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Organoboron-Promoted Regioselective Glycosylations in the Synthesis of a Saponin-Derived Pentasaccharide from *Spergularia ramosa*

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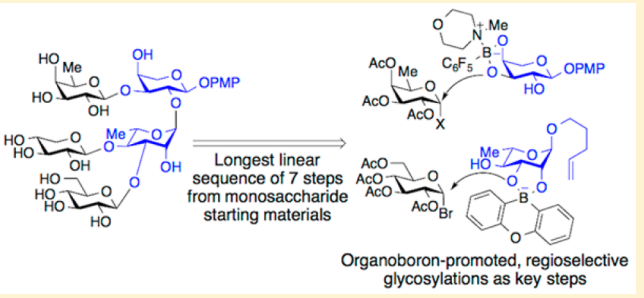
Supporting Information

ABSTRACT: Organoboron-mediated regioselective glycosylations were employed as key steps in the total synthesis of a branched pentasaccharide from a saponin natural product. The ability to use organoboron activation to differentiate OH groups in an unprotected glycosyl acceptor, followed by substrate-controlled reactions of the obtained disaccharide, enabled a streamlining of the synthesis relative to a protective group-based approach. This study revealed a matching/mismatching effect of the relative configuration of donor and acceptor on the efficiency of a regioselective glycosylation reaction, a problem that was solved through the development of a novel boronic acid−amine copromoter system for glycosyl acceptor activation.



INTRODUCTION

Despite advances in methodology and technology for glycosidic bond construction, including one-pot reactivity-based assembly,[1] substrate-controlled, regioselective glycosylations,[2] and automated synthesis,[3] the laboratory synthesis of oligosaccharide natural products remains a time-consuming, laborious, and material-intensive task. A primary source of inefficiency in oligosaccharide synthesis is the use of protective groups to enable regiocontrolled glycosylations. The preparation of selectively protected building blocks often occupies a significant fraction of the total research time involved, and protection/deprotection steps almost invariably outnumber glycosylations.[4,5] Recently disclosed chemoenzymatic syntheses of the blood group B antigen,[6] heparins,[7] and asymmetrically branched *N*-glycans[8] illustrate the dramatic increases in efficiency that are possible by minimizing protective group manipulations in oligosaccharide synthesis.[9]

Although reagent-[10,11] and catalyst-controlled glycosylations[12] arguably represent a complementary set of tools for streamlining the synthesis of oligosaccharides,[13] applications in the preparation of complex targets of this type have been slow to emerge. A pioneering example was reported by O'Doherty and co-workers, who employed Pd-catalyzed, regioselective glycosylation of a stannylene acetal as a key step in the synthesis of the cleistrioside and cleistetroside natural products.[14] Recently, the O'Doherty group has developed a dual catalytic method that merges Pd-mediated glycosyl donor activation with the organoboron-mediated glycosyl acceptor activation strategy developed in our laboratory;[12a] when combined with borinic acid-catalyzed regioselective acylations, this method enabled elegant syntheses of all members of the mezzettiaside family of natural products.[15]

Herein, we describe the synthesis of a branched pentasaccharide derived from a saponin-type natural product, employing organoboron-mediated regioselective glycosylations as key steps. This contribution details a new protocol for boronic acid/Lewis base-promoted activation of glycosyl acceptors and demonstrates how differentiation of hydroxyl (OH) groups by selective glycosylation can minimize protection/deprotection steps in the synthesis of branched oligosaccharides.

RESULTS AND DISCUSSION

Retrosynthetic Analysis. Triterpenoid saponins **1a−d** (Figure 1) are amphiphilic glycosides isolated from the South American herbaceous plant *Spergularia ramosa*.[16] Saponin natural products exert a wide range of biological effects, including stimulation of the immune response and augmentation of targeted immunotoxins. Although biological activities of **1a−d** have not been reported, the plant from which they are derived has been employed in indigenous medicine as an antitubercular agent. The pentasaccharide substituent R^1 common to **1a−d** is composed of β-D-glucopyranosyl, β-D-xylopyranosyl, α-L-rhamnopyranosyl-, β-D-fucopyranosyl, and α-L-arabinopyranosyl moieties. We anticipated that the two 1,2-*trans*-configured glycosidic linkages at the equatorial positions of pyranoside-derived *cis*-vicinal diol groups (that is, the β-(1→3)-D-Fuc-L-Ara and β-(1→3)-D-Glc-L-Rha linkages) could be constructed from unprotected pyranosides as glycosyl acceptors using borinic acid-catalyzed protocols developed in our laboratories.[12a] The prospect of using such selective glycosylations as key steps in

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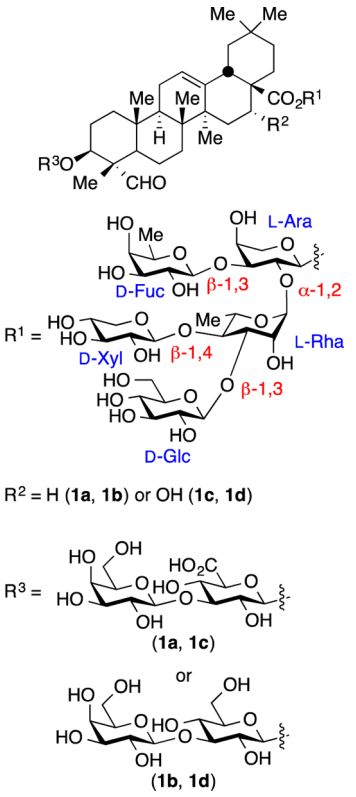


Figure 1. Triterpenoid saponins **1a**–**d** from *Spergularia ramosa*.

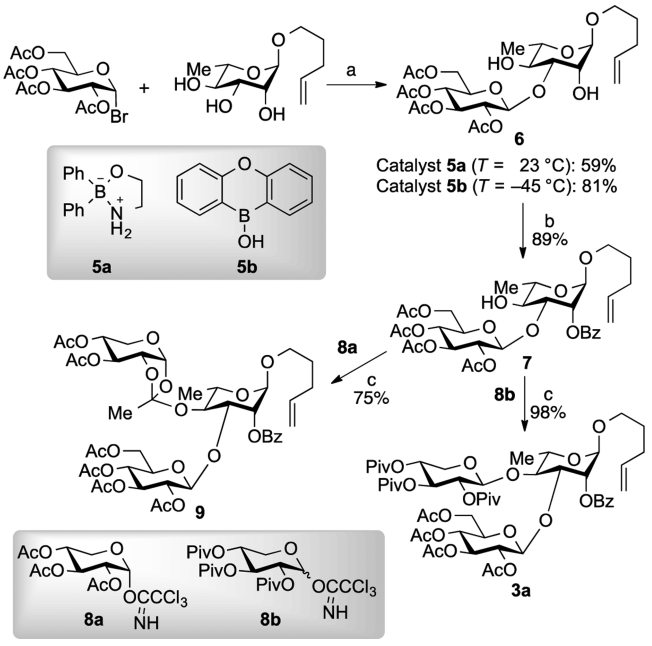
the preparation of 4-methoxyphenyl (PMP) α-glycoside **2** led to the retrosynthetic analysis depicted in Scheme 1.

A regioselective fragment coupling was envisioned wherein a trisaccharide-derived donor (**3**) would react selectively with the 2-OH group of partially protected β-(1→3)-D-Fuc-L-Ara disaccharide acceptor **4a**. The latter could be accessed directly by regioselective glycosylation of 4-methoxyphenyl arabinopyranoside. We anticipated that the requisite trisaccharide donor could be generated from the product of a regioselective glycosylation through protection and glycosylation of the rhamnosyl 2-OH and 4-OH groups, respectively. The relative reactivities of these two OH groups would determine the order in which these two operations would be executed. The use of regioselective glycosylations as initial OH group differentiation steps suggested the possibility of a simple protective group strategy, employing ester groups for all nonanomeric OH moieties, and thus enabling the use of a final, global deprotection. Only the anomeric position of the rhamnosyl group would require an orthogonal protective group: the *n*-pentenyl group was chosen for this purpose, as it allows for either hydrolysis to the free hemiacetal[17] (which, in turn, is a useful precursor to several classes of glycosyl donors) or direct application as a glycosyl donor by activation with an electrophilic iodinating reagent.[18]

Direct precedent for the approach shown in Scheme 1 (and the only reported synthesis of the pentasaccharide moiety common to **1a**–**d**) is the work of Gu and Du, who prepared a peracylated allyl β-glycoside analogue of pentasaccharide **2**.[19] This previous synthesis made use of a similar convergent approach to that described above, coupling a disaccharide-derived acceptor to a trisaccharide-derived donor, but employed a more conventional, protective-group-based approach to OH group differentiation. The reported synthesis provides a benchmark for evaluating the utility of regioselective glycosylations in the current approach.

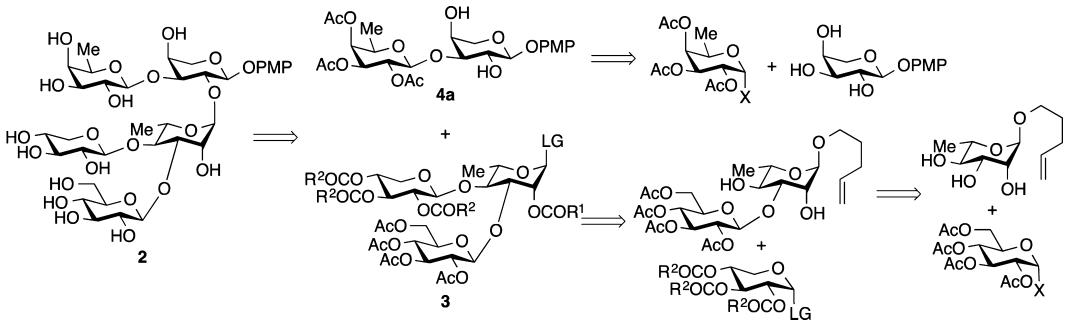
*Preparation of Trisaccharide **3a**.* Our initial efforts were focused on the preparation of trisaccharide **3a** (Scheme 2). The

Scheme 2. Synthesis of Trisaccharide 3a[a]



[a]Reagents and conditions: (a) catalyst (**5a** or **5b**, 10 mol %), Ag_2O, CH_3CN, T °C (catalyst **5a**, 23 °C: 59%; catalyst **5b**, − 45 °C: 81%); (b) BzCl, pyridine, 0 °C; (c) **8a** or **8b**, TMSOTf (10 mol %), CH_2Cl_2, 0 °C (**9**: 75%; **3a**: 98%).

Scheme 1. Retrosynthetic Analysis of Pentasaccharide 2[a]



[a]X denotes a halogen (Br or Cl); LG denotes a leaving group; PMP = 4-methoxyphenyl.

