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Facile synthesis of arabinomannose penta- and decasaccharide fragments of the lipoarabinomannan of the equine pathogen, *Rhodococcus equi*

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Abstract—Pentasaccharide repeating unit **20** of the lipoarabinomannan from the equine pathogen, *Rhodococcus equi*, and its dimer **31**, were synthesized. The pentasaccharide was obtained by assembling a benzoylated 2,6-branched mannosyl trisaccharide acceptor **13** with a free hydroxyl group at C-2′ of the mannose residue attached to the core mannose residue by (1 → 6)-linkage, followed by coupling with 2,3,5-tri-*O*-benzoyl-α-D-arabinofuranosyl-(1 → 2)-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl trichloroacetimidate (**18**), and by deacylation. Meanwhile, the decamer **31** was obtained by firstly preparing a benzoylated mannose (1 → 6)-linked tetrasaccharide backbone **26** with 2-, 2″-O-ClAc, and 2′-, 2‴-O-Ac groups, respectively, then by dechloroacetylation and subsequent condensation with perbenzoylated trichloroacetimidate, and then by deacetylation and subsequent coupling with **18**, and finally, by deacylation.

Keywords: Mannose; Arabinose; Regio- and stereoselective synthesis

1. Introduction

The equine pathogen, *Rhodococcus equi*, is a significant cause of disease in foals between the age of 1 and 5 months and is responsible for around 3% of global foal mortality.[1] This organism has also emerged as an opportunistic human pathogen, notably of people with compromised immunity.[2] *R. equi* is an intracellular pathogen of alveolar macrophages, a member of the mycolata, and its infection is characterized by bronchopneumonia. Members of the mycolata have a characteristic cell envelope that profoundly affects the properties of these bacteria, and its composition and organization have been a major focus of mycobacterial research.[3] Lipoarabinomannan (LAM) is a complex mycobacterial cell envelope component that has been identified as a putative virulence factor of *M. tuberculosis*[4] LAM has also been reported to have powerful immunomodulatory properties, promoting distinctive patterns of macrophages cytokine induction that subsequently directs host immune responses.[5] Small differences in LAM structure can strongly influence these biological activities. The lipoglycan of *R. equi* has been isolated, purified, and characterized,[6] and its structure is shown in Figure 1. It is composed of three domains. The first one is a polysaccharide consisting of a comb-like, 2-Man*p* or -Ara*f*-(1 → 2)-Man*p* branched six-linked mannose pentasaccharide repeating unit. The second one is a polysaccharide consisting of a mannose (1 → 6)-linked disaccharide repeating unit, and the third one is the phosphatidyl-*myo*-inositol anchor attached with diacylated Man*p*. The synthesis of (1 → 6)-linked mannose hexa-, octa-, and dodecasaccharide, corresponding to the structure of the second domain, has been reported by our group.[7] We present herein the synthesis of the pentasaccharide repeating unit and its dimer, corresponding to the structure of the first domain of *R. equi* LAM.

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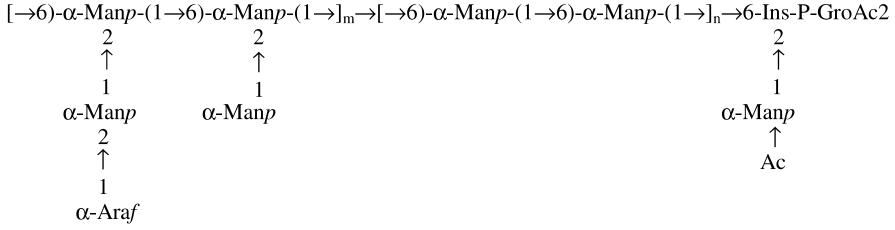


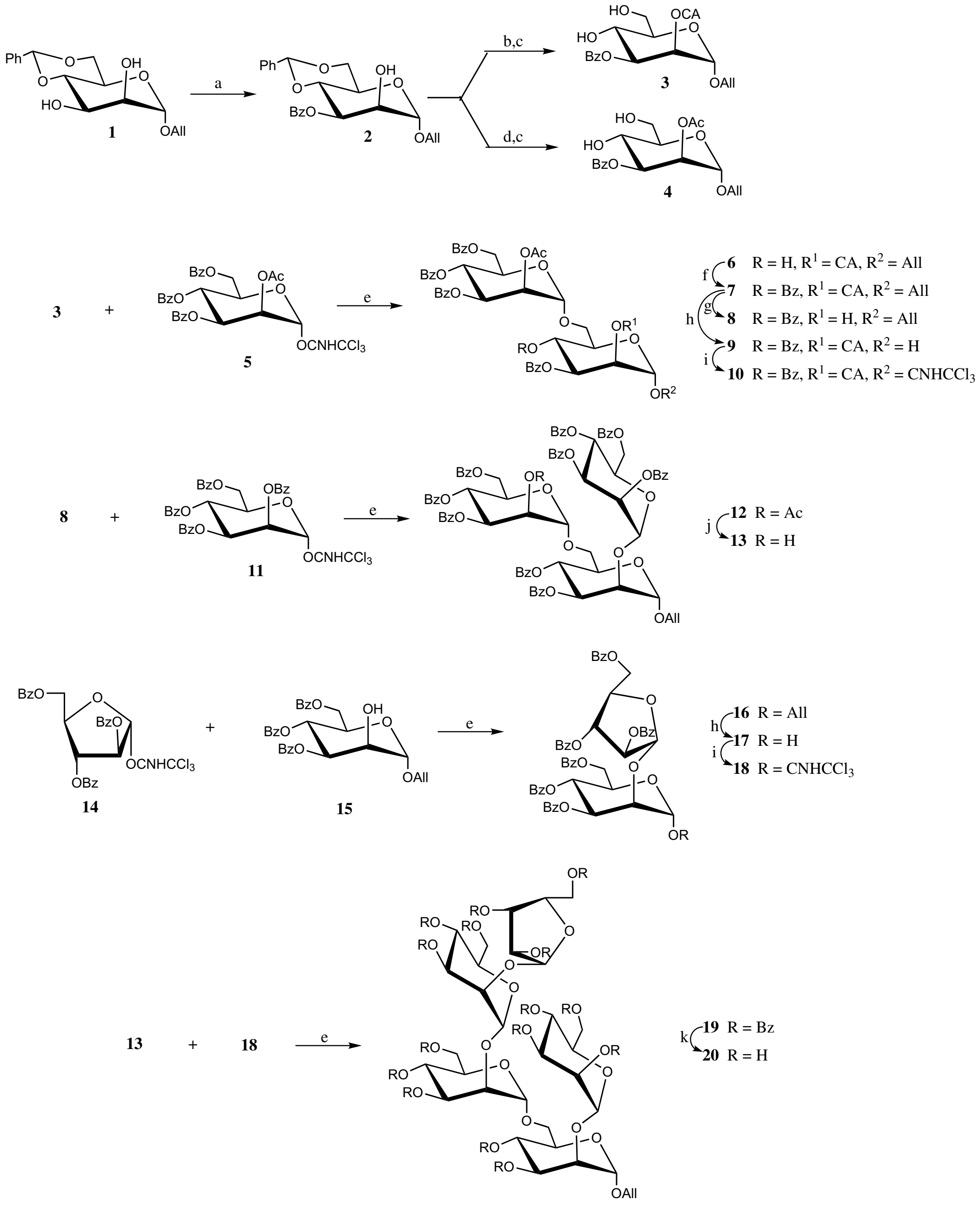
Figure 1. Structure of *R. equi* LAM.

