl oxacarbenium ion. The attractiveness of the new methodology has been demonstrated by the chemical synthesis of a fragment of arabinogalactan, which is an important constituent of the primary plant cell wall.

Results and Discussion

Several factors have complicated the development of a general method for the stereoselective introduction of 1,2-*cis*(β)-arabinofuranosides. For example, the weak anomeric effects of furanosides, which differ little between α and β anomers, makes it difficult to exploit in situ anomerization protocols for controlling anomeric selectivities.[19,20] Furthermore, furanosides are inherently flexible due to their ability to assume several twist and envelope conformations, which can interconvert via pseudorotational itineraries.[9] As a result, furanosides can glycosylate through several different transition states, which may compromise anomeric selectivities. In this respect, it is well accepted that high asymmetric inductions are only achieved when reactions proceed through rigid and well-organized transition states, in which a reactant experiences differential interactions from preexisting stereochemical elements of the substrate along alternative trajectories.[21] These differential interactions may arise from avoidance of steric interactions, minimization of torsional strain, and optimization of orbital interactions.

There is evidence to support that transition states of glycosylations possess substantial oxacarbenium ion character.[22,23] We reasoned that, by examining possible conformers of the arabinofuranosyl oxacarbenium ion, we might be able to identify one that favors attack from the β face. Locking an arabinofuranosyl donor in this conformation should provide a compound that will give mainly β-glycosides in glycosylations.

Oxacarbenium ions have significant double-bond character between the endocyclic oxygen and C-1, which places these two atoms and C-2 and C-4 in one plane. As a result, oxacarbenium ions of L-furanosides can adopt two possible low-energy conformations in which C-3 is either above (^{3}E) or below the plane (E_3) of C-4, O(endo), C-1, and C-2 (the descriptors for ^{3}E and E_3 are opposite for the D series). The geometries of these conformations for the methyl-protected arabinofuranosyl oxacarbenium ion have been optimized by density functional theory (DFT) quantum mechanical calculations at the BL3LYP/6-31G** level (Figure 1). As expected, the C-4−O(endo)−C-1−C-2 dihedral angle of the optimized ^{3}E conformer was very small (4.7°), placing these atoms in one plane. The computed bond length between O(endo) and C-1 is 1.25 Å, indicating partial double-bond character. Analysis of the Newman projection indicates that nucleophilic attack from the β face would suffer significant steric interactions from an eclipsed C-2 substituent. On the other hand, an approach from the α face is expected to be preferred, because it will encounter only staggered substituents. In contrast, nucleophilic attack from the α face of the E_3 conformer is predicted to be disfavored because it will experience an eclipsed H-2.[24−26] In this case, an approach from the β face is more favorable because it will encounter only staggered constituents.

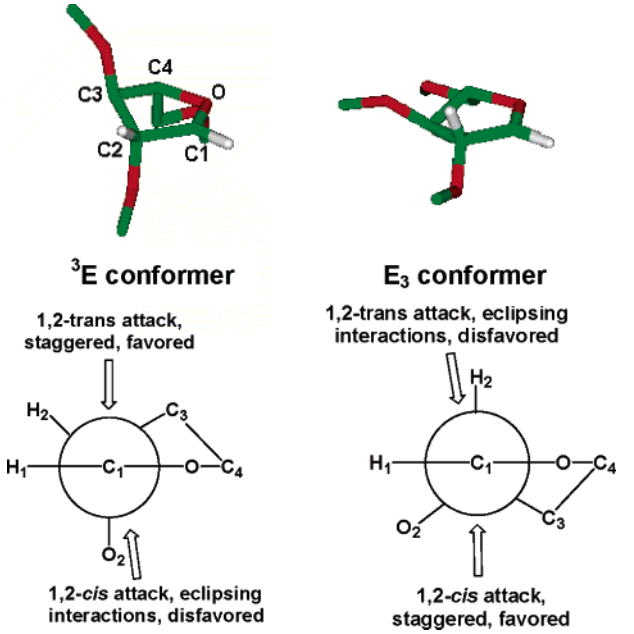

Figure 1. Optimized geometries (B3LYP/6-31G**) of the ^{3}E and E_3 conformers of the oxacarbenium ions of 2,3,5-tri-*O*-methyl-L-arabinofurase. The Newman projection along t eC-1−C-2 bond indicates that, in the case of the ^{3}E conformer, the H-2 hydrogen is in a pseudoequatorial orientation, whereas the O-2 oxygen is in a pseudoaxial orientation, resulting in the preferred 1,2-trans attack of the incoming nucleophile. In the case of the E_3 conformer, however, the H-2 hydrogen is in a pseudoaxial orientation and would result in an eclipsing interaction with the incoming nucleophile, making 1,2-trans (α) attack disfavored. In contrast, the 1,2-cis (β) attack would be favored in this case, as the incoming nucleophile would approach the anomeric carbon in a staggered fashion.

Thus, the computational studies indicate that high β selectivity will be achieved when an arabinofuranosyl oxacarbenium ion is locked in the E_3 conformer. It was anticipated that this can be achieved by employing arabinoside **3**, which has a 3,5-*O*-di-*tert*-butylsilane protecting group.[27] Thus, the E_3 conformer

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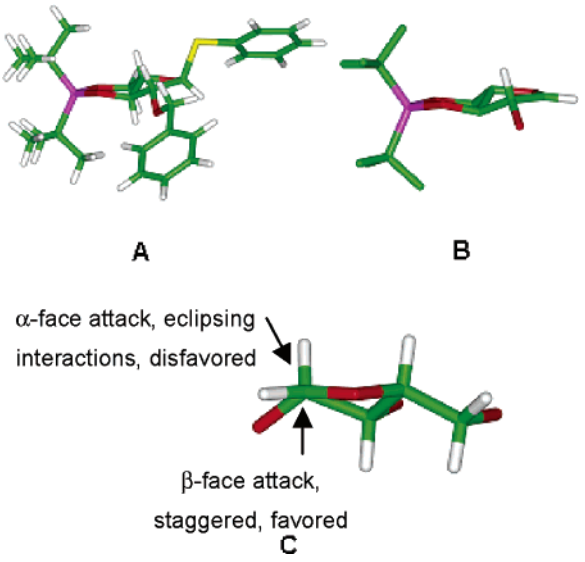
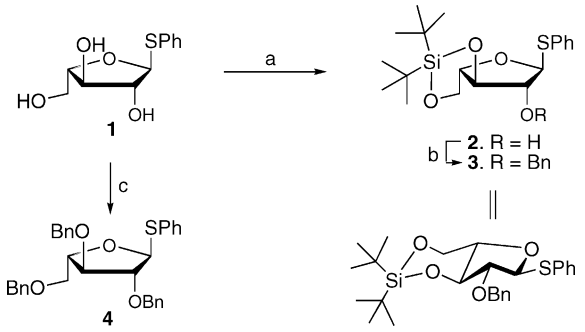


Figure 2. (A) Optimized geometry (B3LYP/6-31G**) of compound **3**. The five-membered ring of **3** is in an E_3 conformation, and the six-membered ring of the cyclic protecting group is in a chair conformation. (B) Optimized structure of the oxacarbenium ion of compound **3**. The five- and six-membered rings are in E_3 and chair conformations, respectively. (C) Newman projection along the C-1−C-2 bond of the oxacarbenium ion, indicating that the 1,2-trans (α) attack is disfavored, as it would encounter an eclipsing H-2 hydrogen. The 1,2-cis (*β*) attack will be staggered and is the favored mode of reaction, resulting in the observed stereoselectivity.

Scheme 1 [a]



[a] Reagents and conditions: (a) *t*-BuSi(OTf)$_2$, 2,6-lutidine, DMF/DCM, 0 °C (81%); (b) BnBr, NaH, THF (79%); (c) BnBr, NaH, DMF (86%).

of the oxacarbenium ion of **3** places C-5 and O-3 in a pseudoequatorial orientation, resulting in a perfect chair conformation of the protecting group. In the alternative ^{3}E conformation, the 3,5-*O*-di-*tert*-butylsilane chair is distorted, inducing considerable ring strain. Indeed, quantum mechanical calculations indicate that the oxacarbenium ion of **3** will adopt an E_3 conformation, in which nucleophilic attack from the α face is disfavored due to unfavorable steric interactions with H-2 (Figure 2).

Compound **3** was conveniently prepared according to a two-step procedure starting from the readily available thioglycoside **1** (Scheme 1). Thus, treatment of **1** with di-*tert*-butylsilane bis(trifluoromethanesulfonate) in the presence of 2,6-lutidine in a mixture of DMF and DCM[27] gave compound **2** in 81% yield. The C-2 hydroxyl of **2** could be benzylated in high yield to give **3** by reaction with benzyl bromide in the presence of NaH in THF. The reference compound **4**, having benzyl ethers at C-3, C-4, and C-5, could easily be prepared by benzylation of

Table 1. Experimental Homonuclear Coupling Constants of Compounds 3 and 4[a]

	3	4
J_{H1-H2}	5.1 (5.7)	3.0
J_{H2-H3}	6.5 (7.5)	3.0
J_{H3-H4}	10.0 (10.2)	6.3
J_{H4-H5a}	5.0 (4.1)	3.9
J_{H4-H5b}	10.0 (10.2)	4.7

[a] The experimental coupling constants indicate that the two compounds have different conformational properties. In the case of compound **3**, an excellent agreement was obtained between the experimental and computed proton−proton coupling constants, indicating that the five-membered ring of **3** is in the E_3 conformation.

2 using benzyl bromide and sodium hydride in DMF. Interestingly, the vicinal proton coupling constants of **3** and **4** differed significantly, thus demonstrating that the two compounds possess different conformational properties (Table 1). It was expected that compound **3** resides mainly in the E_3 conformation. This was confirmed by optimizing the E_3 conformation using DFT quantum mechanical calculations. The validity of the resulting structure was confirmed by computing vicinal proton coupling constants of the geometry-optimized conformer using an empirical Karplus type equation,[28] which were then compared with experimentally determined values. As can be seen in Table 1, the computed and experimentally determined coupling constants were in excellent agreement, confirming that **3** adopts mainly the E_3 conformation.