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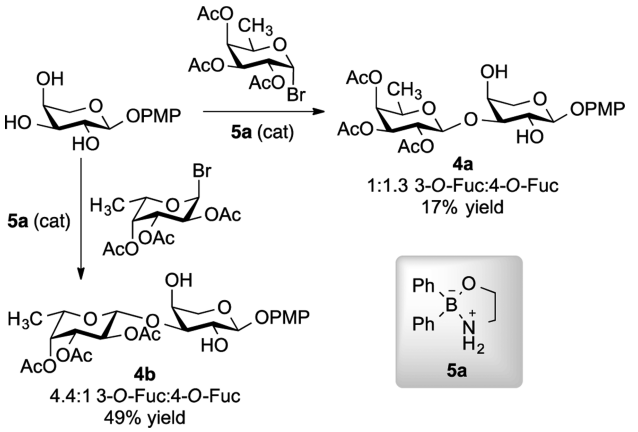
coupling of pentenyl α-rhamnopyranoside (prepared over two steps in 50% yield from commercially available 1,2,3,4-tetra-*O*-acetyl-α/β-L-rhamnopyranose)[20] with peracetylated glucopyranosyl bromide was accomplished in a modest 59% yield using our previously reported protocol, with borinic ester **5a** as precatalyst.[12a] Control experiments revealed that an uncatalyzed background reaction was responsible for the formation of regioisomeric byproducts. This problem could be overcome by carrying out the reaction at reduced temperature (−45 °C) in the presence of oxaboraanthracene-derived borinic acid catalyst **5b**. Under these conditions, disaccharide **6** was obtained in 81% yield. We have previously shown that incorporating the borinic acid group into a 6π electron system, as in **5b**, results in improved catalytic activity for several substrate combinations.[21] Reaction kinetics and computational studies suggested that this effect results from the higher nucleophilic reactivity of borinates derived from **5b** relative to those derived from diphenylborinic acid. The present work demonstrates that the ability to conduct glycosylations at lower temperature and thus to suppress poorly selective background reactions is an additional advantage of **5b**.

Based on transformations of 3-*O*-benzyl-α-rhamnopyranosides described by Yang and co-workers,[22] we attempted selective benzoylation of the 2-OH group of disaccharide **6**. This was achieved in good yield using benzoyl chloride in pyridine at 0 °C,[23] conditions distinct from those developed for the 3-*O*-Bn-protected substrate in the study mentioned above (BzCl, Ag_2O, KI, CH_2Cl_2, 23 °C). Presumably, acylation of the 4-OH group is hindered by the presence of two relatively bulky, equatorially oriented vicinal substituents.[24] At this stage, formation of a β-xylopyranosyl linkage to the free 4-OH group of **7** was required. Coupling with acetylated xylosyl trichloroacetimidate **8a** in the presence of trimethylsilyl trifluoromethanesulfonate (TMSOTf) resulted in orthoester **9** as the major product. Attempts to generate the corresponding trisaccharide by varying the identity or the stoichiometry of the Lewis acid promoter, or by effecting a Lewis acid-promoted rearrangement of **9**, were unsuccessful.[25] However, the desired trisaccharide was obtained in good yield using xylosyl donor **8b**, bearing sterically hindered pivaloyl protective groups (prepared in four steps from D-xylose), in place of per-acetylated **8a**.[26]

*Preparation of Disaccharide Acceptor **4a**.* The other fragment required for this convergent approach, β-(1→3)-Fuc-Ara derivative **4a**, was targeted by application of a second catalyst-controlled glycosylation of a pyranoside-derived triol. However, the reaction of PMP α-L-arabinopyranoside with peracetylated D-fucosyl bromide using catalyst **5a** generated **4a** in only 17% yield (Scheme 3). A significant amount of the β-(1 → 4)-linked regioisomer was formed under these conditions: a ratio of 1:1.3 in favor of the undesired 4-*O*-glycosylated regioisomer was determined by HPLC analysis of the unpurified reaction mixture. An experiment using the L-configured fucopyranosyl bromide donor in place of the D-enantiomer under otherwise identical conditions generated the diastereomeric disaccharide (**4b**) in appreciably higher regioselectivity (4.4:1 3-*O*-glycosylation to 4-*O*-glycosylation by HPLC analysis, 49% isolated yield after purification). These observations suggest that a mismatch between the configurations of the glycosyl donor and the acceptor may contribute to the poor regioselectivity observed in the synthesis of **4a**. Acceptor/donor complementarity in glycosylation reactions has been discussed in detail:[27] whereas effects of donor/acceptor relative configuration on stereoselectivity have been reported,[28] the majority of investigations related to regiocontrol have concerned variation of the type of glycosyl donor or activation method used.[29] As definitive illustrations of the effects of donor/acceptor relative configuration on regiocontrol are rare,[30] further studies exploring the generality of this observation may be warranted. In the present case, we speculate that the lack of a bulky substituent at C-5 of the glycosyl acceptor, along with the use of a 6-deoxypyranosyl donor that is not fully disarmed,[31] may also contribute to the low selectivity. However, using the glycosyl chloride in the presence of the bromide was not fruitful, and employing catalyst **5b** in place of **5a** resulted in only a modest improvement in yield (31% versus 17%).

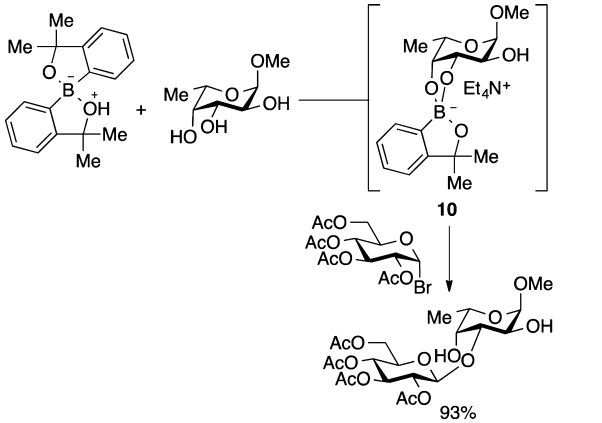
Scheme 3. Matching/Mismatching Effects on Regioselective Glycosylation[a]



[a]Reagents and conditions: **5a** (10 mol %), Ag_2O, CH_3CN, 23 °C.

In light of our inability to access **4a** in a synthetically useful yield by catalyst-controlled glycosylation, we considered an organoboron-mediated protocol involving Lewis base activation of a boronic ester. Processes of this type were developed in the laboratory of Aoyama for regioselective transformations of carbohydrate derivatives:[11,32] in particular, tetracoordinate boronates (e.g., **10**, Scheme 4) were found to behave as activated acceptors in couplings with glycosyl bromides. With the aim of developing an operationally simple protocol employing commercially available reagents, we elected to explore conditions akin to those employed by Aoyama for carbohydrate alkylation,[32]

Scheme 4. Glycosylation of a Tetracoordinate Boronate by Aoyama and Co-workers[a]



[a]Reagents and conditions: 4 Å MS, THF, reflux; then $Et_4N^+I^-$, 23 °C; then Ag_2CO_3, 0 → 23 → 50 °C.

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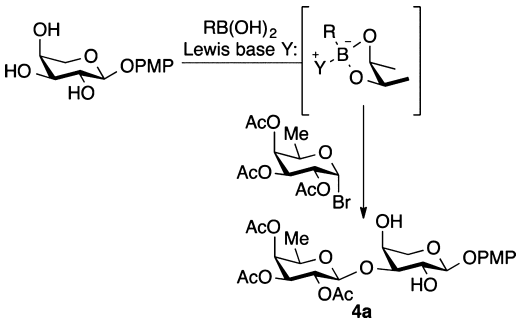
using a combination of boronic acid and Lewis base reagents. We have shown that such combinations, with both components used in catalytic amounts, also promote selective silylations of pyranoside derivatives, suggesting that the general approach is suitable for several classes of electrophiles.[33] An advantage is the ability to rapidly evaluate combinations of components, enabling "tailoring" of the system for a particular set of coupling partners. Indeed, we found that the yield of **4a** was dependent, and not in a straightforward way, on the identity of the boronic acid and Lewis base employed (Table 1). The optimal conditions

Table 1. Evaluation of Boronic Acid/Lewis Base Combinations for the Regioselective Synthesis of 4a[a]



boronic acid	Lewis base	yield[b] (%)
3,5-$(CF_3)_2$-$C_6H_3B(OH)_2$	Et_3N	22
$PhB(OH)_2$	Et_3N	43
9-anthraceneboronic acid	Et_3N	49
4-(OMe)-$C_6H_4B(OH)_2$	Et_3N	63
$C_6F_5B(OH)_2$	Et_3N	68
$C_6F_5B(OH)_2$	Me_3NO	<5
$C_6F_5B(OH)_2$	iPr_2NH	33
$C_6F_5B(OH)_2$	quinuclidine	<5
$C_6F_5B(OH)_2$	*N*-methylmorpholine	74[c]

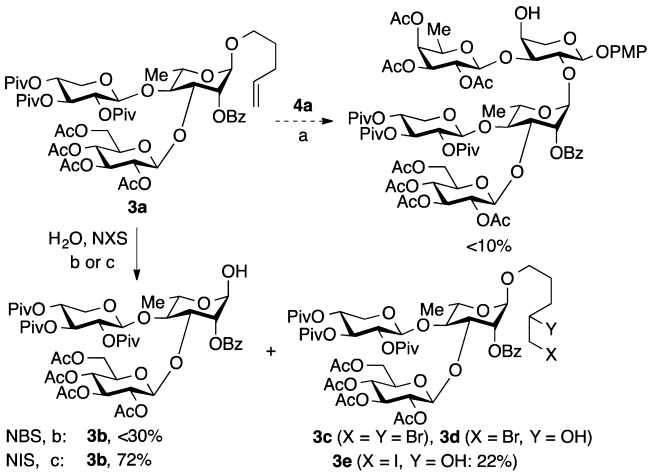
[a]Reagents and conditions: arabinopyranoside, $RB(OH)_2$ (1.0 equiv), 4 Å MS, CH_2Cl_2, 23 °C; then Ag_2O (1.0 equiv), Lewis base (6 equiv) and glycosyl bromide (1.1 equiv), 0 → 23 °C. [b]Yields of **4a** after purification by silica gel chromatography. [c]Portionwise addition of glycosyl donor over 8 h.

involved activation of the acceptor-derived pentafluorophenylboronate with *N*-methylmorpholine (NMM), generating **4a** in 74% yield. A one-pot protocol was employed in which the boronic acid and arabinopyranoside were stirred at 23 °C in the presence of molecular sieves (MS) prior to addition of the glycosyl donor, Lewis base, and Ag_2O.

Fragment Coupling and Synthesis of ***2****.* Having achieved the synthesis of the di- and trisaccharide building blocks, we turned our attention to the fragment coupling reaction. Attempts to employ the pentenyl glycoside **3a** directly in a regioselective coupling with **4a** were not successful: activation of the pentenyl group with *N*-iodosuccinimide (NIS) and TMSOTf led to a complex mixture of products, whereas milder conditions (I_2, 1,2-dichloroethane, −25 °C[34]) led to recovery of the starting materials (Scheme 5).

After failing to improve upon these results through additional experimentation, we attempted the hydrolysis of the pentenyl glycoside to the corresponding free hemiacetal, which could then be converted into another glycosyl donor. However, subjecting **3a** to the standard conditions for pentenyl glycoside hydrolysis developed by Fraser-Reid and co-workers (*N*-bromosuccinimide (NBS), aqueous CH_3CN[17]) resulted in only a low (<30%) yield

Scheme 5. Attempts at Glycosidation and Hydrolysis of Pentenyl Glycoside 3a[a]



[a]Reagents and conditions: (a) **4a**, NIS, TMSOTf (30 mol %), CH_2Cl_2, 23 °C; (b) NBS, 1% H_2O in CH_3CN, <30%; (c) NIS, TMSOTf (30 mol %), 0.1% H_2O in CH_2Cl_2, 72%.

of hemiacetal **3b**, along with the alkene-derived vicinal dibromide and bromohydrin products **3c** and **3d**. This problem was overcome by carrying out the hydrolysis in the presence of NIS and TMSOTf, promoters that are typically used for glycosidation reactions of this class of compounds.[35] Under these conditions, the anomeric hemiacetal was obtained in 72% yield, with the iodohydrin **3e** being the only detectable byproduct (22% yield). Subjecting the simpler substrate pentenyl 2,3,4-tri-*O*-benzoyl-α-L-rhamnopyranoside to these two sets of reaction conditions gave rise to analogous observations: NBS in aqueous acetonitrile generated the free hemiacetal in only 20% yield, along with vicinal dibromide and bromohydrin byproducts (15% and 26% yield, respectively), whereas NIS/TMSOTf in dichloromethane/water resulted in a 70% yield of hemiacetal, along with 15% of the iodohydrin byproduct.