2. Results and discussion

We have reported a method[8] for mannose oligosaccharide syntheses using unprotected or lightly protected sugars as the glycosyl acceptors, and a variety of complex oligosaccharides have been synthesized efficiently.[9] In the present research, a concise synthesis of the pentasaccharide repeating unit of the polysaccharide of *R. equi* LAM was achieved as shown in Scheme 1. Allyl 3-*O*-benzoyl-4,6-*O*-benzylidene-α-D-mannopyranoside (**2**) was chosen as the starting material that was prepared in high yield (90.7%) by selective 3-O-benzoylation of allyl 4,6-*O*-benzylidene-α-D-mannopyranoside (**1**) with benzoyl chloride in dichloromethane–pyridine. The ^{1}H NMR spectrum of **2** showed a characteristic doublet of doublets at δ 5.56 with $J_{2,3} = 3.2$ Hz, $J_{3,4} = 10.3$ Hz for H-3, confirming the selectivity. Chloroacetylation of **2**, followed by debenzylidenation, afforded the monosaccharide acceptor **3**, while acetylation followed by debenzylidenation afforded the monosaccharide acceptor **4**. Subsequent coupling of **3** with 2-*O*-acetyl-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl trichloroacetimidate (**5**) selectively gave the (1→6)-linked disaccharide **6** (86.4%), and the regioselectivity of the coupling was confirmed by benzoylation of **6** to give **7** that showed in its ^{1}H NMR spectrum a newly emerged signal at δ 5.93 ppm with $J_{3,4} = J_{4,5} = 10.1$ Hz for H-4 compared to **6**. Dechloroacetylation of **7** afforded the disaccharide acceptor **8**, while deallylation with $PdCl_2$[10] followed by trichloroacetimidate formation,[11] yielded the disaccharide donor **10**. Condensation of **8** with perbenzoylated mannosyl trichloroacetimidate **11** produced the trisaccharide **12** (87.8%), and subsequent selective deacetylation[12] with acetyl chloride in dichloromethane–methanol (1:5:25 v/v/v) yielded the trisaccharide acceptor **13** in good yield (78.5%). The other disaccharide block **18** was obtained through condensation of allyl 3,4,6-tri-*O*-benzoyl-α-D-mannopyranoside (**15**) with perbenzoylated α-D-arabinofuranosyl trichloroacetimidate **14**[13] to afford the disaccharide **16** (87.2%). Deallylation and subsequent trichloroacetimidate formation then produced the disaccharide donor **18** (77.7% for two steps). Finally, condensation of **18** with the **13** gave pentasaccharide **19** (81.5%), and deacylation in ammonia–saturated methanol yielded the pentasaccharide **20** (91%). The ^{1}H and ^{13}C NMR spectra of **20** showed all of the characteristic signals such as at δ 5.06 (s, 1H, Man*p* H-1), 5.05 (s, 1H, Ara*f* H-1), 5.01 (s, 1H, Man*p* H-1), 4.99 (s, 1H, Man*p* H-1), 4.89 (s, 1H, Man*p* H-1); 109.36 (Ara*f* C-1), 102.32, 101.36, 97.95, and 97.47 (Man*p* C-1).

Decasaccharide **31**, the dimer of the pentasaccharide repeating unit, was obtained in an alternative way. Thus, selective 6-O-glycosylation of **4** with the disaccharide donor **10** gave the trisaccharide **21** (84.5%). Benzoylation of **21** produced **22**, and its ^{1}H NMR spectrum showed a newly emerged signal at δ 5.92 ppm with $J_{3,4} = J_{4,5} = 9.9$ Hz for H-4 compared to **21**, confirming the selective 6-O-glycosylation. Deallylation of **22**, followed by trichloroacetimidate formation, gave the trisaccharide donor **24** (74.7% for two steps). Subsequent selective coupling of the monosaccharide acceptor **3** with **24** yielded the tetrasaccharide **25** (80.1%), and subsequent benzoylation gave the tetrasaccharide **26** with 2-, 2″-chloroacetyl, and 2′-, 2‴-acetyl groups. The structure of **26** could allow different substitution at 2-, 2″-, and 2′-, 2‴-positions. Thus, dechloroacetylation of **26** with thiourea produced tetrasaccharide acceptor **27** (82.3%) with 2- and 2″-free hydroxyl groups, and subsequent condensation with perbenzoylated mannosyl donor **11** gave the hexasaccharide **28** in high yield (85.9%). Then, selective deacetylation under the same conditions as those used for deacetylation of **12** afforded the hexasaccharide acceptor **29** (76.8%) with 2′- and 2‴-free hydroxyl groups. Finally, condensation of **29** with **18** (66.7%), followed by deacylation, gave the target decasaccharide **31** (92.5%). The ^{1}H and ^{13}C NMR spectra of **31** showed all of the characteristic signals such as at δ 5.09 (s, 1H, Man*p* H-1), 5.08 (s, 1H, Man*p* H-1), 5.07 (s, 2H, Ara*f* 2H-1), 5.02 (s, 1H, Man*p* H-1), 5.01 (s, 1H, Man*p* H-1), 4.99 (s, 2H, Man*p* 2H-1), 4.93 (s, 1H, Man*p* H-1), 4.91 (s, 1H, Man*p* H-1); 109.36 (2C, Ara*f* 2C-1), 102.32, 102.19, 101.32, 101.30, 98.17, 98.03, and 97.53 (8C, Man*p* 8C-1) (Scheme 2).

In summary, a facile synthesis of complex arabinomannosyl oligosaccharides was achieved through a regio- and stereoselective manner with readily accessible materials. The described method is suitable for preparation of a 2,6-branched comb-like mannan with arabinofuranose side chains.