Having glycosyl donors **3** and **4** at hand, attention was focused on the glycosylation of a range of different glycosyl acceptors. Thus, coupling of the conformationally constrained glycosyl donor **3** with the glycosyl acceptor **5** in the presence of the powerful thiophilic promoter system *N*-iodosuccinimide/silver triflate (NIS/AgOTf)[29] in DCM at −30 °C gave disaccharide **6** with excellent *β* selectivity (*β*/α = 15/1) in a yield of 91% (Scheme 2). On the other hand, a similar glycosylation of the flexible glycosyl donor **4** with **5** provided disaccharide **7** in good yield but as a mixture of anomers (*β*/α = 3/1).

In general, the anomeric configuration of arabinofuranosides is established by a combination of chemical shift and coupling constant data.[30] In this respect, α-arabinofuranosides are characterized by $^3J_{H-1,H-2}$ = 1−3 Hz and *δ*(C-1) 104−110 ppm, whereas analogous *β*-glycosides have $^3J_{H-1,H-2}$ = 4−5 Hz and *δ*(C-1) 97−104 ppm values. The ^{13}C chemical shift of the anomeric carbon of the major product of **6** was in the expected region for a *β* anomer (*δ*(C-1) 100.3). The geometry-optimized models of the α and *β* anomers of 3,5-*O*-di-*tert*-butylsilane-protected arabinofuranosides predicted, however, dihedral angles of H-1 and H-2 of 131.6 and 34.0°, respectively, corresponding to similar $^3J_{H-1,H-2}$ coupling constants of ∼5.5 Hz. Indeed, the major and minor anomers of **6** gave $^3J_{H-1,H-2}$ = 5.1 and 5.2 Hz, respectively. Furthermore, the models indicate that α-furanosides will display an NOE between H-1 and H-3, whereas this interaction is absent in the *β* anomer. As expected, no NOE was observed between H-1 and H-3 of the major product of **6**, whereas this interaction was present in the minor component. To obtain additional proof of the *β*-anomeric configuration of

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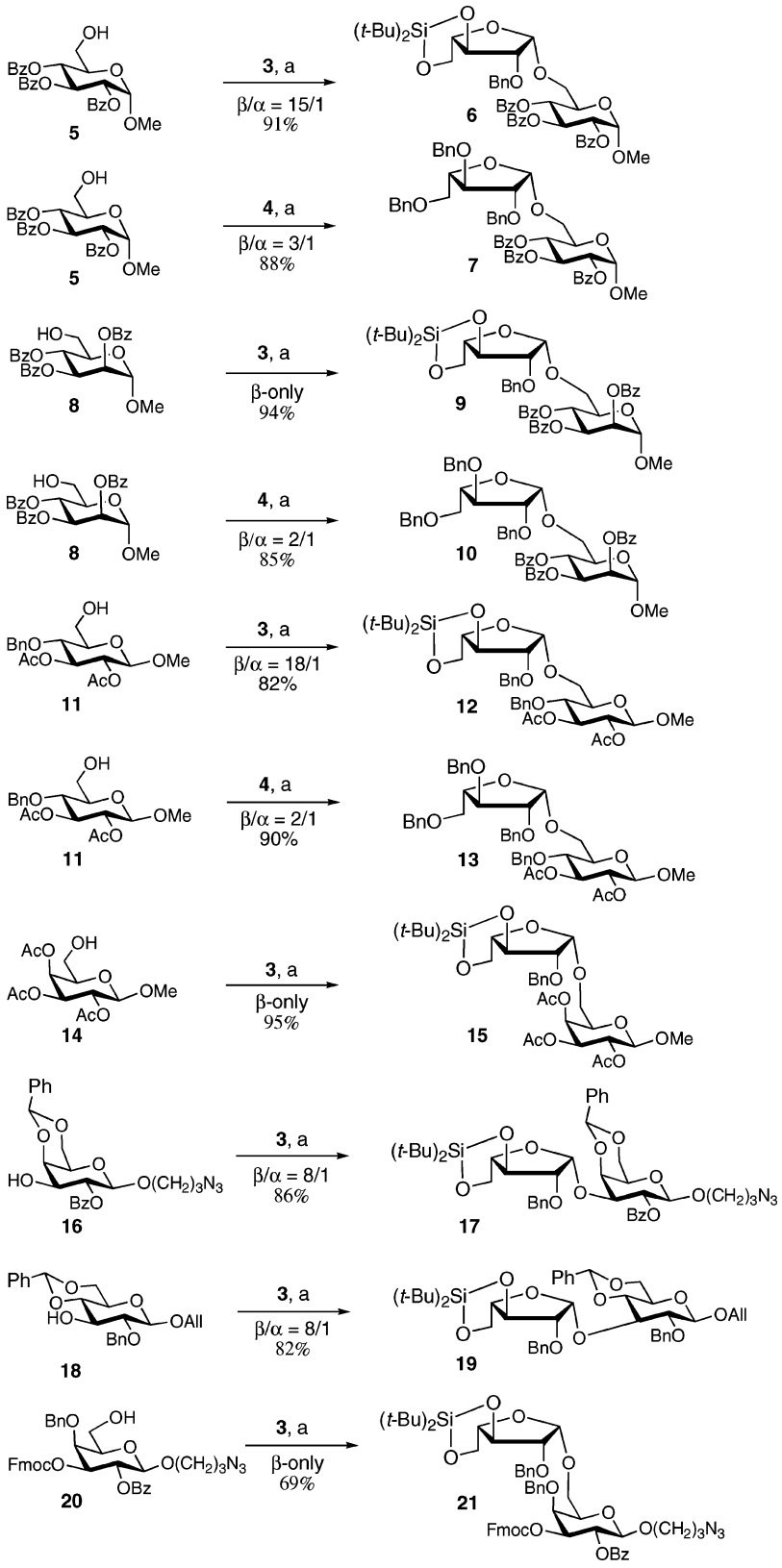
Scheme 2 [a]

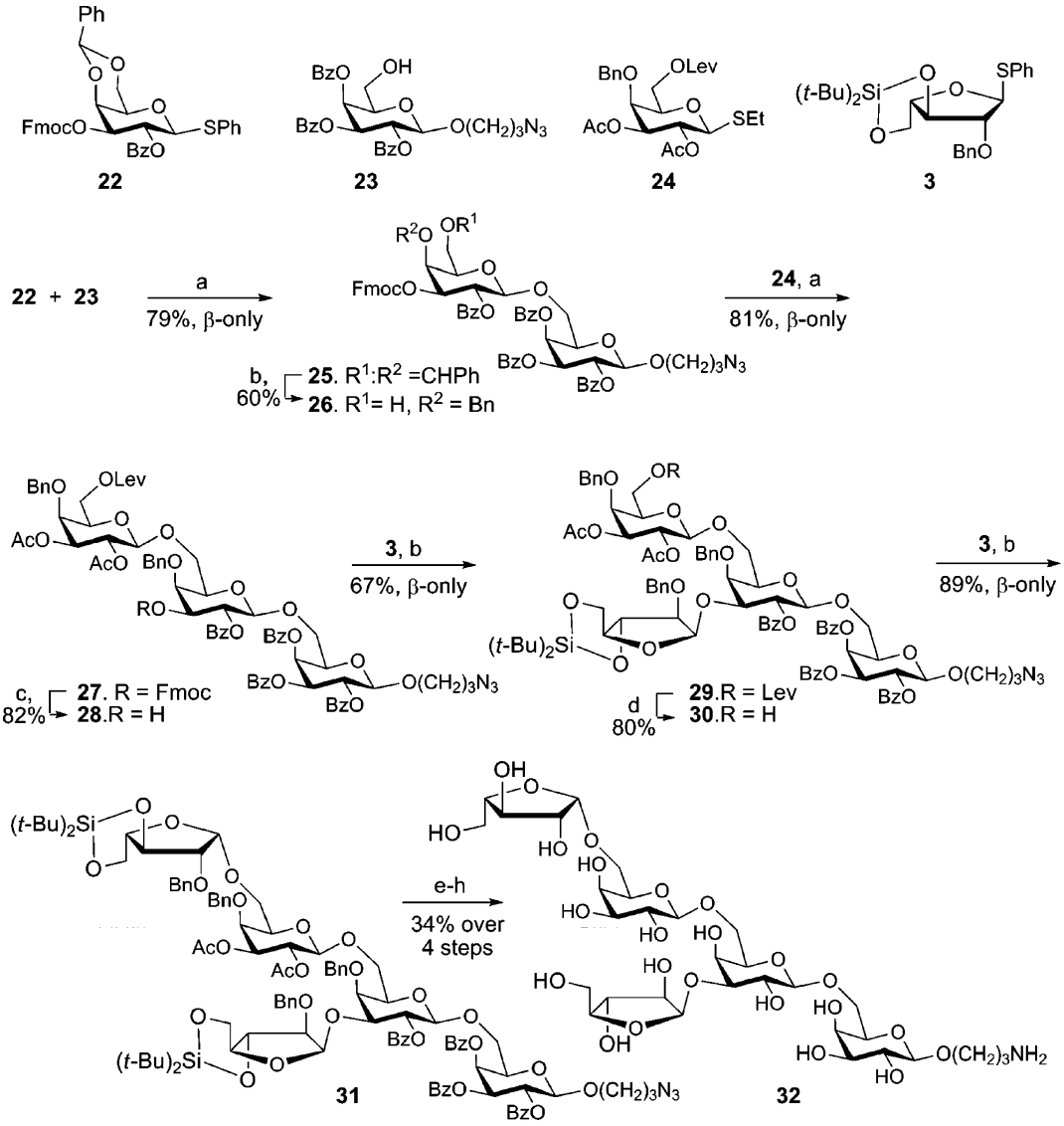


[a] Reagents and conditions: NIS/AgOTf, DCM, −30 °C.

the major component of **6**, the di-*tert*-butylsilane protecting group was removed by treatment with TBAF and the resulting hydroxyls acetylated with acetic anhydride in pyridine. Gratifyingly, the chemical shift and coupling constant data of the resulting compound were in agreement with literature values for β anomers ($^3J_{H-1,H-2} = 4.0$ Hz and δ(C-1) 101.2).[30]

To determine the generality of the methodology, the di-*tert*-butylsilane-protected **3** was coupled with glycosyl acceptors **8**,

Scheme 3 [a]



[a] Reagents and conditions: (a) NIS, AgOTf, DCM, MS 4A, −20 °C; (b) Bu_2BOTf, BH_3, THF, DCM, 0 °C; (c) Et_3N, DCM; (d) H_2NNH_2, DCM/MeOH; (e) TBAF, THF; (f) NaOMa, MeOH, 50 °C; (g) Pd/C, H_2, pyridine; (h) $Pd(OH)_2$, H_2, AcOH, H_2O.