The final glycosylation was achieved by conversion of **3b** to the corresponding α-configured trichloroacetimidate, followed by coupling with **4a** in the presence of TMSOTf (Scheme 6). The selective 2-*O*-glycosylation of **4a** is presumably the result of steric effects. The primary side product—an octasaccharide generated through bis-glycosylation of **4a**, could be minimized by using 1.5 equiv of the acceptor. Under these conditions, protected pentasaccharide **11** was generated in 85% yield. Global deprotection was accomplished by saponification with potassium hydroxide in methanol, generating PMP glycoside **2** in 74% yield after purification by size exclusion chromatography. With the exception of expected differences in the chemical shifts of resonances corresponding to the arabinopyranoside moiety, the proton nuclear magnetic resonance spectrum of **2** in CD_3OD was in excellent agreement with the data reported for the pentasaccharide segment of **1a** (Supporting Information, Table S1).[16]

CONCLUSIONS

The synthesis of pentasaccharide **2** was accomplished in a longest linear sequence of nine steps and 13% overall yield from commercially available 1,2,3,4-tetra-*O*-acetyl-α/β-L-rhamnopyranose (seven steps from the previously reported pentenyl α-L-rhamnopyranoside). Taking into account the preparation of **4a** (three steps from 1,2,3,4-tetra-*O*-acetyl-L-arabinopyranose and

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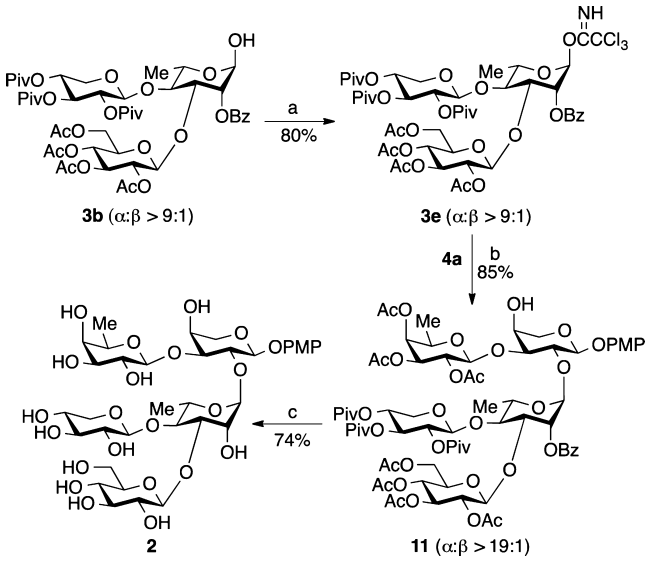
Scheme 6. Fragment-Coupling Glycosylation and Global Deprotection[a]



[a]Reagents and conditions: (a) Cl_3CCN, Cs_2CO_3, CH_2Cl_2, 0 °C, 80% (α:β > 9:1); (b) **4a**, TMSOTf (10 mol %), CH_2Cl_2, −78 °C, 85% (α:β > 19:1); (c) KOH, CH_3OH, 23 °C, 74%.

per-acetylated D-fucopyranosyl bromide) and **8b** (four steps from D-xylose) gives a total of 16 steps. The previously reported synthesis of Gu and Du generated the allyl glycoside analogue of **2** in a longest linear sequence of 11 steps from L-arabinose (assuming that a global deprotection similar to the conversion of **11** to **2** could be carried out on the peracylated product of the latter study) and a total of 22 steps from commercially available precursors. The use of organoboron-catalyzed and -mediated glycosylations thus enabled an improvement in efficiency, especially as reflected by the total number of steps required for the two syntheses.[36] This lower step count resulted from a reduced number of protective group installation/removal reactions. For instance, the synthesis of the β-(1→3)-D-Fuc-L-Ara disaccharide fragment by Gu and Du involved the preparation of a 3,4-*O*-isopropylidene-protected arabinopyranoside, followed by 2-*O*-acetylation, hydrolysis of the isopropylidene group, sequential 3-*O*-silylation, and 4-*O*-benzoylation, followed by desilylation and glycosylation of the free 3-OH group. Selective saponification of the 2-*O*-acetyl group was then followed by coupling with a trisaccharide-derived trichloroacetimidate to construct the α-(1 → 2)-L-Ara-L-Rha linkage, thus generating the pentasaccharide target (a nine-step sequence from the arabinopyranoside starting material). In the present study, boronic acid activation of the arabinopyranoside enabled the selective preparation of the β-(1→3)-D-Fuc-L-Ara disaccharide **4a**, which was subjected directly to a regioselective 2-*O*-glycosylation with trisaccharide donor **3e** to form pentasaccharide **11** (a two-step glycosylation sequence).

Several observations from this work can be highlighted. The relatively high catalytic activity of oxaboraanthracene-derived borinic acid **5b** at low temperature proved to be instrumental to the efficient, regioselective construction of the β-(1→3)-D-Glc-L-Rha linkage. A matching/mismatching effect of glycosyl donor configuration on regioselectivity was inferred in the synthesis of the β-(1→3)-D-Fuc-L-Ara disaccharide. This challenge was ultimately overcome by the development of a boronic acid/amine copromoter system for regioselective glycosylation. Finally, two transformations (the selective benzoylation of **6** and the glycosylation of **4a**) illustrate the utility of regioselectively manipulating disaccharide-derived diols prepared by organoboron-mediated glycosylation. We anticipate that this tactic of using catalyst- or reagent-controlled glycosylations as initial OH differentiation steps, followed by substrate-controlled transformations of the resulting disaccharides, may be applicable to the synthesis of other oligosaccharide targets.

EXPERIMENTAL SECTION

Experimental procedures and characterization data are provided below for all new compounds reported here.

General Procedures. Stainless steel syringes were used to transfer air- and moisture-sensitive liquids. Flash chromatography was performed using silica gel (230−400 mesh). Thin-layer chromatography (TLC) was performed using aluminum-backed silica gel plates. Preparative TLC was performed using glass-backed silica gel plates (mean particle size 25 μm).

Materials. Dichloromethane and acetonitrile were purified by passing through two columns of activated alumina under nitrogen. Deionized water was acquired from an in-house supply. *N*-Iodosuccinamide (NIS) was recrystallized by a 1:1 (v/v) mixture of 1,4-dioxane and diethyl ether, and *N*-bromosuccinimide was recrystallized from water. Pyridine was dried over calcium hydride with stirring at 80 °C. The remainder of the reagents and solvents were purchased from commercial suppliers and used without further purification.

Instrumentation. Proton nuclear magnetic resonance (^{1}H NMR) spectra and carbon nuclear magnetic resonance (^{13}C NMR) spectra were recorded on a 300, 400, 500, 600, or 700 MHz spectrometer (500 and 700 spectrometers are equipped with a cryogenic probe). Chemical shifts for protons are reported in parts per million (ppm) downfield from tetramethylsilane and are referenced to residual protium in the NMR solvent ($CDCl_3$: δ 7.26; CD_3CN: δ 1.94; CD_3OD: δ 3.31; D_2O: δ 4.79). Chemical shifts for carbon are reported in parts per million downfield from tetramethylsilane and are referenced to the carbon resonances of the solvent (CD_3CN: δ 1.32; $CDCl_3$: δ 77.16; CD_3OD: δ 49.00). Data are represented as follows: chemical shift (δ, ppm); multiplicity (s, singlet; d, doublet; app t, apparent triplet; app q, apparent quartet; m, multiplet); integration; coupling constant (J, Hz), proton assignment. Proton resonances were assigned based on 2-D COSY, HSQC, and HMBC experiments. Glycosidic linkages were confirmed by 2-D COSY and HMBC experiments. High-resolution mass spectra (HRMS) were obtained on a VS 70−250S (double focusing) mass spectrometer at 70 eV using either electrospray ionization (ESI) or direct analysis in real time (DART) methods. Infrared (IR) spectra were obtained on a Fourier-transform IR instrument equipped with a single-bounce diamond/ZnSe ATR accessory. Spectral features are represented as follows: wavenumber (cm^{-1}); intensity (s, strong; m, medium; w, weak). Melting points were measured using a Fisher−Johns apparatus and are uncorrected. Optical rotations were measured on an automatic polarimeter.

Preparation of Monosaccharide Starting Materials. *2,3,4,6-Tetra-O-acetyl-α-D-glucopyranosyl Bromide.*[37] Acetic anhydride (28.4 mL, 300 mmol) was added to a solution of D-glucose (5.40 g, 30.0 mmol) in pyridine (50.0 mL) and stirred at 23 °C overnight. The solution was diluted with ethyl acetate and washed three times with aqueous hydrochloric acid (1 M). The organic phase was dried over $MgSO_4$ and filtered, and the solvent was removed under reduced pressure to give a white solid. The crude material was dissolved in anhydrous CH_2Cl_2 (60.0 mL) in an oven-dried round-bottom flask equipped with a stir bar and 4 Å molecular sieves under an atmosphere of argon and cooled to 0 °C. A solution of HBr (33% wt) in acetic acid (30.0 mL) was added slowly to the solution, and the flask was covered with aluminum foil. Once complete, as judged by disappearance of starting material on TLC, the reaction was diluted with CH_2Cl_2, filtered through Celite, and washed three times with water, saturated $NaHCO_3$, and water. The organic phase was collected, dried over $MgSO_4$, and filtered, and solvent was removed under reduced pressure to give a white

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solid. The crude isolate was recrystallized from ethanol to give the title compound as white needle-like prisms (9.05 g, 73%). NMR spectral data were in agreement with those reported previously.[37] ^{1}H NMR (300 MHz, $CDCl_3$): δ (ppm) 6.61 (d, 1H, J = 4.0 Hz, H-1), 5.56 (app t, 1H, J = 10.0 Hz, H-3), 5.16 (app t, 1H, J = 10.0 Hz, H-4), 4.84 (dd, 1H, J = 10.0, 4.0 Hz, H-2), 4.35−4.28 (m, 2H, H-5, H-6), 4.15−4.11 (m, 1H, H-6), 2.10 (s, 3H, CH_3CO), 2.10 (s, 3H, CH_3CO), 2.05 (s, 3H, CH_3CO), 2.04 (s, 3H, CH_3CO).