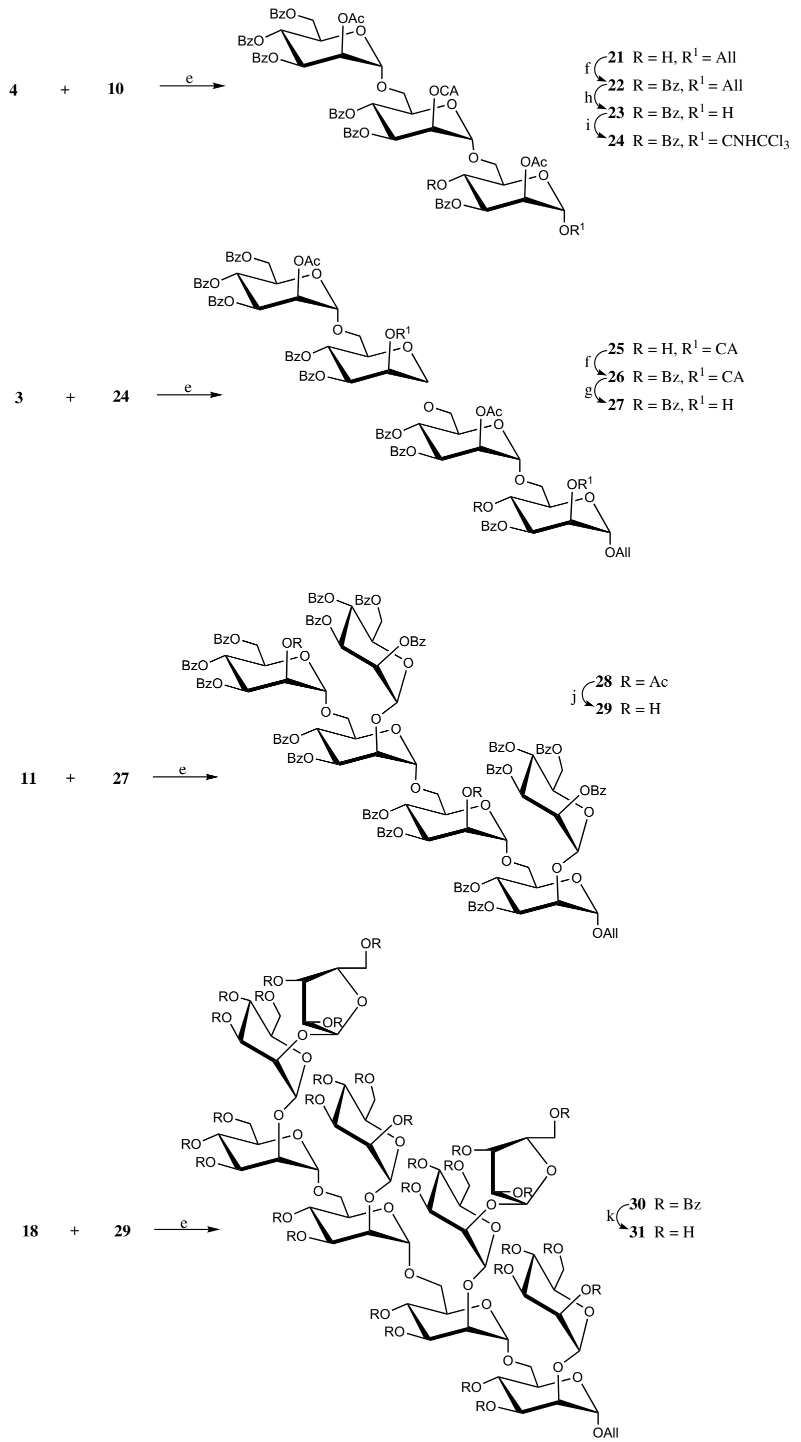


Scheme 1. Reagents and conditions: (a) BzCl, CH_2Cl_2, pyridine, 90.7%; (b), (c) $CH_2ClCOCl$, CH_2Cl_2, pyridine; 90% TFA, rt, 2 h; 78.5% for two steps; (d), (c) Ac_2O–pyridine; 90% TFA, rt, 2 h; 82.3% for two steps; (e) TMSOTf (0.01–0.05 equiv), CH_2Cl_2, −20 to 0 °C, 2–4 h, 86.4% for **6**, 87.8% for **12**, 87.2% for **16**, 81.5% for **19**, 84.5% for **21**, 80.1% for **25**, 85.9% for **28**, and 66.7% for **30**, respectively; (f) BzCl–pyridine, 91.6% for **7**, 89.2% for **22**, 85.5% for **26**; (g) $(NH_2)_2CS$, CH_2Cl_2–CH_3OH, reflux, 16 h, 85.6% for **8**, 82.3% for **27**; (h) $PdCl_2$, CH_3OH, rt, 4 h, 84.5% for **9**, 82.4% for **17**, 82.7% for **23**; (i) CCl_3CN, DBU, CH_2Cl_2, 2h, 88.7% for **10**, 94.3% for **18**, 90.3% for **24**; (j) CH_3OH–2–6% CH_3COCl, rt, 12 h, 78.5% for **13**, 76.8% for **29**; (k) satd NH_3–CH_3OH, rt, 96 h, 91.0% for **20**, 92.5% for **31**.

3. Experimental

3.1. General methods

Optical rotations were determined at 25 °C with a Perkin–Elmer Model 241-Mc automatic polarimeter. ^1H NMR and ^{13}C NMR spectra were recorded with Bruker ARX 400 spectrometers (400 MHz for ^1H, 100 MHz for ^{13}C) for solutions in $CDCl_3$ or D_2O as indicated. Chemical shifts are given in ppm downfield from internal Me_4Si. Mass spectra were measured using MALDITOF-MS with CCA as matrix or recorded with a VG PLATFORM mass spectrometer using the ESI mode. Thin-layer chromatography (TLC) was



Scheme 2. Reagents and conditions: (a) BzCl, CH_2Cl_2, pyridine, 90.7%; (b), (c) $CH_2ClCOCl$, CH_2Cl_2, pyridine; 90% TFA, rt, 2 h; 78.5% for two steps; (d), (c) Ac_2O–pyridine; 90% TFA, rt, 2 h; 82.3% for two steps; (e) TMSOTf (0.01–0.05 equiv), CH_2Cl_2, −20 to 0 °C, 2–4 h, 86.4% for **6**, 87.8% for **12**, 87.2% for **16**, 81.5% for **19**, 84.5% for **21**, 80.1% for **25**, 85.9% for **28**, and 66.7% for **30**, respectively; (f) BzCl–pyridine, 91.6% for **7**, 89.2% for **22**, 85.5% for **26**; (g) $(NH_2)_2CS$, CH_2Cl_2–CH_3OH, reflux, 16 h, 85.6% for **8**, 82.3% for **27**; (h) $PdCl_2$, CH_3OH, rt, 4 h, 84.5% for **9**, 82.4% for **17**, 82.7% for **23**; (i) CCl_3CN, DBU, CH_2Cl_2, 2h, 88.7% for **10**, 94.3% for **18**, 90.3% for **24**; (j) CH_3OH–2–6% CH_3COCl, rt, 12 h, 78.5% for **13**, 76.8% for **29**; (k) satd NH_3–CH_3OH, rt, 96 h, 91.0% for **20**, 92.5% for **31**.

performed on silica gel HF_{254} with detection by charring with 30% (v/v) H_2SO_4 in MeOH or in some cases by a UV detector. Column chromatography was conducted by elution of a column (16 × 240 mm,

18×300 mm, 35×400 mm) of silica gel (100–200 mesh) with EtOAc–petroleum ether (60–90 °C) as the eluent. Solutions were concentrated at <60 °C under reduced pressure.

3.2. General procedure for the glycosylations

A mixture of the donor and acceptor was dried together under high vacuum for 2 h, then dissolved in anhyd CH_2Cl_2 (1 mmol donor in 20 mL). TMSOTf (0.05 equiv) was added dropwise at −20 °C with nitrogen protection. The reaction mixture was stirred for 3 h, during which time the temperature was gradually raised to ambient temperature. Then the mixture was neutralized with Et_3N. Concentration of the reaction mixture, followed by purification on a silica gel column, gave the desired products.

3.3. Allyl 3-*O*-benzoyl-4,6-di-*O*-benzylidene-α-D-mannopyranoside (2)

Compound **1** (1.54 g, 5.0 mmol) was dissolved in dry CH_2Cl_2 (20 mL) containing pyridine (4 mL), then under N_2 protection, benzoyl chloride (0.6 mL, 5.1 mmol) in anhyd CH_2Cl_2 (5 mL) was added dropwise to the solution within 30 min at 0 °C. The reaction mixture was slowly raised to room temperature (rt) and stirred for 2 h, at the end of which time TLC (3:1 petroleum ether–EtOAc) indicated that the reaction was complete. The reaction mixture was diluted with CH_2Cl_2 (50 mL), washed with water, 1 N HCl, and dried over Na_2SO_4. The solution was concentrated, and purification of the residue by column chromatography on a silica gel column (4:1 petroleum ether–EtOAc) gave compound **2** (1.87 g, 90.7%) as a syrup: $[\alpha]_D$ −8.6 (*c* 1.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 8.05–7.28 (m, 10H, 2*Ph*), 5.95–5.86 (m, 1H, –CH_2–C*H*=CH_2), 5.57 (s, 1H, PhC*H*), 5.56 (dd, 1H, $J_{2,3} = 3.2$ Hz, $J_{3,4} = 10.3$ Hz, H-3), 5.34–5.20 (m, 2H, –CH_2–CH=CH_2), 4.89 (d, 1H, $J_{1,2} = 1.2$ Hz, H-1), 4.30-3.87 (m, 7H, H-2, H-4, H-5, H-6, –CH_2–CH=CH_2). Anal. Calcd for $C_{23}H_{24}O_7$: C 66.98; H 5.87. Found: C 67.21; H 5.92.