11, **14**, **16**, **18**, and **20** having primary and secondary hydroxyls. In each case, the corresponding disaccharides **9**, **12**, **15**, **17**, **19**, and **21** were isolated in excellent yields as mainly or exclusively the β anomer. For each compound, the chemical shift of C-1 was in the expected region for β anomers (97−102 ppm) and no NOE was observed between H-1 and H-3. Coupling of the conformationally flexible **4** with glycosyl acceptors **8** and **11** gave the corresponding disaccharides **10** and **13** with poor anomeric selectivities. These results support our model, which predicts that nucleophilic attack at the α face of the oxacarbenium ion of **3** is disfavored due to unfavorable steric interactions.

Having established a robust methodology for the stereoselective introduction of β-arabinofuranosides, attention was focused on the preparation of compound **32**, which is a fragment of arabinogalactans.[13] These polysaccharides are important constituents of the primary plant cell wall, having a 1,3-β-D-galactosyl backbone branched by 1,6-β-linked D-galactosides, which in turn are extended by 1,3- and 1,6-β-linked L-arabinofuranosides. There is evidence that components of the primary cell wall play key roles in the development and differentiation of plant cells. The lack of sensitive methods to detect particular saccharides of the primary cell wall has, however, complicated the determination of structural elements that may regulate development. We are addressing this deficiency by eliciting antibodies against well-defined synthetic oligosaccharides derived from the primary cell wall. Antibodies modified by a fluorescence label will be used to visualize particular saccharide structures in the developing plant.

It was envisaged that the terminal 1,3- and 1,6-linked arabino-β-L-furanosides of **32** could be installed using the conformationally constrained arabinosyl donor **3** (Scheme 3). Furthermore, trisaccharide **27**, carrying the orthogonal 9-fluorenylmethoxycarbonyl (Fmoc) and levulinoyl (Lev) protecting groups,[31] was expected to be an appropriate precursor for the introduction of the arabino-β-L-furanosides. This trisaccharide, in turn, could be assembled from galactosyl building blocks **22**−**24**. Thus, NIS/AgOTf-mediated glycosylation[29] of the thioglycosyl donor **22** with the spacer-containing acceptor **23** gave the disaccharide

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25 in a yield of 79%. Due to neighboring group participation of the C-2 benzoyl ester of **22**, disaccharide **25** was only formed as a β anomer. Next, the benzylidine acetal of **25** was regioselectively opened by treatment with Bu_2BOTf in the presence of BH_3·THF complex in DCM[32] to give compound **26**. The resulting C-6 hydroxyl of **26** was glycosylated with galactosyl donor **24**, using NIS/AgOTf as the promoter, to give trisaccharide **27** in good yield as only the β anomer. The Fmoc protecting group of **27** was selectively removed by treatment with the hindered base triethylamine in DCM to afford **28**. As expected, these reaction conditions did not affect the Lev esters. Gratifyingly, a glycosylation of arabinosyl donor **3** with **28** using standard reaction conditions gave tetrasaccharide **29** as only the β anomer. Next, the Lev ester of **29** was removed using hydrazine acetate in a mixture of DCM and methanol to give the glycosyl acceptor **30**, which was coupled with **3** using standard conditions to give the expected pentasaccharide **31**. In the latter glycosylation, only the β-linked 1,6-arabinofuranoside could be detected. Finally, deprotection of **31** to afford the target compound **32** was accomplished according to a four-step procedure involving removal of the di-*tert*-butylsilane protecting group by treatment with TBAF in THF, saponification of the acetyl and benzoyl esters using sodium methoxide in methanol, catalytic hydrogenolysis over Pd in pyridine to convert the azido moiety into an amine, and finally catalytic hydrogenolysis in a mixture of methanol and acetic acid to remove the benzyl esters. NMR and MS confirmed the structural integrity of compound **32 (**Araf, $^3J_{H-1,H-2} = 4.5$ Hz, δ(C-1) 101.2 ppm; Araf′, $^3J_{H-1,H-2} = 4.5$ Hz, δ(C-1) 98.9 ppm; Gal, $^3J_{H-1,H-2} = 8.0$ Hz, δ(C-1) 103.4 ppm; Gal′, $^3J_{H-1,H-2} = 7.5$ Hz, δ(C-1) 103.5 ppm; Gal, $^3J_{H-1,H-2} = 8.0$ Hz, δ(C-1) 103.1 ppm).

In conclusion, arabinofuranosides can be introduced with high β selectivity using the conformationally constrained arabinofuranosyl donor **3**. This glycosyl donor has a 3,5-*O*-di-*tert*-butylsilane protecting group, which locks the corresponding oxacarbenium ion in an E_3 conformer. The Newman projection of this conformer indicated that nucleophilic attack from the β face is favored. Indeed, glycosylation with the new glycosyl donor gave excellent β selectivities with glycosyl acceptors having primary and secondary alcohols. The new methodology was sufficiently robust for an efficient synthesis of an arabinogalactan fragment derived from the plant cell wall. This paper demonstrates that analysis of conformations of putative intermediates of glycosylations may lead to the design of highly steroeselective glycosylation. Furthermore, the introduction of protecting groups that modify the conformational properties of a glycosyl donor may be an attractive strategy to improve the stereoselectivity of a glycosylation.[18,33,34]

Experimental Section

General Methods and Materials. Solvents were purified according to the standard procedures. Reactions were performed under argon unless stated otherwise. Reactions were monitored by thin-layer chromatography (TLC) using silica gel 60 F_{254}, and the compounds were visualized with UV light (254 nm) or by treatment with a solution of 10% H_2SO_4 in ethanol. Flash chromatography was performed on 70−230 mesh silica gel. Solvents were evaporated under reduced pressure while the water bath temperature was maintained below 40 °C. NMR spectra were recorded on Varian spectrometers (Models Inova300, Inova500, and Inova600) equipped with Sun workstations. ^{1}H NMR spectra were recorded in $CDCl_3$ and referenced to residual $CHCl_3$ at 7.26 ppm, and ^{13}C NMR spectra were referenced to the central peak of $CDCl_3$ at 77.0 ppm. One-dimensional NOE data were collected with an mixing time of 200 ms on a Varian Inova 500 MHz spectrometer using the standard pulse sequence provided. MS spectra were recorded on a VOYAGER-DE Applied Biosystems instrument in the positive mode by using 2,5-dihydroxylbenzoic acid in THF as matrix.

Phenyl 3,5-*O*-(Di-*tert*-butylsilanediyl)-1-thio-α-L-arabinofuranoside (2). To a solution of phenyl 1-thio-α-L-arabinofuranoside (1.08 g, 4.47 mmol) in a mixture of CH_2Cl_2 (35 mL) and DMF (7 mL) at 0 °C were added 2,6-lutidine (2.1 mL, 18 mmol) and di-*tert*-butylsilyl bis-(trifluoromethanesulfonate) (1.5 mL, 4.12 mmol). The resulting reaction mixture was stirred for 2 h, after which it was concentrated in vacuo, diluted with EtOAc (80 mL), and washed successively with water (20 mL) and brine (20 mL). The organic layer was dried ($MgSO_4$) and concentrated in vacuo to give a residue that was purified by flash column chromatography (hexane/EtOAc, 15/1 → 10/1) to afford **2** (1.39 g, 81%) as a white amorphous solid: $R_f = 0.43$ (hexane/EtOAc, 5.5/1). $[\alpha]^{25}_D = -247.6°$ (*c* 3.7, CH_2Cl_2). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.51 (m, 2H, Ar), 7.30 (m, 3H, Ar), 5.32 (d, $J = 6.0$ Hz, 1H, H-1), 4.34 (m, 1H, H-5$_a$), 4.15 (m, 1H, H-3), 4.02 (dd, $J = 9.5$, 7.5 Hz, 1H, H-2), 3.94 (m, 2H, H-4, H-5$_b$), 2.53 (d, $J = 3.0$ Hz, 1H, O*H*), 1.06 (s, 9H, ^{t}Bu), 0.99 (s, 9H, ^{t}Bu). ^{13}C NMR (75 MHz, $CDCl_3$): δ 134.53, 131.65 (×2), 129.25 (×2), 127.77, 91.33, 81.48, 80.97, 73.92, 67.56, 27.72, 27.39, 22.89, 20.37. MALDI HR-MS: *m*/*z* 405.1621 $[M + Na]^+$, calcd for $C_{19}H_{30}O_4SSi$ 405.1634.

Phenyl 2-*O*-Benzyl-3,5-*O*-(di-*tert*-butylsilanediyl)-1-thio-α-L-arabinofuranoside (3). BnBr (1.5 mL, 12.6 mmol) and NaH (0.17 g, 6.84 mmol) were added to a solution of **2** (1.31 g, 3.42 mmol) in dry THF (25 mL), and the mixture was kept stirring at 0 °C for 2 h. The reaction was quenched by the addition of CH_3OH, and solvent was removed in vacuo. The reaction mixture was diluted with CH_2Cl_2 and sequentially washed with a solution of 1 N HCl, a saturated solution of $NaHCO_3$, water, and brine. The organic phase was dried ($MgSO_4$) and concentrated under reduced pressure. The residue was then purified by flash column chromatography (hexane/EtOAc, 60/1 → 30/1) to afford **3** (1.28 g, 79%) as a pale yellow oil: $R_f = 0.65$ (hexane/EtOAc, 8/1). $[\alpha]^{25}_D = -69.2°$ (*c* 4.5, CH_2Cl_2). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.41−7.27 (m, 10H, Ar), 5.43 (d, $J_{1,2} = 5.1$ Hz, 1H, H-1), 4.79 (AB, $J = 12.0$ Hz, 2H, PhC*H*$_2$), 4.34 (q-like, $J_{4,5a} = 5.0$ Hz, 1H, H-5$_a$), 4.15 (m, $J_{2,3} = 6.5$ Hz, $J_{3,4} = 10.0$ Hz, 1H, H-3), 4.03−3.97 (m, $J_{4,5b} = 10.0$ Hz, 3H, H-2, H-4, H-5$_b$), 1.08 (s, 9H, ^{t}Bu), 0.99 (s, 9H, ^{t}Bu). ^{13}C NMR (75 MHz, $CDCl_3$): δ 137.9, 134.9, 131.5, 129.2, 128.7, 128.3, 128.2, 127.6, 90.2, 87.1, 81.6, 74.0, 72.5, 67.6, 27.8, 27.4, 22.9, 20.4. MALDI HR-MS: *m*/*z* 495.2132 $[M + Na]^+$, calcd for $C_{26}H_{36}O_4SSi$ 495.2104.