n-Pentenyl α-L-Rhamnopyranoside.[20] Acetic anhydride (15.0 mL, 160 mmol) was added to a solution of L-rhamnose (3.30 g, 20.0 mmol) in pyridine (20.0 mL) and stirred at overnight. The solution was diluted with dichloromethane and washed three times with aqueous hydrochloric acid (1 M). The organic phase was dried over $MgSO_4$ and filtered and solvent removed under reduced pressure to give 1,2,3,4-tetra-*O*-acetyl-α/β-L-rhamnopyranose as a viscous oil. The oil was dissolved in anhydrous CH_2Cl_2 (35 mL) and added by syringe to an oven-dried round-bottom flask equipped with a stir bar and 4 Å molecular sieves under an atmosphere of argon. 4-Penten-1-ol (3.00 mL, 30.0 mmol) was added, and the solution was stirred for 10 min at room temperature before cooling to 0 °C. Boron trifluoride diethyl etherate (10.0 mL, 80.0 mmol) was added dropwise to the reaction flask, and the reaction was allowed to warm to room temperature. After 24 h, the reaction was diluted with CH_2Cl_2 and quenched with aqueous $NaHCO_3$. The solution was filtered through a pad of Celite and washed with saturated $NaHCO_3$, water, and brine. The organic phase was collected, dried over $MgSO_4$, and filtered. The solvent was removed under reduced pressure. The crude isolate was purified by flash chromatography to afford *n*-pentenyl 2,3,4-tri-*O*-acetyl-α-L-rhamnopyranoside as a clear viscous oil. The oil was dissolved in methanol (74.0 mL), and sodium methoxide (120 mg, 2.20 mmol) was added to the reaction mixture and stirred at 23 °C until judged to be complete by disappearance of starting material on TLC. Dowex 50WX2-100 H^+ resin was rinsed with methanol and added to the reaction to neutralize the solution. The solution was filtered, and the solvent was removed under reduced pressure to afford the title compound as a clear viscous oil (2.30 g, 50%). NMR spectral data were in agreement with those reported previously.[20,38] ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.84−5.75 (m, 1H, $OCH_2CH_2CH_2CHCH_2$), 5.06−4.95 (m, 2H, $OCH_2CH_2CH_2CHCH_2$), 4.73 (d, 1H, J = 1.5 Hz, *H*-1), 4.22 (d, J = 6.6 Hz, 1H, O*H*), 3.93−3.88 (m, 2H, *H*-2, O*H*), 3.82−3.74 (m, 2H, *H*-3, O*H*), 3.68−3.61 (m, 2H, *H*-5, one of OCH_2), 3.50−3.39 (m, 2H, *H*-4, one of OCH_2), 2.14−2.07 (m, 2H, $OCH_2CH_2CH_2$), 1.71−1.64 (m, 2H, OCH_2CH_2), 1.30 (d, 3H, J = 6.0 Hz, CH_3). ^{13}C NMR (100 MHz, $CDCl_3$): δ 138.0, 115.2, 99.9, 73.0, 71.9, 71.2, 68.2, 67.2, 30.4, 28.7, 17.7. R_f = 0.2 (EtOAc/pentanes 7:3).

*2,3,4-Tris-O-(trimethylacetyl)-α/β-D-xylopyranosyl Trichloroacetimidate (**8b**).* Prepared in two steps from 2,3,4-tris-*O*-(trimethylacetyl)-α-D-xylopyranosyl bromide. Hydrolysis of 2,3,4-tris-*O*-(trimethylacetyl)-α-D-xylopyranosyl bromide[39] to 2,3,4-tris-*O*-(trimethylacetyl)-α/β-D-xylopyranose was carried out by adapting a published protocol.[40] 2,3,4-Tris-*O*-(trimethylacetyl)-α-D-xylopyranosyl bromide (4.14 g, 8.90 mmol) was dissolved in acetone (55.0 mL). Water (0.600 mL, 33.8 mmol) was added, and the solution was cooled to 0 °C. Silver(I) carbonate (3.68 g, 13.4 mmol) was added, and the flask was covered with aluminum foil and stirred until judged to be complete by disappearance of starting material on TLC (approximately 2 h). Once complete, the solution was filtered through Celite, and the solvent was removed under reduced pressure to yield the corresponding hemiacetal as a white solid (3.56 g, $\alpha:\beta$ = 1:1.7). Without further purification, this material was dissolved in anhydrous CH_2Cl_2 (88.5 mL) in an oven-dried round-bottomed flask equipped with a stir bar. Trichloroacetonitrile (6.20 mL, 62.0 mmol) and cesium carbonate (1.44 g, 4.40 mmol) were added, and the reaction was stirred until judged to be complete by disappearance of starting material on TLC (1 h). The solution was filtered through Celite, and the solvent was removed under reduced pressure. The crude isolate was purified by flash chromatography (9:1 pentanes/ethyl acetate) to yield **8b** as a white solid (3.80 g, 70% over four steps from D-xylose. $\alpha:\beta$ = 1.6:1). Pure α-anomer was obtained for melting point analysis by recrystallization of the anomeric mixture from boiling ethanol to yield white prisms. α-Anomer. Mp: 125−128 °C. TLC R_f: 0.84 (pentane/ethyl acetate 9:1). $[\alpha]^{20}_D$ = +61.0 (c = 10.0 mg/mL, $CHCl_3$). FTIR (ν_{max}, neat, cm^{-1}): 3315 (w), 2971 (m), 2902 (w), 2873 (w), 1736 (s), 1672 (m), 1479 (m), 1459 (m), 1397 (w), 1366 (w), 1353 (w), 1276 (s), 1177 (s), 1144 (s), 1130 (s), 1108 (s), 1075 (s), 1026 (s), 973 (s), 911 (m), 886 (m), 835 (m), 794 (s), 762 (m), 740 (m), 705 (m). ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.63 (s, 1H, $C(NH)CCl_3$), 6.45 (d, 1H, J = 3.6 Hz, H-1), 5.62 (app t, 1H, J = 9.8 Hz, H-3), 5.09−5.02 (m, 2H, H-2, H-4), 3.90 (dd, 1H, J = 11.2, 6.0 Hz, H-5_{eq}), 3.72 (dd, 1H, J = 11.2, 10.9 Hz, H-5_{ax}), 1.17 (s, 9H, $(CH_3)_3CCO$), 1.16 (s, 9H, $(CH_3)_3CCO$), 1.14 (s, 9H, $(CH_3)_3CCO$). ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 177.5, 177.4, 177.1, 161.0, 96.1, 93.3, 70.0, 69.0, 68.5, 60.9, 38.97, 38.95, 38.92, 27.3, 27.23, 27.20. HRMS (ESI, m/z): calcd for $[C_{20}H_{33}O_7]$ (M − Cl_3CCONH_2)$^+$ 385.2221, found 385.2217. β-Anomer. ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.71 (s, 1H, $C(NH)CCl_3$), 5.97 (d, 1H, J = 6.4 Hz, H-1), 5.33 (app t, 1H, J = 7.9 Hz, H-3), 5.23 (dd, 1H, J = 7.9, 6.4 Hz, H-2), 5.09−4.93 (m, 1H, H-4), 4.20 (dd, 1H, J = 12.0, 4.8 Hz, H-5_{eq}), 3.56 (dd, 1H, J = 12.0, 7.9 Hz, H-5_{ax}), 1.15 (s, 9H, $(CH_3)_3CCO$), 1.14 (s, 9H, $(CH_3)_3CCO$), 1.12 (s, 9H, $(CH_3)_3CCO$).

p-Methoxyphenyl α-L-Arabinopyranoside. Acetic anhydride (7.60 mL, 80.0 mmol) was added to a solution of L-arabinose (1.50 g, 10.0 mmol) in pyridine (10.0 mL) and stirred at 23 °C overnight. The solution was diluted with dichloromethane and washed three times with aqueous hydrochloric acid (1 M). The organic phase was dried over $MgSO_4$ and filtered and solvent removed under reduced pressure to give 1,2,3,4-tetra-*O*-acetyl-α/β-L-arabinopyranose as a viscous oil and was used without further purification. The oil was dissolved in anhydrous CH_2Cl_2 (15.0 mL) and added by syringe to an oven-dried round-bottomed flask equipped with a stir bar, *p*-methoxyphenol (1.86 g, 15.0 mmol), and 4 Å molecular sieves under an atmosphere of argon and stirred for 10 min at room temperature before cooling to 0 °C. Boron trifluoride diethyl etherate (6.20 mL, 50.0 mmol) was added dropwise to the reaction flask, and the reaction was allowed to warm to room temperature. After 24 h, the reaction diluted with CH_2Cl_2 and quenched with aqueous $NaHCO_3$. The solution was filtered through a pad of Celite and washed sequentially with saturated aqueous $NaHCO_3$ solution, water, and brine. The organic phase was collected, dried over $MgSO_4$, and filtered, and the solvent was removed under reduced pressure. The crude isolate was purified by flash chromatography to afford 2,3,4-tri-*O*-acetyl-*p*-methoxyphenyl α-L-arabinopyranoside as a colorless, viscous oil. The oil was dissolved in methanol (13.0 mL), and sodium methoxide (22.0 mg, 0.400 mmol) was added. The reaction was stirred at 23 °C until judged complete by disappearance of starting material on TLC. Dowex 50WX2-100 H^+ resin was rinsed with methanol and added to the reaction to neutralize the solution. The solution was filtered, and the solvent was removed under reduced pressure to afford a white solid (859 mg, 34% over three steps). The solid was recrystallized from boiling ethanol to give the title compound as white needle-like prisms (632 mg). Mp: 165−168 °C. $[\alpha]^{20}_D$ = −3.60 (c = 10 mg/mL, CH_3OH). FTIR (powder, cm^{-1}): 3534 (w), 3367 (m), 1508 (m), 1209 (m), 1070 (s), 1031 (s), 1011 (s). ^{1}H NMR (400 MHz, D_2O): δ (ppm) 7.14 (d, 2H, J = 9.1 Hz, *o*-Ar*H*), 7.01 (d, 2H, J = 9.1 Hz *m*-Ar*H*), 4.93 (d, 1H, J = 6.9 Hz, *H*-1), 4.02−3.96 (m, 2H, *H*-4, *H*-5), 3.84−3.77 (m, 6H, *H*-2, *H*-3, *H*-5, OCH_3). ^{13}C NMR (100 MHz, DMSO-d_6): δ (ppm) 154.3, 151.2, 117.9, 114.5, 102.0, 72.5, 70.4, 67.7, 65.6, 55.4. HRMS (ESI, m/z): calcd for $[C_{12}H_{16}NaO_6]$ (M + Na)$^+$ 279.0839, found 279.0839.

2,3,4-Tri-O-acetyl-α-D-fucopyranosyl Bromide. Acetic anhydride (7.60 mL, 80.0 mmol) was added to a solution of D-fucose (1.64 g, 10.0 mmol) in pyridine (10.0 mL) and stirred at 23 °C overnight. The solution was diluted with ethyl acetate and washed three times with aqueous hydrochloric acid (1 M). The organic phase was dried over $MgSO_4$ and filtered, and the solvent was removed under reduced pressure. The crude material was passed through a short column of silica gel (1:1 pentane/ether) to give 1,2,3,4-tetra-*O*-acetyl-α-D-fucopyranose as a clear oil. The oil was dissolved in anhydrous CH_2Cl_2 (20.0 mL) in an oven-dried round-bottom flask equipped with a stir bar and 4 Å molecular sieves under an atmosphere of argon and cooled to 0 °C. A solution of HBr (33% wt) in acetic acid (9.00 mL) was added dropwise to the solution, and the flask was covered with aluminum foil. The reaction was stirred for 30 min, diluted with CH_2Cl_2, and washed

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successively with water, saturated aqueous $NaHCO_3$ solution, and water. The organic phase was dried over $MgSO_4$ and filtered. Solvent was removed under reduced pressure to give a viscous oil which was purified by passing through a short plug of silica gel (1:1 pentane/ether). The product was dried under high vacuum to give 2,3,4-tri-*O*-acetyl-α-D-fucopyranosyl bromide as an amorphous white solid (2.30 g, 65%). NMR spectral data were in agreement with those reported previously.[41] ^{1}H NMR (400 MHz, $CDCl_3$): δ ppm 6.68 (d, 1H, *J* = 3.9 Hz, *H*-1), 5.43−5.35 (m, 2H, *H*-3, *H*-4), 5.03 (dd, 1H, *J* = 10.5, 3.9 Hz, *H*-2), 4.41 (app q, 1H, *J* = 6.7 Hz, *H*-5), 2.17 (s, 3H, CH_3CO), 2.11 (s, 3H, CH_3CO), 2.01 (s, 3H, CH_3CO), 1.22 (d, 3H, *J* = 6.7 Hz, CH_3). R_f = 0.8 (EtOAc/pentanes; 1:3). An analogous protocol was used to prepare the α-L-enantiomer from L-fucose.