3.4. Allyl 3-*O*-benzoyl-2-*O*-chloroacetyl-α-D-mannopyranoside (3)

Compound **2** (1.24 g, 3.0 mmol) was dissolved in dry CH_2Cl_2 (20 mL) containing pyridine (3 mL), then under N_2 protection, chloroacetyl chloride (0.27 mL, 3.3 mmol) in anhyd CH_2Cl_2 (5 mL) was added dropwise to the solution. The reaction mixture was stirred for 2 h, then was diluted with CH_2Cl_2 (40 mL), washed with water, 1 N HCl, and dried over Na_2SO_4. The solution was concentrated, the residue was dissolved in 90% TFA (20 mL), and the mixture was stirred for 2 h at rt, at the end of which time TLC (2:1 petroleum ether–EtOAc) indicated that the reaction was complete. The mixture was diluted with toluene (80 mL) and concentrated in vacuo directly. The residue was passed through a short silica gel column with 1:1 petroleum ether–EtOAc as the eluent to give **3** (0.94 g, 78.5% for two steps) as syrup: $[\alpha]_D$ +96.7 (*c* 1.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 8.00–7.43 (m, 5H, *Ph*), 5.96–5.86 (m, 1H, –CH_2–C*H*=CH_2), 5.52 (dd, 1H, $J_{2,3} = 3.3$ Hz, $J_{3,4} = 9.9$ Hz, H-3), 5.44 (dd, 1H, $J_{1,2} = 1.6$ Hz, $J_{2,3} = 3.3$ Hz, H-2), 5.36-5.24 (m, 2H, –CH_2–CH=CH_2), 4.93 (d, 1H, $J_{1,2} = 1.6$ Hz, H-1), 4.26–4.02 (m, 5H, H-4, CH_2ClCO, –CH_2–CH=CH_2), 3.93–3.82 (m, 3H, H-5, H-6). Anal. Calcd for $C_{18}H_{21}ClO_8$: C 53.94; H 5.28. Found: C 54.09; H 5.33.

3.5. Allyl 2-*O*-acetyl-3-*O*-benzoyl-α-D-mannopyranoside (4)

To a solution of **16** (412 mg, 1 mmol) in pyridine (10 mL) was added Ac_2O (5 mL, 5 mmol). The reaction mixture, was stirred at rt for 12 h, at the end of which time TLC (3:1 petroleum ether–EtOAc) indicated that the reaction was complete. The reaction mixture was concentrated, the residue was dissolved in 90% TFA (10 mL), and the mixture was stirred for 2 h at rt, at the end of which time TLC (2:1 petroleum ether–EtOAc) indicated that the reaction was complete. The mixture was diluted with toluene (40 mL) and concentrated in vacuo directly. The residue was passed through a short silica gel column with 1:1 petroleum ether–EtOAc as the eluent to give **4** (302 mg, 82.3% for two steps) as syrup: $[\alpha]_D$ +62.6 (*c* 1.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 8.00–7.43 (m, 5H, *Ph*), 5.96–5.86 (m, 1H, –CH_2–C*H*=CH_2), 5.48 (dd, 1H, $J_{2,3} = 3.5$ Hz, $J_{3,4} = 9.9$ Hz, H-3), 5.39 (dd, 1H, $J_{1,2} = 1.6$ Hz, $J_{2,3} = 3.5$ Hz, H-2), 5.35–5.23 (m, 2H, –CH_2–CH=CH_2), 4.90 (d, 1H, $J_{1,2} = 1.6$ Hz, H-1), 4.25–4.01 (m, 3H, H-4, –CH_2–CH=CH_2), 3.94–3.82 (m, 3H, H-5, H-6), 2.15 (s, 3H, CH_3CO). Anal. Calcd for $C_{18}H_{22}O_8$: C 59.01; H 6.05. Found: C 59.28; H 6.11.

3.6. Allyl 2-*O*-acetyl-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-3-*O*-benzoyl-2-*O*-chloroacetyl-α-D-mannopyranoside (6)

Donor **5** (996 mg, 1.47 mmol) was coupled with acceptor **3** (490 mg, 1.22 mmol) as described in the general procedure, and the product was purified by chromatography with 3:1 petroleum ether–EtOAc as the eluent to give **10** (969 mg, 86.4%) as a foamy solid: $[\alpha]_D$ +49.6 (*c* 1.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 8.07–7.26 (m, 20H, 4*Ph*), 5.98–5.88 (m, 2H, H-4′, –CH_2–C*H*=CH_2), 5.84 (dd, 1H, $J_{2',3'} = 3.3$ Hz, $J_{3',4'} = 10.1$ Hz, H-3′), 5.60 (dd, 1H, $J_{1',2'} = 1.8$ Hz, $J_{2',3'} = 3.3$ Hz, H-2′), 5.55 (dd, 1H) 5.38–5.24 (m, 2H, $-\mathrm{CH_2{-}CH{=}C}H_2$), 5.15 (d, 1H, $J_{1',2'} = 1.8$ Hz, H-1′), 4.95 (d, 1H, $J_{1,2} = 1.8$ Hz, H-1), 4.66–4.61 (m, 1H, H-5′), 4.54–4.48 (m, 2H, H-5, H-6′a), 4.36 (dd, 1H, $J_{3,4} = J_{4,5} = 9.8$ Hz, H-4), 4.25 (ABq, 2H, $J = 20.4$ Hz, $\mathrm{C}H_2\mathrm{ClCO}$), 4.24–3.90 (m, 5H, H-6a, H-6b, H-6′b, $-\mathrm{C}H_2\mathrm{{-}CH{=}CH_2}$), 2.11 (s, 3H, $\mathrm{C}H_3\mathrm{CO}$). Anal. Calcd for $\mathrm{C_{47}H_{45}ClO_{17}}$: C 61.54; H 4.94. Found: C 61.38; H 5.01.

3.7. Allyl 2-*O*-acetyl-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-3,4-di-*O*-benzoyl-2-*O*-chloroacetyl-α-D-mannopyranoside (7)