Phenyl 2,3,5-Tri-*O*-benzyl-1-thio-α-L-arabinofuranoside (4). Phenyl 1-thio-α-L-arabinofuranoside (1.45 g, 5.97 mmol) was dissolved in DMF (50 mL), and the solution was then cooled to 0 °C. NaH (60% dispersion in oil, 1.4 g, 35 mmol) was added to the above solution, followed by the dropwise addition of BnBr (7.2 mL, 60.6 mmol). After it was stirred at 0 °C for 30 min, the suspension was warmed to room temperature while stirring was continued for 6 h, after which the reaction was quenched by the addition of MeOH. The resulting mixture was concentrated in vacuo, and the resulting residue was diluted with EtOAc (100 mL), washed successively with 1 N HCl (30 mL) and brine (30 mL), and then dried ($MgSO_4$) and concentrated in vacuo. The residue was purified by flash column chromatography (hexane/EtOAc, 20/1 → 9/1) to give **4** (2.63 g, 86%) as a colorless syrup: $R_f = 0.33$ (hexane/EtOAc, 10/1). $[\alpha]^{25}_D = -128.2°$ (*c* 2.5, CH_2Cl_2). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.60 and 7.33 (m, 20H, Ar), 5.69 (d, $J_{1,2} = 3.0$ Hz, 1H, H-1), 4.72−4.54 (m, 6H, PhC*H*$_2$), 4.48 (m, $J_{3,4} = 6.3$ Hz, 1H, H-4),

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4.21 (t, $J_{2,3}$ = 3.0 Hz, 1H, H-2), 4.14 (m, 1H, H-3), 3.76−3.72 (m, $J_{4,5a}$ = 3.9 Hz, $J_{4,5b}$ = 4.7 Hz, 2H, H-5$_a$, H-5$_b$). ^{13}C NMR (75 MHz, $CDCl_3$): δ 138.4, 138.1, 137.7, 135.2, 131.5, 129.2, 128.8, 128.7, 128.6, 128.28, 128.25, 128.13, 128.11, 128.0, 127.9, 127.4, 90.6, 88.8, 83.7, 80.9, 73.6, 72.6, 72.5, 72.4, 69.4. MALDI HR-MS: *m*/*z* 535.2385 [M + Na]$^+$, calcd for $C_{32}H_{32}O_4S$ 535.2321.

General Procedure for the Synthesis of Disaccharides 6, 7, 9, 10, 12, 13, 15, 17, 19, and 21. A mixture of a thioglycoside (0.16 mmol) and an alcohol (0.10 mmol) in CH_2Cl_2 (10 mL) was stirred at room temperature in the presence of 4 Å molecular sieves (500 mg) for 30 min. After the mixture was cooled to −30 °C, NIS (54 mg, 0.24 mmol) followed by a solution of AgOTf (21 mg, 80 μmol) in toluene (0.2 mL) were added. The reaction mixture was warmed slowly to room temperature, and stirring was continued for 15 min. The reaction was quenched by the addition of Et_3N or pyridine. The suspension was diluted with EtOAc (50 mL) and filtered through a pad of Celite, and the filtrate was washed successively with 10% $Na_2S_2O_3$ (10 mL) and brine (20 mL). The organic layer was dried ($MgSO_4$) and concentrated in vacuo to give a residue, which was purified by flash column chromatography to afford the corresponding disaccharide.

Methyl 2-*O*-Benzyl-3,5-*O*-(di-*tert*-butylsilanediyl)-β-L-arabino-furanosyl-(1→6)-2,3,4-tri-*O*-benzoyl-α-D-glucopyranoside (6). R_f = 0.53 (hexane/EtOAc, 2.5/1). $[\alpha]^{25}_D$ = −16.7° (*c* 1.8, CH_2Cl_2). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.98 (d, *J* = 7.5 Hz, 2H, Ar), 7.94 (d, *J* = 7.0 Hz, 2H, Ar), 7.86 (d, *J* = 7.5 Hz, 2H, Ar), 7.51 (t, *J* = 7.5 Hz, 2H, Ar), 7.44−7.27 (m, 12H, Ar), 6.12 (t, *J* = 10.0, 9.5 Hz, 1H, H-3), 5.56 (t, *J* = 10.0 Hz, 1H, H-4), 5.22 (m, 2H, H-1, H-2), 4.94 (d, *J* = 5.0 Hz, 1H, H-1′), 4.78 (AB, *J* = 12.0 Hz, 2H, PhC*H*$_2$), 4.42 (t, *J* = 9.0 Hz, 1H, H-3′), 4.25 (m, 1H, H-5), 4.17 (dd, *J* = 9.0, 5.0 Hz, 1H, H-2′), 3.92 (dd, *J* = 9.0, 5.0 Hz, 1H, H-4′), 3.89 (dd, *J* = 11.0, 6.0 Hz, 1H, H-6$_a$), 3.85 (t, *J* = 9.5 Hz, 1H, H-5′$_a$), 3.62 (m, 2H, H-6$_b$, H-5′$_b$), 3.45 (s, 3H, OMe), 1.08 (s, 9H, ^{t}Bu), 0.98 (s, 9H, ^{t}Bu). ^{13}C NMR (75 MHz, $CDCl_3$): δ 165.81, 165.79, 165.0, 138.0, 133.3, 133.0, 129.9, 129.8, 129.7, 129.3, 129.13, 129.10, 128.4, 128.3, 128.2, 128.1, 127.7, 100.3 (C-1′), 96.8 (C-1), 80.7, 78.2, 73.9, 72.2, 71.7, 70.7, 69.3, 68.7, 68.1, 66.5, 55.4, 27.5, 27.2, 22.5, 20.1. MALDI HR-MS: *m*/*z* 891.3488 [M + Na]$^+$, calcd for $C_{48}H_{56}O_{13}Si$ 891.3490.

Methyl 2,3,5-Tri-*O*-benzyl-α/β-L-arabinofuranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-α-D-glucopyranoside (7). α/β ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.04 (d, *J* = 7.5 Hz, 2H, Ar), 7.97 (d, *J* = 7.0 Hz, 2H, Ar), 7.91 (d, *J* = 7.5 Hz, 2H, Ar), 7.54 (m, 2H, Ar), 7.44−7.27 (m, 22H, Ar), 6.24−6.20 (m, 1H, H-3α, H-3β), 5.64−5.59 (m, 1H, H-4α, H-4β), 5.37−5.15 (m, 3.4H, H-1α, H-1β, H-2β, H-1′β), 4.78−4.40 (m, 6H, PhCH_2), 4.32−3.97 (m, 6H), 3.89−3.63 (m, 4H), 3.49 (s, 2.3H, OMeβ), 3.44 (s, 0.7H, OMeα). ^{13}C NMR (75 MHz, $CDCl_3$): δ 165.9, 165.8, 165.7, 138.5, 138.4, 138.3, 138.2, 138.1, 138.0, 133.6, 133.5, 133.1, 133.0, 130.2, 130.1, 130.0, 129.9, 129.7, 129.5, 129.43, 129.41, 129.2, 128.9, 128.7, 128.6, 128.5, 128.4, 128.2, 128.1, 128.06, 128.03, 127.95, 127.93, 127.84, 127.80, 127.7, 107.7 (C-1′α), 101.5 (C-1′β), 97.4 (C-1), 88.6, 84.3, 83.5, 83.4, 80.7, 77.6, 77.3, 76.8, 73.6, 73.4, 73.1, 72.5, 72.3, 72.2, 70.8, 70.6, 70.4, 70.3, 70.0, 69.7, 67.6, 67.0, 55.6. MALDI HR-MS: *m*/*z* 931.3410 [M + Na]$^+$, calcd for $C_{54}H_{52}O_{13}$ 931.3408.

Methyl 2-*O*-Benzyl-3,5-*O*-(di-*tert*-butylsilanediyl)-β-L-arabino-furanosyl-(1→6)-2,3,4-tri-*O*-benzoyl-α-D-mannopyranoside (9). R_f = 0.40 (hexane/EtOAc, 3.5/1). $[\alpha]^{25}_D$ = −162.6° (*c* 1.6, CH_2Cl_2). ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.12 (d, *J* = 7.0 Hz, 2H, Ar), 7.97 (d, *J* = 7.5 Hz, 2H, Ar), 7.83 (d, *J* = 7.5 Hz, 2H, Ar), 7.58 (t, *J* = 7.5 Hz, 1H, Ar), 7.53 (t, *J* = 7.5 Hz, 1H, Ar), 7.48−7.38 (m, 7H, Ar), 7.25 (m, 5H, Ar), 5.90 (t, *J* = 10.0 Hz, 1H, H-4), 5.86 (dd, *J* = 10.0, 3.0 Hz, H-3), 5.69 (s, 1H, H-2), 5.00 (s, 1H, H-1), 4.96 (d, *J* = 5.0 Hz, 1H, H-1′), 4.76 (AB, *J* = 12.5 Hz, 2H, PhC*H*$_2$), 4.48 (t, *J* = 9.0 Hz, 1H), 4.30 (t, *J* = 7.0 Hz, 1H, H-5), 4.19 (dd, *J* = 9.0, 5.5 Hz, 1H, H-3′), 4.00−3.90 (m, 3H, H-2′, H-6$_a$), 3.66 (m, 2H), 3.53 (s, 3H, OMe), 1.09 (s, 9H, ^{t}Bu), 1.01 (s, 9H, ^{t}Bu). ^{13}C NMR (75 MHz, $CDCl_3$): δ 165.6, 165.4, 165.3, 137.9, 133.34, 133.27, 133.0, 130.0, 129.74, 129.71, 129.3, 129.2, 128.5, 128.4, 128.2, 128.1, 127.6, 100.3 (C-1′), 98.4 (C-1), 80.8, 78.1, 73.9, 71.7, 70.4, 70.3, 69.8, 68.1, 67.1, 66.9, 55.3, 27.5, 27.2, 22.5, 20.1. MALDI HR-MS: *m*/*z* 891.3483 [M + Na]$^+$, calcd for $C_{48}H_{56}O_{13}Si$ 891.3490.