Synthesis of 2. *n-Pentenyl 3-O-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyl)-α-L-rhamnopyranoside (**6**).* *n*-Pentenyl α-L-rhamnopyranoside (1.16 g, 5.00 mmol) was dissolved in anhydrous acetonitrile (25.0 mL) in a round-bottomed flask equipped with magnetic stir bar and cooled to −45 °C. 10*H*-Dibenzo[*b*,*e*][1,4]oxaborinin-10-ol[21] (98.0 mg, 0.5 mmol), 2,3,4,6-tetra-*O*-acetyl-α-D-bromoglucopyranoside (2.26 g, 5.50 mmol), and silver(I) oxide (1.16 g, 5.00 mmol) were added, and the solution was stirred vigorously overnight, allowing the temperature to rise gradually. After 20.5 h, the reaction was quenched with methanol and filtered through a pad of Celite. The filtrate was concentrated under reduced pressure and then purified by flash chromatography (gradient elution from 10% to 15% acetone in dichloromethane) to afford **6** as an amorphous white solid (2.29 g, 81%). The regiochemical outcome of the glycosylation was supported by the downfield shift of the H-3 proton resonance, and confirmed by COSY NMR (correlations between 2-OH/H-2 and 4-OH/H-4 observed). The configuration of the glycosidic linkage was assigned as β based on the $J^3_{H\text{-}1',H\text{-}2'}$ value of 8.0 Hz. TLC R_f: 0.45 (CH_2Cl_2/acetone 8:2). FTIR (powder, cm^{-1}): 3534 (w), 3484 (w), 2932 (w), 1748 (s), 1367 (m), 1260 (m), 1214 (s), 1168 (m), 1130 (m), 1085 (s), 1034 (s), 921 (m), 899 (m), 837 (w), 805 (m), 691 (m). ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 5.84−5.77 (m, 1H, $OCH_2CH_2CH_2CHCH_2$), 5.24 (app t, 1H, *J* = 9.5 Hz, H-3′), 5.08−4.97 (m, 4H, H-2′, H-4′, $OCH_2CH_2CH_2CHCH_2$), 4.79 (d, 1H, *J* = 1.6 Hz, H-1), 4.71 (d, 1H, *J* = 8.0 Hz, H-1′), 4.20 (d, 2H, *J* = 4.0 Hz, H-6′, H-6′), 3.97 (ddd, 1H, *J* = 4.5, 3.0, 1.5 Hz, H-2), 3.80−3.61 (m, 5H, H-3, H-4, H-5, H-5′, one of OCH_2), 3.43−3.41 (m, 1H, one of OCH_2), 2.65 (d, 1H, *J* = 3.0 Hz, C-2 OH), 2.24 (d, 1H, *J* = 2.8 Hz, C-4 OH), 2.13−2.07 (m, 2H, $OCH_2CH_2CH_2$), 2.08 (s, 3H, CH_3CO), 2.06 (s, 3H, CH_3CO), 2.03 (s, 3H, CH_3CO), 2.01 (s, 3H, CH_3CO), 1.73−1.66 (m, 2H, OCH_2CH_2), 1.31 (d, 3H, *J* = 6.0 Hz, CH_3). ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 170.8, 170.3, 170.1, 169.5, 138.0, 115.1, 101.2, 99.4, 83.4, 72.5, 72.1, 71.8, 71.1, 69.8, 68.5, 67.6, 67.0, 61.9, 30.4, 28.7, 20.9, 20.8, 20.74, 20.71, 17.7. HRMS (DART, *m*/*z*): calcd for $[C_{25}H_{42}NO_{14}]$ $(M + NH_4)^+$ 580.2600, found 580.2598.

*n-Pentenyl 2-O-Benzoyl-3-O-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyl)-α-L-rhamnopyranoside (**7**).* A published protocol for selective protection with trimethylacetyl chloride was adapted.[24] Compound **6** (2.95 g, 5.25 mmol) was dissolved in anhydrous pyridine (7.80 mL) in an oven-dried round-bottomed flask equipped with a stir bar and cooled to 0 °C. Benzoyl chloride (0.73 mL, 6.30 mmol) was added quickly to the solution with rapid stirring, and the reaction was stirred for 1 h. The solution was diluted with ethyl acetate and washed three times with aqueous hydrochloric acid (1 M). The organic phase was dried over $MgSO_4$ and filtered, and the solvent was removed under reduced pressure. The crude isolate was purified by flash chromatography (20 → 40% ethyl acetate in pentane) to give **7** as an amorphous white solid (3.11 g, 89%). The assignment of the regiochemical outcome is based on the downfield shift of the H-2 resonance in the ^{1}H NMR spectrum. TLC R_f: 0.62 (pentane/ethyl acetate 6:4). $[\alpha]^{20}_D$ = −8.15 (*c* = 8.1 mg/mL, $CHCl_3$). FTIR (powder, cm^{-1}): 3512 (br), 2933 (w), 1745 (s), 1721 (s), 1451 (w), 1365 (m), 1214 (s), 1035 (s), 908 (m), 712 (s). ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 8.00 (d, 2H, *J* = 7.5 Hz, *o*-Ar), 7.56 (app t, 1H, *J* = 7.5 Hz, *p*-Ar), 7.44 (app t, 2H, *J* = 7.5 Hz, *m*-Ar), 5.88−5.78 (m, 1H, $OCH_2CH_2CH_2CHCH_2$), 5.31 (dd, 1H, *J* = 3.5, 1.5 Hz, H-2), 5.17 (app t, 1H, *J* = 9.5 Hz, H-3′), 5.08−4.93 (m, 4H, $OCH_2CH_2CH_2CHCH_2$, H-2′, H-4′), 4.83 (d, 1H, *J* = 1.5 Hz, H-1), 4.72 (d, 1H, *J* = 8.0 Hz, H-1′), 4.07 (dd, 1H, *J* = 12.0, 4.0 Hz, H-6′), 3.99−3.95 (m, 2H, H-3, H-6′), 3.79−3.66 (m, 4H, H-4, H-5, H-5′, one of OCH_2), 3.48−3.42 (m, 1H, one of OCH_2), 2.54 (s, 1H, OH), 2.18−2.13 (m, 2H, $OCH_2CH_2CH_2$), 2.06 (s, 3H, CH_3CO),1.98 (s, 3H, CH_3CO), 1.97 (s, 3H, CH_3CO), 1.81 (s, 3H, CH_3CO), 1.76−1.68 (m, 2H, OCH_2CH_2), 1.35 (d, 3H, *J* = 6.0 Hz, CH_3). ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 170.8, 170.3, 170.2, 169.5, 166.1, 138.0, 133.2, 130.1, 130.0, 128.5, 115.2, 100.9, 97.6, 80.0, 72.6, 71.9, 71.8, 71.7, 71.3, 68.0, 67.8, 67.5, 61.7, 30.4, 28.8, 20.9, 20.72, 20.69, 20.5, 17.9. HRMS (ESI, *m*/*z*): calcd for $[C_{32}H_{46}NO_{15}]$ $(M + NH_4)^+$ 684.2862, found 684.2861.

*n-Pentenyl 2-O-Benzoyl-3-O-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyl)-4-O-(2″,3″,4″-tris-O-(trimethylacetyl)-β-D-xylopyranosyl)-α-L-rhamnopyranoside (**3a**).* Glycosyl trichloroacetimidate **8b** (3.80 g, 6.98 mmol) and acceptor 7 (3.10 g, 4.65 mmol) were dissolved in anhydrous CH_2Cl_2 (23.3 mL) in an oven-dried round-bottomed flask equipped with a stir bar and 4 Å molecular sieves under an atmosphere of argon and cooled to 0 °C. A freshly prepared 1.0 M solution of TMSOTf in anhydrous CH_2Cl_2 (0.460 mL, 0.460 mmol) was added dropwise, and the reaction was stirred for 1 h. The reaction was quenched with excess triethylamine and filtered through a pad of Celite. The solvent was removed under reduced pressure, and the crude isolate was purified by flash chromatography (8:2 pentane/ethyl acetate) to yield **3a** as an amorphous white solid (4.77 g, 98%). The configuration of the glycosidic linkage was assigned as β based on the $J^3_{H\text{-}1'',H\text{-}2''}$ value of 7.8 Hz. TLC R_f: 0.80 (pentane/ethyl acetate 6:4). $[\alpha]^{20}_D$ = −36.26 (*c* = 10.7 mg/mL, $CHCl_3$). FTIR (powder, cm^{-1}): 2977 (w), 2938 (w), 2875 (w), 1738(s), 1602 (w), 1480 (w), 1452 (w), 1365 (m), 1324 (w), 1272 (s), 1215 (s), 1139 (s), 1112 (s), 1035 (s), 990 (s), 906 (m) 825 (m), 762 (w), 713 (s). ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 7.98 (dd, 2H, *J* = 8.4, 1.2 Hz, *o*-Ar*H*), 7.56 (tt, 1H, *J* = 7.8, 1.2 Hz, *p*-Ar*H*), 7.44 (dd, 2H, *J* = 7.8 Hz, 8.4 Hz, *m*-Ar*H*), 5.82−5.75 (m, 1H, $OCH_2CH_2CH_2CHCH_2$), 5.35 (dd, 1H, *J* = 3.6, 1.8 Hz, H-2), 5.23 (dd, 1H, *J* = 9.6, 9.6 Hz, H-3″), 5.13 (app t, 1H, *J* = 9.6, Hz, H-3′), 5.06−4.90 (m, 6H, H-2′, H-4′, H-2″, H-4″, $OCH_2CH_2CH_2CHCH_2$), 4.82 (d, 1H, *J* = 1.8 Hz, H-1), 4.79 (d, 1H, *J* = 7.8 Hz, H-1″), 4.73 (d, 1H, *J* = 7.8 Hz, H-1′), 4.12 (dd, 1H, *J* = 11.4, 5.4 Hz, H-5″), 4.08−4.06 (m, 2H, H-3, H-6′), 4.02−3.98 (m, 2H, H-4, H-6′), 3.68−3.60 (m, 3H, H-5, H-5′, one of OCH_2), 3.43−3.40 (m, 1H, one of OCH_2), 4.34 (dd, 1H, *J* = 11.4, 10.2 Hz, H-5″), 2.29 (s, 3H, CH_3CO), 2.13−2.07 (m, 2H, $OCH_2CH_2CH_2$), 1.96 (s, 3H, CH_3CO), 1.96 (s, 3H, CH_3CO), 1.77 (s, 3H, CH_3CO), 1.72−1.67 (m, 2H, OCH_2CH_2), 1.27 (d, 3H, *J* = 6.6 Hz, CH_3), 1.20 (s, 9H, $(CH_3)_3CCO$), 1.15 (s, 9H, $(CH_3)_3CCO$), 1.11 (s, 9H, $(CH_3)_3CCO$). ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 177.4, 177.3, 176.7, 170.8, 170.2, 170.1, 169.4, 166.0, 137.9, 133.1, 130.3, 130.0, 128.5, 115.3, 100.8, 99.1, 96.7, 80.5, 73.5, 73.3, 72.2, 72.1, 71.9, 71.6, 71.4, 69.4, 67.9, 67.2, 66.6, 62.7, 61.6, 38.91, 38.89, 38.82, 30.4, 28.7, 27.34, 27.26, 27.21, 21.7, 20.68, 20.65, 20.5, 18.2. HRMS (ESI, *m*/*z*): calcd for $[C_{52}H_{75}O_{22}]$ $(M + H)^+$ 1051.4745, found 1051.4744.