To a solution of **6** (842 mg, 0.92 mmol) in pyridine (10 mL) was added benzoyl chloride (0.13 mL, 1.1 mmol). After stirring the mixture overnight at rt, TLC (2:1 petroleum ether–EtOAc) indicated that the reaction was complete. MeOH (one drop) was added to the reaction mixture, and stirring was continued for 10 min. Water (10 mL) was added, and the mixture was extracted with $\mathrm{CH_2Cl_2}$ (3 × 10 mL). The extract was washed with M HCl and satd aq $\mathrm{NaHCO_3}$, dried ($\mathrm{Na_2SO_4}$), and concentrated. Purification by flash chromatography (3:1 petroleum ether–EtOAc) gave **7** (859 mg, 91.6%) as a foamy solid: $[\alpha]_D$ +40.56 (*c* 1.0, $\mathrm{CHCl_3}$); ^{1}H NMR (400 MHz, $\mathrm{CDCl_3}$): 8.04–7.26 (m, 25H, 5*Ph*), 6.05–5.95 (m, 1H, $-\mathrm{CH_2{-}C}H\mathrm{{=}CH_2}$), 5.97 (dd, 1H, $J_{3',4'} = J_{4',5'} = 10.1$ Hz, H-4′), 5.93 (dd, 1H, $J_{3,4} = J_{4,5} = 10.1$ Hz, H-4), 5.88 (dd, 1H, $J_{2',3'} = 3.3$ Hz, $J_{3',4'} = 10.1$ Hz, H-3′), 5.85 (dd, 1H, $J_{2,3} = 3.3$ Hz, $J_{3,4} = 10.1$ Hz, H-3), 5.58 (dd, 1H, $J_{1',2'} = 1.8$ Hz, $J_{2',3'} = 3.3$ Hz, H-2′), 5.55 (dd, 1H, $J_{1,2} = 1.8$ Hz, $J_{2,3} = 3.3$ Hz, H-2), 5.47–5.31 (m, 2H, $-\mathrm{CH_2{-}CH{=}C}H_2$), 5.04 (d, 1H, $J_{1',2'} = 1.8$ Hz, H-1′), 5.03 (d, 1H, $J_{1,2} = 1.8$ Hz, H-1), 4.47 (dd, 1H, $J_{5',6'a} = 2.4$ Hz, $J_{6'a,6'b} = 11.6$ Hz, H-6′a), 4.43–3.72 (m, 9H, H-5, H-5′, H-6a, H-6b, H-6′b, $\mathrm{C}H_2\mathrm{ClCO}$, $-\mathrm{C}H_2\mathrm{{-}CH{=}CH_2}$), 2.11 (s, 3H, $\mathrm{C}H_3\mathrm{CO}$). Anal. Calcd for $\mathrm{C_{54}H_{49}ClO_{18}}$: C 63.50; H 4.84. Found: C 63.75; H 4.78.

3.8. Allyl 2-*O*-acetyl-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-3,4-di-*O*-benzoyl-α-D-mannopyranoside (8)

To a solution of **7** (320 mg, 0.31 mmol) in MeOH (10 mL)–$\mathrm{CH_2Cl_2}$ (15 mL) was added thiourea (600 mg), and the mixture was refluxed for 16 h, at the end of which time TLC (2:1 petroleum ether–EtOAc) indicated that the reaction was complete. The mixture was concentrated. The residue was passed through a silica-gel column with 3:1 petroleum ether–EtOAc as the eluent to give **8** (253 mg, 85.6% for two steps) as a foamy solid: $[\alpha]_D$ +32.2 (*c* 1.0, $\mathrm{CHCl_3}$); ^{1}H NMR (400 MHz, $\mathrm{CDCl_3}$): δ 8.01–7.26 (m, 25H, 5*Ph*), 6.08–5.98 (m, 1H, $-\mathrm{CH_2{-}C}H\mathrm{{=}CH_2}$), 5.88 (dd, 1H, $J_{3',4'} = J_{4',5'} = 10.1$ Hz, H-4′), 5.87 (dd, 1H, $J_{3,4} = J_{4,5} = 10.1$ Hz, H-4), 5.85 (dd, 1H, $J_{2',3'} = 3.2$ Hz, $J_{3',4'} = 10.1$ Hz, H-3′), 5.70 (dd, 1H, $J_{2,3} = 3.1$ Hz, $J_{3,4} = 10.1$ Hz, H-3), 5.51 (dd, 1H, $J_{1',2'} = 1.5$ Hz, $J_{2',3'} = 3.2$ Hz, H-2′), 5.47–5.29 (m, 2 H, $-\mathrm{CH_2{-}CH{=}C}H_2$), 5.04 (d, 1H, $J_{1',2'} = 1.5$ Hz, H-1′), 5.03 (d, 1H, $J_{1,2} = 1.6$ Hz, H-1), 4.50–3.71 (m, 9H, H-2, H-5, H-5′, H-6, H-6′, $-\mathrm{C}H_2\mathrm{{-}CH{=}CH_2}$), 2.12 (s, 3H, $\mathrm{C}H_3\mathrm{CO}$). Anal. Calcd for $\mathrm{C_{52}H_{48}O_{17}}$: C 66.10; H 5.12. Found: C 65.87; H 5.09.

3.9. 2-*O*-Acetyl-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-3,4-di-*O*-benzoyl-2-*O*-chloroacetyl-α-D-mannopyranosyl trichloroacetimidate (10)

To a solution of **7** (515 mg, 0.50 mmol) in anhyd MeOH (10 mL) was added $\mathrm{PdCl_2}$ (30 mg). After stirring the mixture at rt for 2 h, TLC (2:1 petroleum ether–EtOAc) indicated that the reaction was complete. The mixture was filtered, the solution was concentrated to dryness, and the resultant residue was purified by flash chromatography (2.5:1 petroleum ether–EtOAc) to give **9** (418 mg, 84.5%) as a white foam. A mixture of **9** (418 mg, 0.43 mmol), trichloroacetonitrile (80 μL, 0.80 mmol) and 1,8-diazabicyclo[5.4.0]-undecene (DBU) (25 μL) in dry $\mathrm{CH_2Cl_2}$ (10 mL) was stirred under nitrogen for 3 h and then concentrated. The residue was purified by flash chromatography (3:1 petroleum ether–EtOAc) to give **10** (425 mg, 88.7%) as a foamy solid: $[\alpha]_D$ +55.5 (*c* 1.0, $\mathrm{CHCl_3}$); ^{1}H NMR (400 MHz, $\mathrm{CDCl_3}$): δ 8.97 (s, 1H, $\mathrm{CN}H\mathrm{CCl_3}$), 8.08–7.26 (m, 25H, 5*Ph*), 6.44 (d, 1H, $J_{1,2} = 1.5$ Hz, H-1), 6.12 (dd, 1H, $J_{3',4'} = J_{4',5'} = 10.0$ Hz, H-4′), 5.93 (dd, 1H, $J_{3,4} = J_{4,5} = 9.9$ Hz, H-4), 5.91–5.82 (m, 2H, H-3, H-3′), 5.78 (dd, 1H, $J_{1',2'} = 1.4$ Hz, $J_{2',3'} = 3.2$ Hz, H-2′), 5.57 (dd, 1H, $J_{1,2} = 1.5$ Hz, $J_{2,3} = 3.0$ Hz, H-2), 5.01 (d, 1H, $J_{1',2'} = 1.4$ Hz, H-1′), 4.52–3.78 (m, 8H, H-5, H-5′, H-6, H-6′, $\mathrm{C}H_2\mathrm{ClCO}$), 2.12 (s, 3H, $\mathrm{C}H_3\mathrm{CO}$). Anal. Calcd for $\mathrm{C_{53}H_{45}Cl_4NO_{18}}$: C 56.55; H 4.03. Found: C 56.32; H 3.97.