Methyl 2,3,5-Tri-*O*-benzyl-α/β-L-arabinofuranosyl-β-(1→6)-2,3,4-tri-*O*-benzoyl-α-D-mannopyranoside (10). α/β ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.11 (d, *J* = 7.2 Hz, 2H, Ar), 7.97 (d, *J* = 7.2 Hz, 2H, Ar), 7.85 (d, *J* = 7.2 Hz, 2H, Ar), 7.58−7.47 (m, 2H, Ar), 7.45−7.19 (m, 22H, Ar), 5.92−5.88 (m, 2H, H-3, H-4), 5.69 (s, 1H, H-2), 5.16 (s, 0.34H, H-1′α), 4.98 (d, *J* = 1.2 Hz, 0.33H, H-1α), 4.94−4.90 (m, 1.34H, H-1β, H-1′β), 4.69−4.27 (m, 8H), 4.14−3.97 (m, 4H), 3.61−3.54 (m, 3H), 3.50 (s, 1H, OMeα), 3.47 (s, 2H, OMeβ). ^{13}C NMR (75 MHz, $CDCl_3$): δ 165.8, 165.7, 138.5, 138.4, 138.3, 138.2, 138.1, 137.9, 133.7, 133.3, 130.2, 130.1, 130.0, 129.9, 129.6, 129.5, 129.48, 129.42, 129.3, 128.8, 128.7, 128.6, 128.57, 128.50, 128.28, 128.20, 128.04, 128.01, 127.97, 127.93, 127.85, 127.82, 127.7, 107.4 (C-1′α), 101.2 (C-1′β), 98.7 (C-1α,β), 88.7, 84.3, 83.6, 83.5, 80.7, 77.7, 77.5, 77.3, 76.8, 73.6, 73.4, 73.1, 72.5, 72.3, 72.2, 70.8, 70.6, 70.4, 70.3, 70.0, 69.7, 67.6, 67.0, 55.6. MALDI HR-MS: *m*/*z* 931.3401 [M + Na]$^+$, calcd for $C_{54}H_{52}O_{13}$ 931.3408.

Methyl 2-*O*-Benzyl-3,5-*O*-(di-*tert*-butylsilanediyl)-β-L-arabino-furanosyl-(1→6)-2,3-di-*O*-acetyl-4-*O*-benzyl-β-D-glucopyranoside (12). R_f = 0.75 (hexane/EtOAc, 1.5/1). $[\alpha]^{25}_D$ = −210.4° (*c* 0.5, CH_2Cl_2); ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.48 (d, *J* = 7.5 Hz, 2H, Ar), 7.37 (t, *J* = 7.5 Hz, 2H, Ar), 7.29 (m, 4H, Ar), 7.22 (d, *J* = 7.0 Hz, 2H, Ar), 5.17 (t, *J* = 10.0, 9.5 Hz, 1H, H-3), 5.14 (d, *J* = 5.0 Hz, 1H, H-1′), 4.86 (dd, *J* = 9.5, 8.5 Hz, 1H, H-2), 4.81 (AB, *J* = 12.0 Hz, 2H, PhC*H*$_2$), 4.65 and 4.50 (AB, *J* = 11.5 Hz, 2H, PhC*H*$_2$), 4.37 (d, *J* = 8.0 Hz, 1H, H-1), 4.36 (t, *J* = 8.5 Hz, 1H), 4.29 (dd, *J* = 9.5, 5.0 Hz, 1H), 4.03 (dd, *J* = 12.0, 4.0 Hz, 1H, H-2′), 3.97 (dd, *J* = 9.0, 5.5 Hz, 1H, H-5), 3.87 (t, *J* = 10.0 Hz, 1H), 3.82 (m, 2H), 3.66 (dt, *J* = 10.0, 5.0 Hz, 1H, H-4), 3.49 (dd, *J* = 9.5, 2.0 Hz, 1H), 3.46 (s, 3H, OMe), 2.04, 1.86 (2 × s, 6H, Ac), 1.05 (s, 9H, ^{t}Bu), 1.00 (s, 9H, ^{t}Bu). ^{13}C NMR (75 MHz, $CDCl_3$): δ 170.1, 169.7, 138.0, 137.8, 128.41, 128.36, 128.0, 127.9, 127.8, 127.6, 101.5 (C-1), 101.0 (C-1′), 81.0, 78.6, 75.7, 74.9, 74.8, 74.7, 73.5, 71.9, 71.8, 68.4, 66.7, 356.7, 27.5, 27.1, 22.6, 20.8, 20.7, 20.1. MALDI HR-MS: *m*/*z* 753.3330 [M + Na]$^+$, calcd for $C_{38}H_{54}O_{12}Si$ 753.3385.

Methyl 2,3,5-Tri-*O*-benzyl-α/β-L-arabinofuranosyl-β-(1→6)-2,3-di-*O*-acetyl-4-*O*-benzyl-β-D-glucopyranoside (13). α/β ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.44−7.19 (m, 20H, Ar), 5.24−5.14 (m, 1.35H, H-3β, H-1′β), 4.92−4.46 (m, 10.2H), 4.37 (m, 1H, H-1α, H-1β), 4.18−3.96 (m, 4H), 3.89−3.51 (m, 6H), 3.46 (s, 3H, OMeα, OMeβ), 2.04 (s, 3H, Acα, Acβ), 1.94 (s, 1H, Acα), 1.86 (s, 2H, Acβ). ^{13}C NMR (75 MHz, $CDCl_3$): δ 170.4, 170.1, 170.0, 138.4, 138.3, 138.1, 138.04, 138.03, 137.8, 137.7, 128.8, 128.72, 128.68, 128.58, 128.3, 128.2, 128.1, 128.0, 127.9, 127.8, 106.8 (C-1′α), 101.8 (C-1α), 101.7 (C-1β), 101.5 (C-1′β), 88.5, 84.4, 83.7, 83.2, 80.9, 80.5, 77.7, 77.2, 76.9, 76.0, 75.3, 74.8, 74.7, 73.6, 73.4, 72.8, 72.4, 72.2, 72.1, 69.9, 66.6, 65.8, 57.1, 56.9, 21.0, 20.9. MALDI HR-MS: *m*/*z* 793.3311 [M + Na]$^+$, calcd for $C_{44}H_{50}O_{12}$ 793.3302.

Methyl 2-*O*-Benzyl-3,5-*O*-(di-*tert*-butylsilanediyl)-β-L-arabino-furanosyl-(1→6)-2,3,4-tri-*O*-acetyl-β-D-galactopyranoside (15). R_f = 0.57 (hexane/EtOAc, 1.5/1). $[\alpha]^{25}_D$ = −152.2° (*c* 0.5, CH_2Cl_2). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.41 (d, *J* = 7.5 Hz, 2H, Ar), 7.35 (t, *J* = 7.5 Hz, 2H, Ar), 7.29 (t, *J* = 7.0 Hz, 1H, Ar), 5.45 (d, *J* = 2.5 Hz, 1H, H-4), 5.18 (dd, *J* = 10.0, 8.0 Hz, 1H, H-2), 4.99 (dd, *J* = 10.5, 3.0 Hz, H-3), 4.85 (d, *J* = 5.0 Hz, 1H, H-1′), 4.78 (AB, *J* = 12.5 Hz, 2H, PhC*H*$_2$), 4.36 (d, *J* = 7.5 Hz, 1H, H-1), 4.32 (t, *J* = 9.0 Hz, 1H, H-3′), 4.28 (dd, *J* = 9.0, 5.0 Hz, 1H), 3.96 (t, *J* = 10.0 Hz, 1H), 3.89 (m, 2H, H-2′, H-5′$_a$), 3.73 (dd, *J* = 10.5, 6.0 Hz, 1H, H-5′$_b$), 3.61 (m, 2H, H-4′), 3.49 (s, 3H, OMe), 2.12, 2.05, 1.97 (3 × s, 9H, Ac), 1.07 (s, 9H, ^{t}Bu), 0.98 (s, 9H, ^{t}Bu). ^{13}C NMR (75 MHz, $CDCl_3$): δ 170.11, 169.95, 169.5, 137.8, 128.3, 128.1, 127.7, 102.0 (C-1), 101.1 (C-1′), 80.5, 78.2, 73.8, 71.83, 71.79, 71.1, 69.1, 68.2, 67.5, 66.7, 56.9, 27.5, 27.1, 22.5, 20.8, 20.7, 20.6, 20.0. MALDI HR-MS: *m*/*z* 705.2890 [M + Na]$^+$, calcd for $C_{33}H_{50}O_{13}Si$ 705.3021.

3-Azidopropyl 2-*O*-Benzyl-3,5-*O*-(di-*tert*-butylsilanediyl)-β-L-arabinofuranosyl-(1→3)-2-*O*-benzoyl-4,6-*O*-benzylidene-β-D-galactopyranoside (17). R_f = 0.16 (hexane/EtOAc, 2/1). ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.07 (d, *J* = 7.5 Hz, 2H, Ar), 7.57 (t, *J* = 7.5 Hz, 1H, Ar), 7.50 (d, *J* = 7.0 Hz, 2H), 7.45 (t, *J* = 7.5 Hz, 2H), 7.29−7.19 (m, 8H, Ar), 5.60 (dd, *J* = 10.0, 8.5 Hz, 1H, H-2), 5.54 (s, 1H, PhC*H*), 5.18 (d, *J* = 5.0 Hz, 1H, H-1′), 4.65 (d, *J* = 8.0 Hz, 1H, H-1), 4.60 (AB peak, *J* = 12.0 Hz, 2H, PhCH_2), 4.37 (m, 2H), 4.15 (t, *J* = 9.0 Hz, 1H), 4.10 (m, 2H), 4.00 (m, 2H), 3.89 (dd, *J* = 9.0, 5.0 Hz, 1H), 3.56 (m, 2H), 3.49 (t, *J* = 9.0 Hz, 2H, $CH_2CH_2N_3$), 3.23 (m, 2H, CH_2-CH_2N_3), 1.78 (m, 2H), 0.91 (s, 9H, ^{t}Bu), 0.79 (s, 9H, ^{t}Bu). ^{13}C NMR (75 MHz, $CDCl_3$): δ 164.9, 138.1, 137.4, 133.0, 130.0, 129.7, 128.9, 128.4, 128.12, 128.11, 127.7, 127.3, 126.3, 101.4, 101.1, 97.2 (C-1′), 80.5, 77.3, 74.5, 74.2, 72.3, 70.9, 70.2, 69.2, 68.2, 66.7, 65.7, 48.0, 29.0, 27.2, 27.1, 22.3, 20.0. MALDI MS: *m*/*z* 841.3605 $[M + Na]^+$, calcd for $C_{43}H_{55}N_3O_{11}Si$ 840.3606.