*p-Methoxyphenyl 3-O-(2′,3′,4′-Tri-O-acetyl-β-D-fucopyranosyl)-α-L-arabinopyranoside (**4a**).* *p*-Methoxyphenyl α-L-arabinopyranoside (128 mg, 0.500 mmol), pentafluorophenylboronic acid (106 mg, 0.500 mmol), and 4 Å molecular sieves (500 mg) were placed in an oven-dried round-bottomed flask equipped with a stir bar. Anhydrous CH_2Cl_2 (3.85 mL) was added, and the reaction was stirred at 23 °C overnight. The reaction was then cooled to 0 °C before addition of silver(I) oxide (116 mg, 0.500 mmol) and 4-methylmorpholine (0.330 mL, 3.00 mmol). 2,3,4-Tri-*O*-acetyl-α-D-fucopyranosyl bromide (194 mg, 0.550 mmol) was added portionwise (approximately 24.0 mg every hour for 8 h). Once donor addition was complete, the reaction was stirred overnight and allowed to warm gradually to room temperature. Once complete, the reaction was quenched by addition of excess methanol, and the solution was filtered through a thin pad of Celite. The solvent was removed under reduced pressure, and the crude isolate was purified by flash chromatography (5% → 10% acetone in dichloromethane) to give **4a** as a white solid (196 mg, 74%). The regiochemical outcome was assigned based on the large downfield shift of the C-3 carbon resonance. The configuration of the glycosidic linkage was assigned as β based on the $J^3_{H\text{-}1',H\text{-}2'}$ value of 8.0 Hz. Mp: 90−94 °C. TLC R_f = 0.5 (acetone/CH_2Cl_2 1:4). $[\alpha]^{20}_D$ = +8.46 (*c* = 8.75 mg/mL, $CHCl_3$). HPLC (cyano-functionalized silica column, 5 μm pore size, 25 cm × 4.6 mm column, 80:20 hexanes/2-propanol, 1 mL/min, UV detection at 245 nm): t_R =

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19.9 min. FTIR (powder, cm^{-1}): 3490 (br), 2960 (m), 2929 (m), 2873 (m), 1741 (s), 1507 (s), 1367 (m), 1216 (s), 1064 (s), 1035 (s), 906 (m), 872 (w), 829 (m), 787 (w), 742 (m), 664 (w). ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.02 (d, 2H, J = 9.0 Hz, Ar*H*), 6.82 (d, 2H, J = 9.0 Hz, Ar*H*), 5.27−5.21 (m, 2H, *H*-2′, *H*-4′), 5.06 (dd, 1H, J = 10.6, 3.3 Hz, *H*-3′), 4.76 (d, 1H, J = 8.0 Hz, *H*-1′), 4.70 (d, 1H, J = 7.2 Hz, *H*-1), 4.11 (dd, 1H, J = 12.9, 2.5 Hz, *H*-5$_a$), 4.06−3.97 (m, 2H, *H*-2, *H*-4), 3.85 (m, 1H, *H*-5′), 3.77 (s, 3H, OC*H*$_3$), 3.72 (dd, 1H, J = 8.9, 3.4 Hz, *H*-3), 3.57 (dd, 1H, J = 12.9, 2.0, *H*-5$_b$), 2.80 (d, 1H, J = 2.3 Hz, C-4 O*H*), 2.44 (d, 1H, J = 2.8 Hz, 1H, C-2 O*H*), 2.20 (s, 3H, C*H*$_3$CO), 2.07 (s, 3H, C*H*$_3$CO), 2.00 (s, 3H, C*H*$_3$CO), 1.22 (d, 3H, J = 6.4 Hz, C*H*$_3$). ^{13}C NMR (100 MHz, $CDCl_3$): δ 170.7, 170.3, 170.2, 155.6, 151.0, 119.0, 114.7, 102.5, 101.9, 81.9, 71.0, 70.5, 70.1, 69.6, 69.1, 67.5, 65.3, 55.8, 21.0, 20.81, 20.77, 16.3. HRMS (ESI, m/z): calcd for $[C_{24}H_{36}NO_{13}]$ $(M + NH_4)^+$ 546.2187, found 546.2199.

*p-Methoxyphenyl 3-O-(2′,3′,4′-Tri-O-acetyl-β-L-fucopyranosyl)-α-L-arabinopyranoside (**4b**).* An oven-dried round-bottomed flask equipped with a stir bar was charged with *p*-methoxyphenyl α-L-arabinopyranoside (51.0 mg, 0.200 mmol), 2-aminoethyl diphenylborinate (4.50 mg, 20.0 μmol), and silver(I) oxide (46.0 mg, 0.200 mmol). A solution of 2,3,4-tri-*O*-acetyl-α-L-fucopyranosyl bromide in acetonitrile (1.0 mL) was added, and the suspension was stirred overnight at room temperature. Once complete, the reaction was quenched by addition of excess methanol, and the solution was filtered through a thin pad of Celite. The solvent was removed under reduced pressure, and the crude isolate was purified by flash chromatography (5% → 10% acetone in dichloromethane) to give **4b** as an amorphous white solid (52.0 mg, 49%). The regiochemical outcome was assigned on the basis of 2-D HMBC analysis (correlation observed between H-1′/C-3). The configuration of the glycosidic linkage was assigned as β based on the $J^3_{H\text{-}1',H\text{-}2'}$ value of 7.8 Hz. TLC R_f = 0.5 (acetone/CH_2Cl_2 1:4). $[\alpha]^{20}_D$ = +1.14 (c = 8.75 mg/mL, $CHCl_3$). HPLC (Rx-C18 silica column, 5 μm pore size, 25 cm × 4.6 mm column, 80:20 water/acetonitrile, 1 mL/min, UV detection at 245 nm): t_R = 18.9 min. The 4-*O*-fucosylated regioisomer had t_R = 28.9 min under these conditions. FTIR (powder, cm^{-1}): 3460 (br), 2980 (w), 2941 (w), 2901 (w), 2834 (w), 1742 (s), 1507 (s), 1441 (s), 1368 (m), 1214 (s), 1172 (m), 1061 (s), 1020 (s) 907 (w), 830 (m), 786 (w), 741 (m), 667 (m). ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.05−7.01 (m, 2H, *o*-Ar), 6.82−6.78 (m, 2H, *m*-Ar), 5.26−5.21 (m, 2H, H-2′, H-4′), 5.05 (dd, 1H, J = 10.5, 3.4 Hz, H-3′), 4.72 (d, 1H, J = 7.5 Hz, H-1), 4.59 (d, 1H, J = 7.8 Hz, H-1′), 4.10 (dd, 1H, J = 13.0, 1.9 Hz, H-5), 4.00 (dd, 1H, J = 9.0, 7.8 Hz, H-2), 3.92−3.88 (m, 2H, H-4, H-5′), 3.75 (s, 3H, OC*H*$_3$), 3.61 (dd, 1H, J = 9.0, 3.5 Hz, H-3), 3.55 (dd, 1H, J = 13.0, 1.2 Hz, H-5), 2.19 (s, 3H, C*H*$_3$CO), 2.08 (s, 3H, C*H*$_3$CO), 2.00 (s, 3H, C*H*$_3$CO), 1.24 (d, 3H, J = 6.3 Hz, C*H*$_3$). ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 170.7, 170.2, 170.0, 155.6, 151.1, 119.2, 114.6, 102.6, 101.4, 84.4, 70.9, 70.0, 69.9, 69.6, 69.3, 67.7, 65.6, 55.7, 20.9, 20.8, 20.7, 16.1. HRMS (ESI, m/z) calcd for $[C_{24}H_{32}NaO_{13}]$ $(M + Na)^+$ 551.1735, found 551.1733.

*p-Methoxyphenyl 4-O-(2′,3′,4′-Tri-O-acetyl-β-D-fucopyranosyl)-α-L-arabinopyranoside (**4c**).* Compound **4c** was isolated as a byproduct in the catalytic preparation of compound **4a**. The regiochemical outcome was assigned based on 2-D COSY NMR (correlations between 2-OH/H-2 and 3-OH/H-3). The configuration of the glycosidic linkage was assigned as β on the basis of the $J^3_{H\text{-}1',H\text{-}2'}$ value of 7.9 Hz. HPLC (cyano-functionalized silica column, 5 μm pore size, 25 cm × 4.6 mm column, 80:20 hexanes/2-propanol, 1 mL/min, UV detection at 245 nm): t_R = 22.8 min. ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 7.01−6.99 (m, 2H, *o*-ArH), 6.84−6.80 (m, 2H, *m*-ArH), 5.28−5.22 (m, 2H, H-2′, H-4′), 5.03 (dd, 1H, J = 10.5, 3.6 Hz, H-3′), 4.71 (d, 1H, J = 7.0 Hz, H-1), 4.66 (d, 1H, J = 7.9 Hz, H-1′), 4.23 (dd, 1H, J = 12.8, 2.9 Hz, H-5), 3.97−3.95 (m, 1H, H-4), 3.87−3.80 (m, 2H, H-2, H-5′), 3.77 (s, 3H, OCH_3), 3.74−3.69 (m, 1H, H-3), 3.61 (dd, 1H, J = 12.8, 1.7 Hz, H-5), 2.55 (d, 1H, J = 7.8 Hz, 3-OH), 2.51 (d, 1H, J = 2.7 Hz, 2-OH), 2.17 (s, 3H, C*H*$_3$CO), 2.09 (s, 3H, C*H*$_3$CO), 1.99 (s, 3H, C*H*$_3$CO), 1.20 (d, 3H, J = 6.4 Hz, CH_3). ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 170.8, 170.3, 170.0, 155.6, 151.1, 118.7, 114.7, 102.7, 102.3, 77.4, 72.4, 72.1, 71.4, 70.2, 69.5, 69.3, 65.5, 55.8, 21.0, 20.9, 20.8, 16.3. FTIR (ν_{max}, neat, cm^{-1}): 3400 (br, w), 2980 (w), 2921 (w), 2834 (w), 1741 (s), 1644 (w), 1507 (s), 1443 (w), 1369 (m), 1218 (s), 1173 (m) 1062 (s), 1035 (s), 914 (m), 830 (m), 745 (m). HRMS (DART, m/z): calcd for $[C_{24}H_{36}NO_{13}]$ $(M + NH_4)^+$ 546.2186, found 546.2193.