3.10. Allyl 2-*O*-acetyl-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-[2,3,4,6-tetra-*O*-benzoyl-α-D-mannopyranosyl-(1 → 2)]-3,4-di-*O*-benzoyl-α-D-mannopyranoside (12)

Compound **8** (240 mg, 0.25 mmol) and **11** (226 mg, 0.31 mmol) were coupled under the same conditions as those used for preparation of **6** from **3** and **5**, giving **12** (340 mg, 87.8%) as a foamy solid: $[\alpha]_D$ −32.5 (*c* 1.0, $\mathrm{CHCl_3}$); ^{1}H NMR (400 MHz, $\mathrm{CDCl_3}$): δ 8.13–7.05 (m, 45H, 9*Ph*), 6.17 (dd, 1H, $J_{3,4} = J_{4,5} = 9.8$ Hz, H-4), 6.10–5.91 (m, 7H, H-2, 3H-3, 2H-4, $-\mathrm{CH_2{-}C}H\mathrm{{=}CH_2}$), 5.63 (dd, 1H, $J_{1,2} = 1.4$ Hz, $J_{2,3} = 2.9$ Hz, H-2), 5.50–5.29 (m, 2H, $-\mathrm{CH_2{-}C{=}HC}H_2$), 5.32 (d, 1H, $J_{1,2} = 1.2$ Hz, H-1), 5.27 (d, 1H, $J_{1,2} = 1.3$ Hz, H-1), 5.27 (d, 1H,

$J_{1,2} = 1.4$ Hz, H-1), 5.08 (d, 1H, $J_{1,2} = 1.5$ Hz, H-1), 4.77–3.79 (m, 12H, H-2, 3H-5, 6H-6, $-CH_2-CH{=}CH_2$), 2.06 (s, 3H, CH_3CO); ^{13}C NMR (100 MHz, $CDCl_3$): δ 169.67 (CH_3CO), 166.09, 165.99, 165.87, 165.67, 165.60, 165.29, 164.95, 164.81, 167.80 (PhCO), 99.66, 97.86, 97.55 (C-1), 71.06, 70.23, 70.03, 69.97, 69.76, 69.74, 68.83, 68.67, 67.35, 66.86, 66.83, 66.73, 63.02, 62.89, 60.34, 20.69. Anal. Calcd for $C_{86}H_{74}O_{26}$: C 67.80; H 4.90. Found: C 67.68; H 4.83.

3.11. Allyl 3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-[2,3,4,6-tetra-*O*-benzoyl-α-D-mannopyranosyl-(1 → 2)]-3,4-di-*O*-benzoyl-α-D-mannopyranoside (13)

To a solution of **12** (325 mg, 0.21 mmol) in anhyd CH_2Cl_2 (5 mL) was added anhyd MeOH (25 mL), then acetyl chloride (1 mL) was added to the reaction mixture at 0 °C. The solution was stoppered in a flask and stirred at rt until TLC (1:1 petroleum ether–EtOAc) showed that the reaction was complete. The solution was neutralized with Et_3N, then concentrated to dryness. The residue was passed through a short silica gel column to give **13** (248 mg, 78.5%) as a foamy solid: $[\alpha]_D$ −11.6 (*c* 1.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 8.02–7.04 (m, 45H, 9*Ph*), 6.25 (dd, 1H, $J_{3,4} = J_{4,5} = 9.8$ Hz, H-4), 6.11–5.79 (m, 7H, H-2, 3H-3, 2H-4, $-CH_2-CH{=}CH_2$), 5.54 (s, 1H, H-1), 5.40–5.27 (m, 2H, $-CH_2-CH{=}CH_2$), 5.37 (s, 1H, H-1), 5.17 (s, 1H, H-1), 4.81 (m, 1H, H-2), 4.72–3.73 (m, 12H, H-2, 3H-5, 6H-6, $-CH_2-CH{=}CH_2$); ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.25, 166.10, 165.83, 165.75, 165.65, 165.64, 165.33, 164.79, 164.71 (PhCO), 100.60, 99.41, 97.97 (C-1), 72.80, 71.34, 71.13, 70.35, 69.89, 69.70, 68.89, 68.63, 67.34, 67.10, 66.54, 64.65, 63.74, 63.01, 60.39. Anal. Calcd for $C_{84}H_{72}O_{25}$: C 68.10; H 4.90. Found: C 67.95; H 4.91.

3.12. Allyl 2,3,5-tri-*O*-benzoyl-α-D-arabinofuranosyl-(1 → 2)-3,4,6-tri-*O*-benzoyl-α-D-mannopyranoside (16)

Acceptor **15** (266 mg, 0.50 mmol) was coupled with donor **14** (364 mg, 0.60 mmol) as described in the general procedure, and the product was purified by chromatography with 1.5:1 petroleum ether–EtOAc as the eluent to give **16** (426 mg, 87.2%) as a foamy solid: $[\alpha]_D$ −36.6 (*c* 1.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 8.14–7.21 (m, 30H, 6*Ph*), 6.01 (dd, 1H, $J_{3,4} = J_{4,5} = 10.0$ Hz, Man*p* H-4), 6.10–5.90 (m, 1H, $-CH_2-CH{=}CH_2$), 5.87 (dd, 1H, $J_{2,3} = 3.2$ Hz, $J_{3,4} = 10.0$ Hz, Man*p* H-3), 5.71 (d, 1H, $J_{2,3} = 1.1$ Hz, Ara*f* H-2), 5.62 (dd, 1H, $J_{2,3} = 1.1$ Hz, $J_{3,4} = 3.5$ Hz, Ara*f* H-3), 5.48 (s, 1H, Ara*f* H-1), 5.33–5.18 (m, 2H, $-CH_2-CH{=}CH_2$), 5.13 (d, 1H, $J_{1,2} = 1.7$ Hz, Man*p* H-1), 4.76–4.36 (m, 7H, Man*p* H-2, H-5, 2H-6, Ara*f* H-4, 2H-5), 4.31–4.06 (m, 2H, $-CH_2-CH{=}CH_2$). Anal. Calcd for $C_{56}H_{48}O_{16}$: C 68.85; H 4.95. Found: C 68.95; H 5.02.

3.13. 2,3,5-Tri-*O*-benzoyl-α-D-arabinofuranosyl-(1 → 2)-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl trichloroacetimidate (18)

Deallylation of disaccharide **16** (415 mg, 0.07 mmol), followed by trichloroacetimidation under the same conditions as those used for preparation of **10** from **7** gave a residue that was purified by flash chromatography (3:1 petroleum ether–EtOAc) to give **18** (357 mg, 77.7% for two steps) as a foamy solid: $[\alpha]_D$ −14.5 (*c* 1.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 8.81 (s, 1H, $CNHCCl_3$), 8.11–7.23 (m, 30H, 6*Ph*), 6.56 (d, 1H, $J_{1,2} = 1.6$ Hz, Man*p* H-1), 6.15 (dd, 1H, $J_{3,4} = J_{4,5} = 10.1$ Hz, Man*p* H-4), 5.89 (dd, 1H, $J_{2,3} = 3.2$ Hz, $J_{3,4} = 10.1$ Hz, Man*p* H-3), 5.72 (d, 1H, $J_{2,3} = 1.1$ Hz, Ara*f* H-2), 5.63 (dd, 1H, $J_{2,3} = 1.1$ Hz, $J_{3,4} = 4.4$ Hz, Ara*f* H-3), 5.53 (s, 1H, Ara*f* H-1), 4.81–4.37 (m, 7H, Man*p* H-2, H-5, 2 H-6, Ara*f* H-4, 2H-5). Anal. Calcd for $C_{55}H_{44}Cl_3NO_{16}$: C 61.09; H 4.10. Found: C 61.18; H 4.04.