Allyl 2-*O*-Benzyl-3,5-*O*-(di-*tert*-butylsilanediyl)-β-L-arabinofuranosyl-(1→3)-2-*O*-benzyl-4,6-*O*-benzylidene-β-D-glucopyranoside (19). R_f = 0.32 (hexane/EtOAc, 6/1). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.43−7.17 (m, 15H, Ar), 5.91 (m, 1H, OCH_2CHCH_2), 5.42 (s, 2H, PhCH_2), 5.31 (d, *J* = 17.5 Hz, 1H, $OCH_2CHCH_aCH_b$), 5.19 (d, *J* = 10.5 Hz, 1H, $OCH_2CHCH_aCH_b$), 4.87 (AB peak, *J* = 11.5 Hz, 2H, PhCH_2), 4.76 and 4.59 (AB, *J* = 12.5 Hz, 2H), 4.56 (d, *J* = 7.5 Hz, 1H, H-1), 4.37 (dd, *J* = 13.0, 5.5 Hz, 1H, $OCH_aH_bCHCH_2$), 4.34 (t, *J* = 9.5 Hz, 1H), 4.32 (dd, *J* = 10.5, 4.5 Hz, 1H), 4.15 (m, 1H), 4.13 (d, *J* = 5.0 Hz, 1H, H-1′), 3.99 (t, *J* = 9.0 Hz, 1H), 3.85 (dd, *J* = 9.5, 5.5 Hz, 1H), 3.74 (t, *J* = 10.0 Hz, 1H), 3.72 (t, *J* = 10.0, 1H), 3.67 (t, *J* = 9.5 Hz, 1H), 3.58 (m, 1H), 3.53 (t, *J* = 8.0 Hz, 1H), 3.41 (dt, *J* = 9.5, 5.0 Hz, 1H), 1.04 (s, 9H, ^{t}Bu), 0.94 (s, 9H, ^{t}Bu). ^{13}C NMR (75 MHz, $CDCl_3$): δ 138.5, 137.9, 137.2, 133.7, 129.2, 128.4, 128.2, 127.6, 127.5, 127.45, 127.42, 126.2, 117.7, 103.0, 101.6, 100.8, 81.5, 80.3, 80.2, 79.2, 78.2, 75.1, 73.6, 71.2, 70.8, 68.8, 68.3, 65.7, 27.5, 27.1, 22.5, 20.0. MALDI MS: *m*/*z* 783.3524 $[M + Na]^+$, calcd for $C_{43}H_{56}O_{10}Si$ 783.3643.

3-Azidopropyl 2-*O*-Benzyl-3,5-*O*-(di-*tert*-butylsilanediyl)-β-L-arabinofuranosyl-(1→6)-2-*O*-benzoyl-4-*O*-benzyl-3-*O*-(9-fluorenylmethoxycarbonyl)-β-D-galactopyranoside (21). R_f = 0.47 (hexane/EtOAc, 3/1). ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.08 (d, *J* = 7.5 Hz, 2H, Ar), 7.72 (t, *J* = 7.0 Hz, 2H, Ar), 7.57 (t, *J* = 7.5 Hz, 1H, Ar), 7.50−7.28 (m, 15H, Ar), 7.24 (t, *J* = 7.5 Hz, 1H, Ar), 7.13 (m, 2H, Ar), 5.71 (t, *J* = 10.0, 8.0 Hz, 1H), 5.04 (dd, *J* = 10.5, 3.0 Hz, 1H), 4.91 (d, *J* = 5.5 Hz, 1H, H-1′), 4.86 and 4.77 (AB, *J* = 12.5 Hz, 2H, PhCH_2), 4.80 and 4.61 (AB, *J* = 12.0 Hz, 2H, PhCH_2), 4.59 (d, *J* = 8.0 Hz, 1H, H-1), 4.38 (t, *J* = 9.5 Hz, 1H), 4.33 (m, 2H), 4.20 (t, *J* = 10.5, 8.5 Hz, 1H), 4.16 (br s, 1H), 4.11 (t, *J* = 7.5 Hz, 1H), 3.96 (m, 3H), 3.82 (m, 3H), 3.67 (m, 1H), 3.55 (m, 1H), 3.24 (m, 2H, $CH_2CH_2N_3$), 1.76 (m, 2H, $CH_2CH_2N_3$), 1.09 (s, 9H, ^{t}Bu), 1.03 (s, 9H, ^{t}Bu). ^{13}C NMR (75 MHz, $CDCl_3$): δ 165.1, 154.5, 143.2, 142.8, 141.2, 141.1, 137.9, 137.7, 133.2, 129.7, 129.6, 128.4, 128.3, 128.2, 128.0, 127.8, 127.72, 127.66, 127.1, 127.0, 125.2, 124.9, 119.9, 101.4 (C-1), 101.1 (C-1′), 80.5, 78.7, 77.7, 75.0, 73.7, 73.6, 73.1, 71.8, 70.15, 70.11, 68.3, 66.6, 66.1, 47.9, 46.4, 28.9, 27.5, 27.1, 22.5, 20.0. MALDI HR-MS: *m*/*z* 1064.4761 $[M + Na]^+$, calcd for $C_{58}H_{67}N_3O_{13}Si$ 1064.4443.

3-Azidopropyl 2-*O*-Benzoyl-4,6-*O*-benzylidene-3-*O*-(9-fluorenylmethoxycarbonyl)-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranoside (25). A mixture of the glycosyl donor **22** (602 mg, 0.88 mmol), the acceptor **23** (436 mg, 0.76 mmol), and powdered 4 Å molecular sieves (0.9 g) in CH_2Cl_2 (14 mL) was stirred at room temperature for 30 min and then cooled to −20 °C. NIS (260 mg, 1.16 mmol), followed by a solution of AgOTf (100 mg, 0.39 mmol) in toluene (0.8 mL), was added. The reaction mixture was warmed slowly to room temperature, stirred for 20 min, and then quenched by the addition of pyridine. The suspension was diluted with EtOAc (50 mL) and filtered through a pad of Celite, and the filtrate was washed successively with 10% $Na_2S_2O_3$ (8 mL) and brine (10 mL). The organic layer was dried ($MgSO_4$) and concentrated in vacuo to give a residue, which was purified by flash column chromatography (hexane/EtOAc, 5/1 → 1/1) to give **25** (691 mg, 79%) as a white foam: R_f = 0.61 (hexane/EtOAc, 1/1). $[\alpha]^{25}_D$ = −119.3° (*c* 0.7, CH_2Cl_2). ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.03 (t, *J* = 7.5 Hz, 4H, Ar), 7.93 (d, *J* = 7.8 Hz, 2H, Ar), 7.75 (d, *J* = 8.1 Hz, 2H, Ar), 7.69−7.19 (m, 23H, Ar), 7.11 (t, *J* = 7.5 Hz, 1H, Ar), 7.01 (t, *J* = 7.5 Hz, 1H, Ar), 5.87 (d, *J* = 3.3 Hz, 1H, H-4), 5.78 (dd, *J* = 9.9, 8.4 Hz, 1H, H-2), 5.65 (t, *J* = 9.1 Hz, 1H, H-2′), 5.57 (s, 1H, PhC*H*), 5.48 (dd, *J* = 10.2, 3.3 Hz, H-3′), 5.02 (dd, *J* = 10.5, 3.3 Hz, 1H, H-3), 4.74 (d, *J* = 7.8 Hz, 1H, H-1), 4.57 (d, *J* = 7.8 Hz, 1H, H-1′), 4.49 (d, *J* = 3.0 Hz, 1H, H-4′), 4.43 (d, *J* = 12.6 Hz, 1H, H-6_a), 4.28 (d, *J* = 7.5 Hz, 2H), 4.18 (m, 1H), 4.08 (m, 3H), 3.84 (dd, *J* = 10.5, 7.5 Hz, 1H), 3.61 (m, 2H, H-5), 3.26 (m, 1H, H-6_b), 3.07 (t, *J* = 6.9 Hz, 2H, $CH_2CH_2N_3$), 1.53 (m, 2H, CH_2-CH_2N_3). ^{13}C NMR (75 MHz, $CDCl_3$): δ 165.81, 165.64, 165.52, 165.10, 154.71, 143.31, 143.19, 141.37, 137.59, 133.72, 133.48, 133.38, 130.27, 130.05, 129.96, 129.86, 129.78, 129.52, 129.34, 129.09, 128.78, 128.66, 128.44, 127.98, 127.29, 126.59, 125.35, 125.29, 120.15, 101.46, 101.16, 75.72, 73.68, 73.40, 71.97, 70.56, 70.09, 69.22, 69.02, 68.56, 66.54, 66.49, 48.04, 46.62, 28.97. MALDI HR-MS: *m*/*z* 1174.3673 $[M + Na]^+$, calcd for $C_{65}H_{57}N_3O_{17}$ 1174.3688.

3-Azidopropyl 2-*O*-Benzoyl-4-*O*-benzyl-3-*O*-(9-fluorenylmethoxycarbonyl)-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranoside (26). To a stirred and cooled (0 °C) solution of **25** (507 mg, 0.44 mmol) in CH_2Cl_2 (15 mL) were added successively BH_3·THF (1.0 M in THF, 5 mL, 5 mmol) and Bu_2BOTf (1.0 M in CH_2Cl_2, 0.5 mL, 0.5 mmol). After it was stirred for 2 h, the reaction mixture was concentrated to a small volume and then diluted with EtOAc (30 mL), washed successively with saturated aqueous $NaHCO_3$ (15 mL) and brine (20 mL), dried ($MgSO_4$), and concentrated in vacuo. The residue was purified by flash column chromatography (hexane/EtOAc, 2/1 → 1/1) to give the alcohol **26** (305 mg, 60%) as a white foam: R_f = 0.52 (hexane/EtOAc, 1/1). $[\alpha]^{25}_D$ = −78.4° (*c* 1.0, CH_2Cl_2). ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.05 (d, *J* = 6.9 Hz, 4H, Ar), 7.95 (d, *J* = 7.2 Hz, 2H, Ar), 7.76 (d, *J* = 7.8 Hz, 2H, Ar), 7.69−7.09 (m, 25H, Ar), 5.89 (br s, 1H, H-4), 5.75 (t, *J* = 8.7 Hz, 1H, H-2′), 5.68 (t, *J* = 8.4 Hz, 1H, H-2), 5.51 (d-like, *J* = 10.5 Hz, 1H, H-3), 5.03 (d, *J* = 10.8 Hz, 1H, H-3′), 4.85 and 4.54 (AB, *J* = 11.5 Hz, 2H, PhCH_2), 4.66 (d, *J* = 8.1 Hz, 1H), 4.63 (d, *J* = 8.4 Hz, 1H), 4.30 (m, 2H), 4.08 (m, 4H), 3.83 (m, 2H), 3.61 (m, 3H), 3.33 (m, 1H), 3.10 (m, 2H, $CH_2CH_2N_3$), 1.58 (m, 2H, $CH_2CH_2N_3$). ^{13}C NMR (75 MHz, $CDCl_3$): δ 165.6, 165.4, 165.2, 164.9, 154.5, 143.1, 142.7, 141.1, 141.0, 137.3, 133.5, 133.2, 133.1, 129.9, 129.8, 129.6, 129.5, 129.2, 128.9, 128.7, 128.53, 128.46, 128.4, 128.2, 128.1, 127.8, 127.0, 125.0, 124.8, 101.4, 101.3, 77.8, 77.2, 74.95, 74.85, 73.3, 73.2, 71.6, 70.1, 70.0, 69.8, 68.9, 68.5, 66.2, 61.5, 47.7, 46.4, 28.7. MALDI HR-MS: *m*/*z* 1176.3878 $[M + Na]^+$, calcd for $C_{65}H_{59}N_3O_{17}$ 1176.3845.