*2-O-Benzoyl-3-O-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyl)-4-O-(2″,3″,4″-tris-O-(trimethylacetyl)-β-D-xylopyranosyl)-α-L-rhamnopyranose (**3b**).* Compound **3b** was prepared using a modified literature procedure.[42] Compound **3a** (210 mg, 0.200 mmol) was dissolved in 0.1% aqueous CH_2Cl_2 (8.00 mL) in an oven-dried round-bottomed flask equipped with a stir bar. *N*-Iodosuccinimide (90.0 mg, 0.400 mmol) was added to the reaction flask, followed by dropwise addition of a freshly prepared 0.25 M solution of TMSOTf in anhydrous CH_2Cl_2 (240 μL, 60.0 μmol) over a period of 2.5 min. The reaction was stirred at 23 °C for an additional 30 s before quenching with a 10% aqueous solution of sodium thiosulfate. The solution was diluted with CH_2Cl_2 and washed with 10% aqueous $Na_2S_2O_3$, saturated $NaHCO_3$, and brine. The organic phase was dried over $MgSO_4$ and filtered. Solvent was removed under reduced pressure, and the crude isolate was purified by flash chromatography (20% → 50% ethyl acetate in pentanes) to yield **3b** as an amorphous white solid (141 mg, 72%). TLC R_f: 0.57 (pentane/ethyl acetate 6:4). FTIR (powder, cm^{-1}): 2966 (w), 1740 (s), 1480 (w), 1452 (w), 1366 (m), 1274 (s), 1215 (s), 1141 (s), 1111 (s), 1035 (s), 988 (s), 894 (m), 846 (w), 799 (w), 762 (w), 713 (m). ^{1}H NMR (600 MHz, $CDCl_3$): δ (ppm) 8.00−7.98 (m, 2H, *o*-Ar), 7.57−7.55 (m, 1H, *p*-Ar), 7.47−7.44 (m, 2H, *m*-Ar), 5.43 (dd, 1H, J = 3.5, 2.5 Hz, H-2), 5.24 (d, 1H, J = 2.5 Hz, H-1), 5.22 (app t, 1H, J = 10.0 Hz, H-3″), 5.12 (app t, 1H, J = 9.5 Hz, H-3′), 5.05−4.91 (m, 4H, H-2′, H-2″, H-4′, H-4″), 4.79 (d, 1H, J = 8.0 Hz, H-1″), 4.73 (d, 1H, J = 8.0 Hz, H-1′), 4.19−4.10 (m, 2H, H-3, H-5″$_{eq}$), 4.05−3.99 (m, 3H, H-4, H-6′, H-6′), 3.65 (m, 1H, H-5′), 3.33 (dd, 1H, J = 12.0, 10.0 Hz, H-5″$_{ax}$), 2.29 (s, 3H, C*H*$_3$CO), 1.97 (s, 3H, C*H*$_3$CO), 1.96 (s, 3H, C*H*$_3$CO), 1.85 (s, 3H, C*H*$_3$CO), 1.27 (d, 3H, J = 6.0 Hz, C*H*$_3$), 1.22 (s, 9H, (C*H*$_3$)$_3$CCO), 1.15 (s, 9H, (C*H*$_3$)$_3$CCO), 1.12 (s, 9H, (C*H*$_3$)$_3$CCO). ^{13}C NMR (150 MHz, $CDCl_3$): δ (ppm) 177.4, 177.3, 176.8, 171.0, 170.2, 169.8, 169.4, 166.0, 133.2, 130.2, 130.0, 128.5, 100.9, 99.3, 91.7, 79.8, 77.4, 72.7, 72.0, 71.9, 71.7, 71.5, 69.4, 68.0, 66.9, 62.7, 61.6, 38.91, 38.83, 38.82, 27.36, 27.25, 27.20, 21.6, 20.7, 20.6, 20.5, 18.3. HRMS (ESI, m/z): calcd for $C_{47}H_{66}O_{22}$ $[M + NH_4]^+$ 1000.4384, found 1000.4373.

*2-O-Benzoyl-3-O-(2′,3′,4′,6′-tetra-O-acetyl-β-D-glucopyranosyl)-4-O-(2″,3″,4″-tris-O-(trimethylacetyl)-β-D-xylopyranosyl)-α-L-rhamnopyranosyl trichloroacetimidate (**3e**).* Compound **3b** (197 mg, 0.200 mmol) and Cl_3CCN (140 μL, 1.40 mmol) were dissolved in anhydrous CH_2Cl_2 (2.00 mL) in an oven-dried round-bottomed flask equipped with a stir bar. The solution was cooled to 0 °C, and Cs_2CO_3 (33.0 mg, 0.100 mmol) was added to the reaction flask. The flask was removed from the ice bath and allowed to warm to room temperature with stirring. After 8 h, the solution was diluted with dichloromethane and filtered through a thin pad of Celite. The solvent was removed under reduced pressure, and the crude mixture was purified by flash chromatography (8:2 → 7:3 pentanes/ethyl acetate) to yield **3e** as an amorphous white solid (181 mg, 80%). TLC R_f: 0.78 (pentane/ethyl acetate 6:4). $[\alpha]^{20}_D$ = −35.40 (c = 9.20 mg/mL, $CHCl_3$). FTIR (powder, cm^{-1}): 2972 (w), 2936 (w), 2872 (w), 1739 (s), 1679 (w), 1480 (w), 1453 (w), 1366 (m), 1319 (w), 1216 (s), 1141 (s), 1111 (s), 1066 (s), 1035 (s), 974 (s), 926 (m), 894 (m), 796 (s), 762 (w), 712 (s), 687 (w). ^{1}H NMR (600 MHz, CD_3CN): δ (ppm) 9.12 (s, 1H, NH), 8.01 (dd, 2H, J = 8.5, 1.5 Hz, *o*-Bz), 7.68 (m, 1H, *p*-Bz), 7.55 (m, 2H, J = 6 Hz, *m*-Bz) 6.32 (d, 1H, J = 2.5 Hz, H-1) 5.59 (dd, 1H, J = 3.5, 2.5 Hz, H-2) 5.26−5.20 (m, 2H, H-3″, H-3′), 4.97−4.85 (m, 6H, H-1′, H-1″, H-2′, H2″, H-4′, H-4″), 4.31 (dd, 1H, J = 9.0, 3.5 Hz, H-3), 4.12−4.09 (m, 2H, H-4, H-5″) 3.97 (dd, 1H, J = 12.0, 4.0 Hz, H-6′), 3.93 (dd, 1H, J = 12.0, 2.5 Hz, H-6′), 3.90−3.87 (m, 1H, H-5), 3.85−3.82 (m, 1H, H-5′), 3.34 (dd, 1H, J = 12.0, 10.0 Hz, H-5″), 2.24 (s, 3H, C*H*$_3$CO), 2.15 (s, 3H, C*H*$_3$CO), 1.95 (s, 3H, C*H*$_3$CO), 1.77 (s, 3H, C*H*$_3$CO), 1.30 (d, 3H, J = 6.0 Hz, C*H*$_3$), 1.21 (s, 9H, (C*H*$_3$)$_3$CCO), 1.15 (s, 9H, (C*H*$_3$)$_3$CCO), 1.11 (s, 9H, (C*H*$_3$)$_3$CCO). ^{13}C NMR (150 MHz, CD_3CN): δ (ppm) 177.98, 177.96, 177.6, 171.2, 170.9, 170.8, 170.4, 166.3, 160.2, 134.5, 130.8, 130.6, 129.7, 100.1, 99.9, 94.7, 80.0, 73.5, 72.8, 72.6, 72.25, 72.21, 71.4, 70.2, 70.1, 68.8, 63.4, 62.6, 39.52, 39.42, 39.36, 27.6, 27.4, 27.3, 22.0, 20.85, 20.81, 20.7, 18.5. HRMS (ESI, m/z): calcd for $[C_{49}H_{66}Cl_3NNaO_{22}]$ $(M + Na)^+$ 1148.3034, found 1148.2999.

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*para-Methoxyphenyl 2-O-[2′-O-Benzoyl-3′-O-(2″,3″,4″,6″-tetra-O-acetyl-β-D-glucopyranosyl)-4′-O-(2‴,3‴,4‴-tris-O-(trimethylacetyl)-β-D-xylopyranosyl)-α-L-rhamnopyranosyl]-3-O-(2⁗,3⁗,4⁗-tri-O-acetyl-β-D-fucopyranosyl)-α-L-arabinopyranoside (**11**).* Donor **3e** and acceptor **4a** were each dried by azeotropic removal of water with toluene and placed under high vacuum for 6 h to remove residual solvent prior to use. Compounds **3e** (113 mg, 0.100 mmol) and **4a** (79.0 mg, 0.150 mmol) were dissolved in anhydrous CH_2Cl_2 (0.750 mL) in an oven-dried round-bottomed flask equipped with a stir bar and 4 Å molecular sieves under an atmosphere of argon. The reaction was cooled to −78 °C, and a freshly prepared 0.25 M solution of TMSOTf (40.0 μL, 10.0 μmol) in anhydrous CH_2Cl_2 was added dropwise to give a faint yellow solution. The reaction was stirred at −78 °C for 40 min and then quenched by addition of excess triethylamine. Solvent was removed under reduced pressure, and the crude isolate was purified by flash chromatography (5% → 10% acetone in dichloromethane) to yield 112 mg of pure product as an amorphous white solid. The fractions of product that had coeluted with the excess acceptor were combined and purified by preparative TLC (50% → 60% ethyl acetate in pentane) to yield an additional 16.0 mg of product for a total yield of 128 mg (85%). The regiochemical outcome was assigned based on 2-D HMBC analysis (correlation observed between H-1′[Rha]/C-2[Ara] and H-2[Ara]/C-1′ [Rha]). The configuration of the glycosidic linkage was assigned as α based on the $J^3_{H\text{-}1',H\text{-}2'}$ value of 2.0 Hz. All glycosidic bonds were confirmed as shown based on 1D and 2D NMR analysis ($^1H/^{13}C$). TLC R_f: 0.73 (ethyl acetate/pentane 7:3). $[\alpha]^{20}_D = -31.45$ (c = 12.4 mg/mL, $CHCl_3$). FTIR (powder, cm^{-1}): 2972 (w), 2940 (w), 2874 (w), 1740 (s), 1507 (m), 1480 (w), 1452 (w), 1367 (m), 1215 (s), 1172 (m), 1140 (s), 1111 (s), 1061 (s), 1033 (s), 905 (m), 842 (m), 803 (w), 761 (w), 713 (m). ^1H NMR (700 MHz, $CDCl_3$): δ (ppm) 8.01−7.99 (m, 2H, *o*-Bz), 7.59−7.56 (m, 1H, *p*-Bz), 7.46−7.44 (m, 2H, *m*-Bz), 6.96−6.93 (m, 2H, *o*-PMP), 6.88−6.85 (m, 2H, *m*-PMP), 5.42 (dd, 1H, J = 3.6, 1.8 Hz, H-2′), 5.31 (dd, 1H, J = 2.8, 1.3 Hz, H-4⁗), 5.21−5.18 (m, 4H, H-1′, H-2‴, H-3‴, H-3⁗), 5.11 (app t, 1H, J = 9.5 Hz, H-3″), 5.03−4.94 (m, 5H, H-1, H-2″, H-2⁗, H-4″, H-4⁗), 4.81 (app t, 1H, J = 3.9 Hz, H-1⁗), 4.78 (d, 1H, J = 7.3 Hz, H-1‴), 4.72 (d, 1H, J = 7.8 Hz, H-1″), 4.17 (dd, 1H, J = 12.2, 2.0 Hz, H-6″), 4.13 (dd, 1H, J = 11.6, 5.5 Hz, H-5‴$_{eq}$), 4.09−3.95 (m, 9H, H-2, H-3′, H-3, H-4′, H-4, H-5′, H-5$_{ax}$, H-5⁗, H-6″), 3.78 (s, 3H, OCH_3), 3.55 (ddd, 1H, J = 10.0, 2.5, 3.5, Hz, H-5″), 3.53 (dd, 1H, J = 12.0, 2.6 Hz, H-5$_{eq}$), 3.29 (dd, 1H, J = 11.7, 9.6 Hz, H-5‴$_{ax}$), 2.26 (s, 3H, CH_3CO), 2.18 (s, 3H, CH_3CO), 1.98 (s, 3H, CH_3CO), 1.96 (s, 3H, CH_3CO), 1.94 (s, 3H, CH_3CO), 1.91 (s, 3H, CH_3CO), 1.68 (s, 3H, CH_3CO), 1.30 (d, 3H, J = 6.2 Hz, CH_3 rhamnose), 1.23 (d, 3H, J = 6.4 Hz, CH_3 fucose), 1.15 (s, 9H, $(CH_3)_3CCO$), 1.13 (s, 9H, $(CH_3)_3CCO$), 1.11(s, 9H, $(CH_3)_3CCO$). ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 177.41, 177.35, 176.5, 170.9, 170.8, 170.2, 170.1, 169.9, 169.7, 169.3, 165.7, 155.2, 150.9, 133.3, 130.1, 130.0, 128.6, 117.9, 114.9, 101.0, 100.8, 99.3, 99.0, 96.6, 79.8, 79.6, 73.32, 73.26 (2 signals), 72.3, 71.8 (2 signals), 71.6, 71.5, 71.2, 70.5, 69.7, 69.3, 68.9, 67.8, 67.0, 66.9, 63.2, 62.6, 61.2, 38.9, 38.8 (2 signals), 27.29, 27.23, 27.19, 21.5, 20.9, 20.69, 20.67, 20.63, 20.5, 18.1, 16.1. HRMS (DART, m/z): Calculated for $C_{71}H_{96}O_{34}$ $[M + NH_4]^+$: 1510.6121; Found: 1510.6115.