3.14. Allyl [2,3,5-tri-*O*-benzoyl-α-D-arabinofuranosyl-(1 → 2)-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 2)]-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-[2,3,4,6-tetra-*O*-benzoyl-α-D-mannopyranosyl-(12)]-3,4-di-*O*-benzoyl-α-D-mannopyranoside (19)

As described in the general procedure, **13** (235 mg, 0.16 mmol) and **18** (206 mg, 0.19 mmol) were coupled, and the product was purified by silica gel column chromatography with 1.5:1 petroleum ether–EtOAc as the eluent to give **19** (310 mg, 81.5%) as a foamy solid: $[\alpha]_D$ −34.7 (*c* 1.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 8.09–6.95 (m, 75H, 15*Ph*), 6.14–5.83 (m, 10H, Man*p* H-2, 4H-3, 4H-4, $-CH_2-CH{=}CH_2$), 5.54 (s, 1H, Ara*f* H-2), 5.53 (d, 1H, $J_{3,4} = 4.3$ Hz, Ara*f* H-3), 5.45–5.28 (m, 2H, $-CH_2-CH{=}CH_2$), 5.32 (s, 1H, Ara*f* H-1), 5.28 (s, 1H, Man*p* H-1), 5.22 (s, 2H, Man*p* 2H-1), 5.20 (s, H, Man*p* H-1), 4.75–3.64 (m, 20H, Man*p* 3H-2, 4H-5, 8H-6, Ara*f* H-4, 2H-5, $-CH_2-CH{=}CH_2$); ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.19, 166.07, 165.98, 165.86, 165.66, 165.65, 165.57, 165.54, 165.34, 165.31, 165.28, 165.23, 164.85, 164.83, 164.78 (PhCO), 106.87 (Ara*f* C-1), 100.86, 99.46, 98.63, 97.98 (C-1), 81.90, 81.77, 76.26, 75.45, 71.74, 71.26, 70.90, 70.19, 69.80, 69.74, 69.64, 68.68, 68.65, 67.59, 67.54, 66.91, 66.73, 63.77, 63.51, 63.11, 62.97. Anal. Calcd for $C_{137}H_{114}O_{40}$: C 68.55; H 4.79. Found: C 68.37; H 5.70.

3.15. Allyl [α-D-arabinofuranosyl-(1 → 2)-α-D-mannopyranosyl-(1 → 2)]-α-D-mannopyranosyl-(1 → 6)-[α-D-mannopyranosyl-(1 → 2)]-α-D-mannopyranoside (20)

Pentasaccharide **19** (299 mg, 0.13 mmol) was dissolved in satd NH_3–MeOH (60 mL). After 96 h at rt, the reaction mixture was concentrated, and the residue was purified by chromatography on Sephadex LH-20 (MeOH) to afford **30** (95 mg, 91.0%) as a foamy solid: $[\alpha]_D$ +78.5 (*c* 1.0, H_2O); ^1H NMR (400 MHz, D_2O): δ 5.89–5.79 (m, 1H, –CH_2–C*H*=CH_2), 5.24 (d, 1H, J = 17.2 Hz, –CH_2–C*H*=CH_{trans}), 5.16 (d, 1H, J = 10.4 Hz, –CH_2–C*H*=CH_{cis}), 5.06 (s, 1H, Man*p* H-1), 5.05 (s, 1H, Ara*f* H-1), 5.01 (s, 1H, Man*p* H-1), 4.99 (s, 1H, Man*p* H-1), 4.89 (s, 1H, Man*p* H-1); ^{13}C NMR (100 MHz, D_2O): δ 109.36 (Ara*f* C-1), 102.32, 101.36, 97.95, 97.47 (Man*p* C-1), 83.62, 81.19, 78.85, 78.67, 77.43, 76.44, 73.31, 73.15, 72.82, 71.07, 70.47, 70.38, 70.08, 70.04, 68.42, 66.98, 66.81, 66.75, 66.69, 65.66, 61.15, 61.06, 60.91. Anal. Calcd for $C_{32}H_{54}O_{25}$: C 45.82; H 6.49. Found: C 46.01; H 6.55.

3.16. Allyl 2-*O*-acetyl-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-3,4-di-*O*-benzoyl-2-*O*-chloroacetyl-α-D-mannopyranosyl-(1 → 6)-2-*O*-acetyl-3-*O*-benzoyl-α-D-mannopyranoside (21)

Donor **10** (411 mg, 0.37 mmol) was coupled with acceptor **4** (160 mg, 0.44 mmol) as described in the general procedure, and the product was purified by chromatography with 2:1 petroleum ether–EtOAc as the eluent to give **21** (410 mg, 84.5%) as a foamy solid: $[\alpha]_D$ +42.7 (*c* 0.6, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 8.03–7.26 (m, 30H, 6*Ph*), 5.98–5.88 (m, 1H, –CH_2–C*H*=CH_2), 5.91 (dd, 1H, $J_{3'',4''} = J_{4'',5''}$ = 10.1 Hz, H-4″), 5.90 (dd, 2H, $J_{2'',3''} = J_{2',3'}$ = 3.3 Hz, $J_{3'',4''} = J_{3',4'}$ = 10.1 Hz, H-3″, H-3″), 5.85 (dd, 1H, $J_{3',4'} = J_{4',5'}$ = 10.1 Hz, H-4′), 5.66 (dd, 1H, $J_{1'',2''}$ = 1.6 Hz, $J_{2'',3''}$ = 3.3 Hz, H-2″), 5.54 (dd, 1H, $J_{2,3}$ = 3.4 Hz, $J_{3,4}$ = 9.9 Hz, H-3), 5.52 (dd, 1H, $J_{1',2'}$ = 1.6 Hz, $J_{2',3'}$ = 3.3 Hz, H-2′), 5.44 (dd, 1H, $J_{1,2}$ = 1.7 Hz, $J_{2,3}$ = 3.4 Hz, H-2), 5.39–5.21 (m, 2H, –CH_2–CH=C*H*$_2$), 5.17 (d, 1H, $J_{1'',2''}$ = 1.6 Hz, H-1″), 5.02 (d, 1H, $J_{1',2'}$ = 1.6 Hz, H-1′), 4.97 (d, 1H, $J_{1,2}$ = 1.7 Hz, H-1), 4.52–3.72 (m, 14H, H-4, 3H-5, 6H-6, –C*H*$_2$–CH=CH_2, C*H*$_2$ClCO), 2.16 (s, 3H, C*H*$_3$CO), 2.12 (s, 3H, C*H*$_3$CO). Anal. Calcd for $C_{69}H_{65}ClO_{25}$: C 62.33; H 4.93. Found: C 62.13; H 4.95.

3.17. Allyl 2-*O*-acetyl-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-3,4-di-*O*-benzoyl-2-*O*-chloroacetyl-α-D-mannopyranosyl-(1 → 6)-2-*O*-acetyl-3,4-di-*O*-benzoyl-α-D-mannopyranoside (22)