3-Azidopropyl 2,3-Di-*O*-acetyl-4-*O*-benzyl-6-*O*-levulinoyl-β-D-galactopyranosyl-(1→6)-2-*O*-benzoyl-4-*O*-benzyl-3-*O*-(9-fluorenylmethoxycarbonyl)-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranoside (27). The coupling of the glycosyl donor **24** (110 mg, 0.22 mmol) and the acceptor **26** (145 mg, 0.13 mmol) was performed as described for **25** to give the trisaccharide **27** (160 mg, 81%) as a white amorphous solid: R_f = 0.21 (hexane/EtOAc, 1/1). ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.04 (d, *J* = 7.5 Hz, 2H, Ar), 8.01 (d, *J* = 8.0 Hz, 2H, Ar), 7.93 (d, *J* = 7.5 Hz, 2H, Ar), 7.74 (d, *J* = 7.5 Hz, 2H, Ar), 7.66 (d, *J* = 8.0 Hz, 1H, Ar), 7.64 (d, *J* = 7.5 Hz, 1H, Ar), 7.60 (t, *J* = 7.5 Hz, 1H, Ar), 7.52−7.25 (m, 23H, Ar), 7.22 (t, *J* = 8.0 Hz, 2H, Ar), 7.12 (t, *J* = 8.0 Hz, 1H, Ar), 7.08 (t, *J* = 7.5 Hz, 1H, Ar), 5.79 (d, *J* = 3.0 Hz, 1H), 5.67 (dd, *J* = 10.5, 8.0 Hz, 1H), 5.64 (dd, *J* = 10.0, 8.0 Hz, 1H), 5.47 (dd, *J* = 10.5, 3.5 Hz, 1H), 5.34 (dd, *J* = 10.0, 8.0 Hz, 1H), 4.98 (dd, *J* = 7.0, 3.0 Hz, 1H), 4.96 (dd, *J* = 7.0, 3.0 Hz, 1H), 4.74 and 4.55 (AB, *J* = 11.5 Hz, 2H), 4.70 and 4.60 (AB, *J* = 11.0 Hz, 2H), 4.62 (d, *J* = 10.5 Hz, 2H), 4.46 (d, *J* = 8.5 Hz, 1H), 4.26 (dd, *J* = 10.5, 7.0 Hz, 1H), 4.21 (m, 2H), 4.17−3.99 (m, 6H), 3.94 (d, *J* = 3.0 Hz, 1H), 3.72 (m, 4H), 3.58 (dt, *J* = 10.0, 5.0 Hz, 1H), 3.28 (m, 1H), 3.06 (t, *J* = 6.5 Hz, 2H, $CH_2CH_2N_3$), 2.69

(m, 2H), 2.48 (m, 2H, $CH_2CH_2N_3$), 2.16, 2.01, 1.97 (3 × s, 9H), 1.54 (m, 1H), 1.45 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 206.3, 172.2, 170.2, 169.3, 165.4, 165.3, 165.2, 164.8, 154.4, 143.1, 142.8, 141.1, 141.0, 137.7, 137.4, 133.4, 133.2, 133.1, 130.0, 129.7, 129.64, 129.55, 129.2, 129.0, 128.8, 128.5, 128.4, 128.2, 128.1, 127.9, 127.73, 127.70, 127.6, 127.02, 126.99, 125.0, 124.9, 119.8, 101.3, 101.1, 100.8 (three anomeric carbons), 77.3, 75.1, 75.0, 73.7, 73.3, 73.2, 72.9, 72.1, 71.6, 70.0, 69.8, 69.6, 68.9, 68.5, 66.4, 66.1, 62.3, 47.7, 46.4, 37.8, 29.7, 28.6, 27.7, 20.71, 20.66. MALDI HR-MS: *m*/*z* 1610.5524 $[M + Na]^+$, calcd for $C_{87}H_{85}N_3O_{26}$ 1610.5421.

3-Azidopropyl 2,3-Di-*O*-acetyl-4-*O*-benzyl-6-*O*-levulinoyl-β-D-galactopyranosyl-(1→6)-[2-*O*-benzyl-3,5-*O*-(di-*tert*-butylsilanediyl)-β-L-arabinofuranosyl-(1→3)]-2-*O*-benzoyl-4-*O*-benzyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranoside (29). Et_3N (2.4 mL) was added to a solution of **27** (157 mg, 99 μmol) in CH_2Cl_2 (12 mL). After it was stirred at room temperature for 18 h, the reaction mixture was concentrated in vacuo and the residue was purified by flash column chromatography (hexane/EtOAc, 1/1 → 1/2) to furnish **28** (111 mg, 82%) as a white foam, which was used directly in the next step without further identification: R_f = 0.28 (hexane/EtOAc, 1/1.2). MALDI HR-MS: *m*/*z* 1388.5251 $[M + Na]^+$, calcd for $C_{72}H_{75}N_3O_{24}$ 1388.4741. A mixture of the thioglycoside **3** (76 mg, 0.16 mmol) and the sugar alcohol **28** (111 mg, 81 μmol) in CH_2Cl_2 (10 mL) was stirred at room temperature in the presence of 4 Å molecular sieves (500 mg) for 30 min and then cooled to −30 °C. NIS (48 mg, 0.21 mmol), followed by a solution of AgOTf (28 mg, 0.1 mmol) in toluene (0.2 mL), was added. The reaction mixture was warmed slowly to room temperature, stirred for 15 min, and then quenched by the addition of Et_3N. The suspension was diluted with EtOAc (40 mL) and filtered through a pad of Celite, and the filtrate was washed successively with 10% $Na_2S_2O_3$ (8 mL) and brine (10 mL). The organic layer was dried ($MgSO_4$) and concentrated in vacuo to give a residue, which was purified by flash column chromatography (hexane/EtOAc, 2/1 → 1/1) to furnish the tetrasaccharide **29** (94 mg, 67%) as a white amorphous solid: R_f = 0.21 (hexane/EtOAc, 1.5/1). ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.01 (t, J = 7.0 Hz, 4H, Ar), 7.92 (d, J = 7.5 Hz, 2H, Ar), 7.72 (d, J = 7.5 Hz, 2H, Ar), 7.59 (t, J = 7.5 Hz, 1H, Ar), 7.54 (t, J = 7.0 Hz, 1H, Ar), 7.50 (t, J = 7.5 Hz, 1H, Ar), 7.46−7.19 (m, 24H, Ar), 5.76 (d, J = 3.0 Hz, 1H), 5.61 (dd, J = 10.5, 8.0 Hz, 1H), 5.55 (t, J = 9.0 Hz, 1H), 5.44 (dd, J = 10.0, 3.5 Hz, 1H), 5.30 (dd, J = 10.0, 8.0 Hz, 1H), 5.05 (d, J = 11.0 Hz, 1H), 5.02 (d, J = 5.0 Hz, 1H, H-1‴), 4.95 (dd, J = 10.5, 3.0 Hz, 1H), 4.78 (d, J = 12.5 Hz, 1H), 4.72 and 4.68 (AB, J = 12.0 Hz, 2H), 4.58−4.49 (m, 4H), 4.42 (d, J = 8.0 Hz, 1H), 4.19 (m, 2H), 4.14 (dd, J = 11.0, 7.0 Hz, 1H), 4.05 (dd, J = 7.5, 3.0 Hz, 1H), 3.98 (dd, J = 11.0, 3.0 Hz, 1H), 3.94 (d, J = 2.5 Hz, 1H), 3.89 (m, 2H), 3.84 (br s, 1H), 3.79 (dd, J = 10.0, 2.0 Hz, 1H), 3.72−3.64 (m, 4H), 3.53 (t, J = 6.0 Hz, 1H), 3.49 (dt, J = 10.0, 5.0 Hz, 1H), 3.38 (m, 2H), 3.24 (m, 1H), 3.03 (m, 2H), 2.67 (m, 2H), 2.47 (t, J = 6.5 Hz, 2H), 2.15, 1.99, 1.92 (3 × s, 9H), 1.50 (m, 1H), 1.42 (m, 1H), 0.90, 0.87 (2 × s, 18H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 206.4, 172.2, 170.3, 169.4, 165.4, 165.3, 165.2, 164.8, 138.6, 137.7, 137.5, 133.4, 133.2, 133.1, 132.9, 130.3, 130.0, 129.73, 129.70, 129.6, 129.2, 129.1, 128.8, 128.5, 128.4, 128.33, 128.27, 128.2, 128.0, 127.9, 127.7, 127.3, 101.5, 101.1, 101.0, 100.3 (four anomeric carbons), 80.1, 80.0, 78.2, 75.1, 74.6, 73.8, 73.74, 73.70, 73.3, 73.1, 72.0, 71.7, 71.5, 71.2, 69.8, 69.7, 69.0, 68.4, 67.9, 67.7, 66.1, 62.3, 47.8, 37.8, 29.8, 28.6, 27.7, 27.4, 27.0, 22.3, 20.8, 20.7, 19.9. MALDI HR-MS: *m*/*z* 1750.8198 $[M + Na]^+$, calcd for $C_{92}H_{105}N_3O_{28}Si$ 1750.6654.