*para-Methoxyphenyl 3-O-(2′, 3′, 4′-Tri-O-acetyl-β-D-fucopyranosyl)-4-O-[2″-O-benzoyl-3″-O-(2‴,3‴,4‴,6‴-tetra-O-acetyl-β-D-glucopyranosyl)-4″-O-(2⁗,3⁗,4⁗-tris-O-(trimethylacetyl)-β-D-xylopyranosyl)-α-L-rhamnopyranosyl]-α-L-arabinopyranoside (**12**, Side Product Obtained from Coupling of **3e** and **4a**).* Donor **3e** and acceptor **4a** were each dried via azeotropic removal of water with toluene and placed under high vacuum for 6 h to remove residual solvent prior to use. Compounds **3e** (79.0 mg, 70.0 μmol) and **4a** (26.5 mg, 50.0 μmol) were dissolved in anhydrous CH_2Cl_2 (0.250 mL) in an oven-dried round-bottom flask equipped with a stir bar under an atmosphere of argon. The reaction was cooled to −78 °C, and a freshly prepared 0.10 M solution of TMSOTf in anhydrous CH_2Cl_2 was added with slow dropwise addition (50.0 μL, 5.00 μmol) to the reaction flask to give a faint yellow solution. The reaction was stirred at −78 °C for 45 min and then quenched by addition of excess triethylamine. Solvent was removed under reduced pressure, and the crude isolate was purified by flash chromatography gradient elution from 20% to 50% ethyl acetate in pentanes) to yield 24.7 mg of the title compound as an amorphous white solid (23%) as a byproduct of the reaction. Regiochemistry of the glycosidic linkage was confirmed by $^1H/^{13}C$ HMBC experiment. All glycosidic bonds were confirmed as shown on the basis of 1D and 2D NMR analysis ($^1H/^{13}C$). ^1H NMR (700 MHz, $CDCl_3$): δ (ppm) 8.0 (m, 2H, *o*-Bz), 7.57−7.54 (m, 1H, *p*-Bz), 7.44−7.42 (m, 2H, *m*-Bz), 6.95−6.93 (m, 2H, *o*-Ar), 6.89−6.86 (m, 2H, *m*-Ar), 5.49 (dd, 1H, J = 3.8, 1.3 Hz, H-2″), 5.32−5.30 (m, 2H, H-1″, H-4′), 5.20−5.17 (m, 2H, H-3⁗, H-2′), 5.08 (app t, 1H, J = 9.5 Hz, H-3‴), 5.03 (app t, 1H, J = 9.5 Hz, H-4‴), 4.98−4.95 (m, 4H, H-2‴, H-2⁗, H-4⁗, H-3′), 4.90 (d, 1H, J = 7.5 Hz, H-1′), 4.78 (d, 1H, J = 7.3 Hz, H-1), 4.77 (d, 1H, J = 7.2 Hz, H-1⁗), 4.68 (d, 1H, J = 7.8 Hz, H-1‴), 4.25−4.19 (m, 2H, H-5″, H-6‴), 4.16−4.11 (m, 2H, H-2, H-5⁗), 4.07−3.90 (m, 5H, H-4, H-3″, H-4″, H-6‴, H-5′), 3.87−3.84 (m, 2H, H-3, H-5), 3.79 (s, 3H, OCH_3), 3.60 (dt, 1H, J = 9.8, 2.7 Hz, H-5‴), 3.55 (d, 1H, J = 11.8 Hz, H-5), 3.26 (dd, 1H, J = 11.6, 9.6 Hz, H-5⁗), 2.24 (s, 3H, CH_3CO), 2.13 (s, 3H, CH_3CO), 1.98 (s, 3H, CH_3CO), 1.98 (s, 3H, CH_3CO), 1.95 (s, 3H, CH_3CO), 1.91 (s, 3H, CH_3CO), 1.50 (s, 3H, CH_3CO), 1.32 (d, 3H, J = 6.0 Hz, CH_3), 1.21 (d, 3H, J = 6.2 Hz, CH_3), 1.15 (s, 9H, $(CH_3)_3CCO$), 1.11 (s, 9H, $(CH_3)_3CCO$), 1.10 (s, 9H, $(CH_3)_3CCO$). ^{13}C NMR (125 MHz, $CDCl_3$): δ (ppm) 177.4, 177.4, 176.4, 171.0, 170.8, 170.3, 170.1, 169.8, 169.3, 169.3, 165.4, 155.1, 151.4, 133.2, 130.3, 130.0, 128.5, 117.6, 114.9, 101.2, 100.7, 100.3, 99.3, 96.3, 80.41, 79.7, 74.2, 73.3, 72.3, 71.8, 71.8, 71.8, 71.6, 71.5, 71.5, 70.9, 70.0, 69.3, 69.1, 69.1, 68.0, 67.3, 66.5, 62.5, 61.1, 55.7, 38.9, 38.8, 38.8, 27.3, 27.2, 27.2, 21.5, 20.8, 20.7, 20.7, 20.7, 20.6, 20.3, 18.0, 16.3. HRMS (ESI, m/z): calcd for $[C_{71}H_{100}NO_{34}]$ $(M + NH_4)^+$ 1510.61, found 1510.61.

*p-Methoxyphenyl 2-O-[3′-O-(β-D-Glucopyranosyl)-4′-O-(β-D-xylopyranosyl)-α-L-rhamnopyranosyl]-3-O-(β-D-fucopyranosyl)-α-L-arabinopyranoside (**2**).* Pentasaccharide **11** (65.0 mg, 40.0 μmol) was dissolved in methanol (1.30 mL), and potassium hydroxide (73.0 mg, 1.30 mmol) was added. The solution was stirred overnight at room temperature and then acidified to neutral pH with Amberlite IR-120 H^+ resin that had been rinsed with methanol. The solution was filtered, and solvent was removed under reduced pressure to give approximately 50 mg of crude material. The crude isolate was purified by size-exclusion chromatography using Bio Rad Bio-Gel P4 Gel (elution with H_2O). The product fractions were collected, and solvent was removed under reduced pressure. The resulting white solid was azeotroped twice with toluene and dried in vacuo to remove residual solvent before lyophilizing to remove residual water and acetic acid. Compound **2** was isolated as a white, amorphous solid (25.0 mg, 74%). Glycosidic linkages were confirmed through analysis of the 2-D HMBC NMR spectrum. NMR data were consistent with those reported for the isolated natural product, with the exception of expected differences in the signals corresponding to the arabinopyranosyl moiety.[43] $[\alpha]^{20}_D = -30.24$ (c = 8.40 mg/mL, CH_3OH). ^1H NMR (700 MHz, CD_3OD): δ (ppm) 6.96−6.94 (m, 2H, *o*-Ar), 6.85−6.83 (m, 2H, *m*-Ar), 5.21 (d, 1H, J = 1.7 Hz, H-1′), 4.89 (d, 1H, J = 7.4 Hz, H-1), 4.68 (d, 1H, J = 7.8 Hz, H-1‴), 4.53 (d, 1H, J = 7.6 Hz, H-1″), 4.44 (d, 1H, J = 7.5 Hz, H-1⁗), 4.33 (dd, 1H, J = 3.0, 1.9 Hz, H-2′), 4.12 (m, 1H, H-4), 4.10−4.07 (m, 1H, H-5′), 4.00 (dd, 1H, J = 9.1, 7.4 Hz, H-2), 3.93−3.90 (m, 2H, H-3′, H-5), 3.85 (dd, 1H, J = 12.0, 2.0 Hz, H-6″), 3.83−3.81 (m, 2H, H-3, H-5‴) 3.75 (s, 3H, OCH_3), 3.71−3.67 (m, 4H, H-4′, H-5⁗, H-5, H-6″), 3.63 (d, 1H, J = 3.2 Hz, H-4⁗), 3.57 (dd, 1H, J = 9.8, 7.5 Hz, H-2⁗), 3.53 (dd, 1H, J = 9.8, 3.2 Hz, H-3⁗), 3.48−3.44 (m, 1H, H-4‴), 3.33−3.28 (m, 4H, H-2″, H-3″, H-4″, H-5″), 3.26 (app t, 1H, J = 9.1 Hz, H-3‴), 3.15 (app t, 1H, J = 11.0 Hz, H-5‴), 3.05 (dd, 1H, J = 9.3, 8.0 Hz, H-2‴), 1.28 (d, 3H, J = 6.2 Hz, CH_3 rhamnose), 1.26 (d, 3H, J = 6.5 Hz, CH_3 fucose). ^{13}C NMR (125 MHz, CD_3OD): δ (ppm) 156.4, 152.4, 118.4, 115.6, 106.1, 105.2, 104.9, 102.4, 101.3, 84.6, 83.1, 78.9, 78.4, 78.1, 77.7, 76.5, 75.6, 75.3, 75.0, 72.9, 72.4, 71.8, 71.5, 71.4, 71.3, 69.9, 68.4, 67.0, 66.5, 62.5, 56.1, 18.4, 16.9. FTIR (ν_{max}, neat, cm^{-1}): 3260 (broad, w), 2919 (w), 1561 (m), 1507 (m), 1383 (m), 1218 (m), 1163 (m), 1063 (s), 1029 (s), 898 (m), 825 (m), 744 (m), 721 (m). HRMS (EI, m/z): calcd for $[C_{35}H_{54}NaO_{23}]$ $(M + Na)^+$ 865.2948, found 865.2957.

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■ ASSOCIATED CONTENT

Supporting Information

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^{1}H and ^{13}C NMR spectra of new compounds, copies of HPLC chromatograms, and a table comparing the ^{1}H NMR chemical shift data for compounds **2** and **1a** (PDF)

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Notes

The authors declare no competing financial interest.

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