3-Azidopropyl 2-*O*-Benzyl-3,5-*O*-(di-*tert*-butylsilanediyl)-β-L-arabinofuranosyl-(1→6)-2,3-di-*O*-acetyl-4-*O*-benzyl-β-D-galactopyranosyl-(1→6)-[2-*O*-benzyl-3,5-*O*-(di-*tert*-butylsilanediyl)-β-L-arabinofuranosyl-(1→3)]-2-*O*-benzoyl-4-*O*-benzyl-β-D-galactopyranosyl-(1→6)-2,3,4-tri-*O*-benzoyl-β-D-galactopyranoside (31). Hydrazine acetate (10 mg, 0.11 mmol) was added to a solution of **29** (92 mg, 53 μmol) in a mixture of CH_2Cl_2 (9 mL) and MeOH (0.9 mL). After it was stirred at room temperature for 5 h, the reaction mixture was concentrated in vacuo and the residue was purified by flash column chromatography (hexane/EtOAc, 2/1 → 1/1) to afford **30** (69 mg, 80%) as a white amorphous solid, which was used directly in the next step without further identification: R_f = 0.21 (hexane/EtOAc, 1.5/1). MALDI HR-MS: *m*/*z* 1652.4940 $[M + Na]^+$, calcd for $C_{87}H_{99}N_3O_{26}Si$ 1652.6286. The coupling of the glycosyl donor **3** (19 mg, 40 μmol) and the acceptor **30** (26 mg, 16 μmol) was performed as described for **29** to give the pentasaccharide **31** (28 mg, 89%) as a white amorphous solid: R_f = 0.61 (hexane/EtOAc, 1.4/1). $[\alpha]^{25}_D$ = −175.9° (*c* 0.7, CH_2Cl_2). ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.03 (t, J = 7.0 Hz, 4H, Ar), 7.94 (d, J = 8.0 Hz, 2H, Ar), 7.75 (d, J = 7.5 Hz, 2H, Ar), 7.61 (t, J = 7.5 Hz, 1H, Ar), 7.56 (t, J = 7.5 Hz, 1H, Ar), 7.52 (t, J = 7.5 Hz, 1H, Ar), 7.48−7.22 (m, 29H, Ar), 5.79 (d, J = 3.0 Hz, 1H), 5.63 (dd, J = 10.0, 8.0 Hz, 1H), 5.57 (t, J = 10.0 Hz, 1H), 5.46 (dd, J = 10.5, 3.0 Hz, 1H), 5.28 (dd, J = 10.0, 8.0 Hz, 1H), 5.07 (d, J = 11.0 Hz, 1H), 5.03 (d, J = 5.0 Hz, 1H, H-1‴), 4.93 (dd, J = 10.5, 3.0 Hz, 1H), 4.85 and 4.70 (AB, J = 12.0 Hz, 2H), 4.83 (d, J = 8.0 Hz, 1H, H-1), 4.80 and 4.75 (AB, J = 12.5 Hz, 2H), 4.61 (q-like, J = 12.0 Hz, 2H), 4.58 (d, J = 8.0 Hz, 1H, H-1′), 4.53 (d, J = 9.0 Hz, 1H), 4.52 (d, J = 7.5 Hz, 1H, H-1″), 4.39 (br s, 1H), 4.37 (d, J = 4.0 Hz, 1H, H-1⁗), 4.33 (m, 1H), 4.20 (t, J = 9.0 Hz, 1H), 4.05 (m, 2H), 4.00−3.89 (m, 5H), 3.85 (br s, 1H), 3.80 (d-like, J = 10.0 Hz, 1H), 3.74−3.59 (m, 7H), 3.53 (m, 2H), 3.40 (m, 2H), 3.26 (m, 1H), 3.06 (m, 2H), 1.93, 1.91 (2 × s, 6H), 1.53 (m, 1H), 1.45 (m, 1H), 1.11, 1.03, 0.92, 0.88 (4 × s, 36H). ^{13}C NMR (125 MHz, $CDCl_3$): δ 170.1, 169.5, 165.4, 165.32, 165.27, 164.8, 138.8, 138.4, 137.83, 137.79, 133.4, 133.2, 133.1, 132.9, 130.4, 130.0, 129.8, 129.7, 129.6, 129.3, 129.2, 128.9, 128.5, 128.4, 128.31, 128.29, 128.26, 128.24, 128.19, 128.0, 127.9, 127.72, 127.66, 127.5, 127.2, 101.5, 101.23, 101.20, 101.16, 100.2 (five anomeric carbons), 80.5, 80.2, 80.0, 78.8, 78.2, 74.9, 74.6, 74.0, 73.9, 73.7, 73.5, 73.43, 73.36, 73.1, 72.8, 71.7, 71.6, 71.2, 69.9, 69.0, 68.34, 68.28, 67.9, 67.6, 66.2, 66.1, 47.8, 28.7, 27.6, 27.4, 27.1, 27.0, 22.6, 22.3, 20.8, 20.7, 20.1, 19.9. MALDI HR-MS: *m*/*z* 2014.8250 $[M + Na]^+$, calcd for $C_{107}H_{129}N_3O_{30}Si_2$ 2014.8200.

3-Aminopropyl β-L-Arabinofuranosyl-(1→6)-β-D-galactopyranosyl-(1→6)-[β-L-arabinofuranosyl-(1→3)]-β-D-galactopyranosyl-(1→6)-β-D-galactopyranoside (32). TBAF (75 μL, 1.0 M in THF) and AcOH (11.0 μL) were added to the solution of the pentasaccharide **31** (25 mg, 12.5 μmol) in THF (3 mL). The reaction mixture was stirred at room temperature for 26 h, after which the solvent was removed in vacuo. The reaction residue was dissolved in DCM, washed with water (2 × 5 mL), and then dried ($MgSO_4$). After filtration and evaporation of solvent, the residue was dried in vacuo for several hours. Then, it was dissolved in dry MeOH (6 μL) and treated with NaOMe (10 mg, 30% in MeOH). The reaction mixture was stirred at 50 °C in an oil bath for 1 h and then neutralized with weakly acidic resin (Amberlite IRC-50). After filtration and concentration in vacuo, the residue was purified by silica gel column chromatography (DCM/MeOH, 10/1). MALDI HR-MS: *m*/*z* 1234.4219 $[M + Na]^+$, calcd for $C_{59}H_{77}N_3O_{24}$ 1234.4897. Pd/C (10%, 1.5 times the weight of the starting material) was added to a solution of the protected azido pentasaccharide in pyridine under an atmosphere of Ar. After evacuation, the flask was placed under an atmosphere of H_2. The reaction mixture was stirred for 18 h until TLC analysis. Hexane/EtOAc (1/1, v/v), $CHCl_3/CH_3OH$ (9/1, v/v), and *i*-PrOH/28% NH_4OH (95/5, v/v) indicated completion of the reaction. The mixture was filtered through a polytetrafluoroethene (PTFE) syringe filter (diameter 25 mm, pore size 0.2 mm), which was further washed with pyridine. The solvents were coevaporated with toluene. The residue was dried in vacuo for several hours. Matrix-assisted time-of-flight (MALDI-TOF) MS and NMR spectroscopy confirmed the reduction of the azido groups. $Pd(OH)_2$ (Degussa type, Aldrich, 2.0 times the weight of the starting material) was added to the material obtained above and dissolved in a mixture of *t*-BuOH, AcOH, and H_2O (5/10/1, v/v/v, 2−5 mL) under Ar. The mixture was placed under an atmosphere of H_2 and stirred overnight. TLC analyses *i*-PrOH/28% NH_4OH (95/5, v/v) and *i*-PrOH/H_2O/28% NH_4OH (30/

10/5, v/v or 30/20/10, v/v) indicated the presence of a single compound. The mixture was filtered through a PTFE syringe filter (as above) and further washed with AcOH. The solvents were coevaporated with toluene. The residue was dried in vacuo for several hours. The recovered materials were passed through a small amount of Iatrobeads and slowly eluted with a mixture of *i*-PrOH and 28% NH_4OH. Fractions containing the products were collected and concentrated in vacuo. The products were brought to pH 4.5 by the addition of AcOH and freeze-dried to afford the fully deprotected pentasaccharide **32** (3.5 mg, 34% over four steps). ^{1}H NMR (500 MHz, $CDCl_3$): δ 5.08 (d, $J = 4.5$ Hz, 1H, H-1‴), 4.93 (d, $J = 4.5$ Hz, 1H, H-1⁗), 4.42 (d, $J = 8.0$ Hz, 1H, H-1), 4.37 (d, $J = 7.5$ Hz, 1H, H-1′), 4.34 (d, $J = 8.0$ Hz, 1H, H-1″), 4.13−4.02 (m, 5H, H-2‴, H-2⁗), 3.99−3.89 (m, 4H), 3.86−3.73 (m, 8H, H-3‴, H-3), 3.71−3.65 (m, 3H, H-3⁗), 3.64−3.51 (m, 6H, H-2, H-3′, H-3″), 3.46−3.40 (m, 2H, H-2′, H-2″), 3.07−3.03 (m, 2H, $CH_2CH_2NH_2$), 1.92−1.88 (m, 2H, $CH_2CH_2NH_2$). ^{13}C NMR (125 MHz, $CDCl_3$): δ 103.5, 103.4, 103.1, 101.2, 98.9 (five anomeric carbons), 82.0, 78.8, 76.4, 74.6, 73.8, 73.6, 73.4, 73.1, 72.6, 70.9, 70.6, 69.4, 69.3, 69.2, 68.4, 67.3, 67.1, 66.0, 63.2, 62.7, 62.1, 61.4, 61.3, 61.2, 44.8, 27.0. MALDI HR-MS: *m*/*z* 848.3322 $[M + Na]^+$, calcd for $C_{31}H_{55}NO_{24}$ 848.3114.

Computational Methods. All the geometry optimizations were performed with the Gaussian03 program[35] using density functional theory (B3LYP[36−38]) and the 6-31G** basis set.[39] The figures were generated using Insight II. The *xyz* coordinates of all the optimized structures are given in the Supporting Information.

Acknowledgment. This research was supported by the NSF (Grant No. DBI 0421683).

Supporting Information Available: Text giving procedures for the preparation of compounds **22**−**24**, figures giving ^{1}H NMR spectra of all synthetic compounds, tables giving *xyz* coordinates of optimized structures, and a full list of authors for reference 35. This material is available free of charge via the Internet at http://pubs.acs.org.

JA0629817

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