Compound **21** (395 mg, 0.3 mmol) was benzoylated under the same conditions as those used for preparation of **7** from **6**, giving a residue that was purified by flash chromatography (2.5:1 petroleum ether–EtOAc) to furnish **22** (380 mg, 89.2%) as a foamy solid: $[\alpha]_D$ +44.6 (*c* 1.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 7.98–7.26 (m, 35H, 7*Ph*), 6.02–5.83 (m, 7H, 3H-3, 3H-4, –CH_2–C*H*=CH_2), 6.02–5.91 (m, 1H, –CH_2–C*H*=CH_2), 5.99 (dd, 1H, $J_{3'',4''} = J_{4'',5''}$ = 10.9 Hz, H-4″), 5.98 (dd, 1H, $J_{3',4'} = J_{4',5'}$ = 10.2 Hz, H-4′) 5.92 (dd, 1H, $J_{3,4} = J_{4,5}$ = 9.9 Hz, H-4), 5.91 (dd, 1H, $J_{2'',3''}$ = 3.0 Hz, $J_{3'',4''}$ = 10.9 Hz, H-3″), 5.85 (dd, 1H, $J_{2',3'}$ = 3.0 Hz, $J_{3',4'}$ = 10.2 Hz, H-3′), 5.84 (dd, 1H, $J_{2,3}$ = 3.1 Hz, $J_{3,4}$ = 9.9 Hz, H-3), 5.65 (dd, 1H, $J_{1'',2''}$ = 1.2 Hz, $J_{2'',3''}$ = 3.0 Hz, H-2), 5.54 (dd, 1H, $J_{1',2'}$ = 1.2 Hz, $J_{2',3'}$ = 3.0 Hz, H-2), 5.48 (dd, 1H, $J_{1,2}$ = 1.3 Hz, $J_{2,3}$ = 3.1 Hz, H-2), 5.45–5.27 (m, 2 H, –CH_2–CH=C*H*$_2$), 5.07 (d, 1H, $J_{1'',2''}$ = 1.2 Hz, H-1″), 5.05 (d, 1H, $J_{1',2'}$ = 1.2 Hz, H-1′), 4.88 (d, 1H, $J_{1,2}$ = 1.3 Hz, H-1), 4.46–3.49 (m, 13H, 3H-5, 6H-6, –C*H*$_2$–CH=CH_2, C*H*$_2$ClCO), 2.20 (s, 3H, C*H*$_3$CO), 2.11 (s, 3H, C*H*$_3$CO); ^{13}C NMR (100 MHz, $CDCl_3$): δ 170.26, 169.65 (CH_3*C*O), 166.78, 165.96, 165.48, 165.43, 165.33, 165.28, 165.18 (Ph*C*O), 97.55, 97.37, 96.73 (C-1), 71.34, 70.19, 69.90, 69.89, 69.79, 69.69, 69.68, 68.86, 68.75, 66.67, 66.62, 66.51, 66.14, 65.67, 62.92, 40.74, 20.76, 20.68. Anal. Calcd for $C_{76}H_{69}ClO_{26}$: C 63.66; H 4.85. Found: C 63.48; H 4.92.

3.18. 2-*O*-Acetyl-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-3,4-di-*O*-benzoyl-2-*O*-chloroacetyl-α-D-mannopyranosyl-(1 → 6)-2-*O*-acetyl-3,4-di-*O*-benzoyl-α-D-mannopyranosyl trichloroacetimidate (24)

Deallylation of trisaccharide **22** (365 mg, 0.25 mmol), followed by trichloroacetimidation under the same conditions as those used for preparation of **10** from **7**, gave a residue that was purified by flash chromatography (3:1 petroleum ether–EtOAc) to give **24** (292 mg, 74.7% for two steps) as a foamy solid: $[\alpha]_D$ +50.6 (*c* 1.5, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 8.94 (s, 1H, CN*H*CCl$_3$), 8.05–7.26 (m, 35H, 7*Ph*), 6.44 (s, 1H, H-1), 6.10 (dd, 1H, $J_{3'',4''} = J_{4'',5''}$ = 10.2 Hz, H-4″), 5.96–5.75 (m, 5H, H-3″, H-3′, H-3, H-4′, H-4), 5.75 (s, 1H, H-2″), 5.61 (s, 1H, H-2′), 5.37 (s, 1H, H-2), 5.03 (s, 1H, H-1″), 4.86 (s, 1H, H-1′), 4.56–3.49 (m, 11H, 3H-5, 6H-6, C*H*$_2$ClCO), 2.24 (s, 3H, C*H*$_3$CO), 2.09 (s, 3H, C*H*$_3$CO). Anal. Calcd for $C_{75}H_{65}Cl_4NO_{26}$: C 58.57; H 4.26. Found: C 58.33; H 4.18.

3.19. Allyl 2-*O*-acetyl-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-3,4-di-*O*-benzoyl-2-*O*-chloroacetyl-α-D-mannopyranosyl-(1 → 6)-2-*O*-acetyl-3,4-di-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-3-*O*-benzoyl-2-*O*-chloroacetyl-α-D-mannopyranoside (25)

Donor **24** (277 mg, 0.18 mmol) was coupled with acceptor **3** (87 mg, 0.22 mmol) as described in the general procedure to give a crude product that was purified by flash chromatography (1.5:1 petroleum ether–EtOAc) to give **25** (256 mg, 80.1%) as a foamy solid: $[\alpha]_D$ +50.2 (*c* 1.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 8.00–7.26 (m, 40H, 8*Ph*), 6.00 (dd, 1H, $J_{3''',4'''} = J_{4''',5'''}$ = 10.0 Hz, H-4‴), 5.96–5.81 (m, 6H, H-3‴, H-3″, H-3′, H-4″, H-4′, –CH_2–C*H*=CH_2), 5.63 (dd, 1H,

$J_{1''',2'''} = 1.4$ Hz, $J_{2''',3'''} = 3.2$ Hz, H-2'''), 5.58 (dd, 1H, $J_{2,3} = 3.2$ Hz, $J_{3,4} = 10.0$ Hz, H-3), 5.57 (dd, 1H, $J_{1'',2''} = 1.6$ Hz, $J_{2'',3''} = 3.2$ Hz, H-2''), 5.52 (dd, 1H, $J_{1',2'} = 1.6$ Hz, $J_{2',3'} = 3.2$ Hz, H-2'), 5.49 (dd, 1H, $J_{1,2} = 1.6$ Hz, $J_{2,3} = 3.2$ Hz, H-2), 5.39–5.22 (m, 2H, $-CH_2-CH{=}C\mathit{H}_2$), 5.18 (d, 1H, $J_{1''',2'''} = 1.4$ Hz, H-1'''), 5.06 (d, 1H, $J_{1'',2''} = 1.6$ Hz, H-1''), 5.00 (d, 1H, $J_{1',2'} = 1.6$ Hz, H-1'), 4.92 (d, 1H, $J_{1,2} = 1.6$ Hz, H-1), 4.48–3.59 (m, 19H, H-4, 4H-5, 8H-6, $2C\mathit{H}_2ClCO$, $-C\mathit{H}_2-CH{=}CH_2$), 2.17 (s, 3H, $C\mathit{H}_3CO$), 2.07 (s, 3H, $C\mathit{H}_3CO$). Anal. Calcd for $C_{91}H_{84}Cl_2O_{33}$: C 61.52; H 4.77. Found: C 61.21; H 4.85.

3.20. Allyl 2-*O*-acetyl-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-3,4-di-*O*-benzoyl-2-*O*-chloroacetyl-α-D-mannopyranosyl-(1 → 6)-2-*O*-acetyl-3,4-di-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-3,4-di-*O*-benzoyl-2-*O*-chloroacetyl-α-D-mannopyranoside (26)

Compound **25** (242 mg, 0.14 mmol) was benzoylated under the same conditions as those used for preparation of **7** from **6**, giving a residue that was purified by flash chromatography (2.5:1 petroleum ether–EtOAc) to furnish **26** (219 mg, 85.5%) as a foamy solid: $[\alpha]_D$ +46.6 (*c* 1.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 8.08–7.26 (m, 45H, 9*Ph*), 6.10–5.81 (m, 9H, 4H-3, 4H-4, $-CH_2-C\mathit{H}{=}CH_2$), 5.65 (dd, 1H, $J_{1''',2'''} = 1.4$ Hz, $J_{2''',3'''} = 3.2$ Hz, H-2'''), 5.59 (dd, 1H, $J_{1'',2''} = 1.4$ Hz, $J_{2'',3''} = 3.2$ Hz, H-2''), 5.57 (dd, 1H, $J_{1',2'} = 1.6$ Hz, $J_{2',3'} = 3.2$ Hz, H-2'), 5.43–5.26 (m, 2H, $-CH_2-CH{=}C\mathit{H}_2$), 5.40 (dd, 1H, $J_{1,2} = 1.6$ Hz, $J_{2,3} = 3.2$ Hz, H-2), 5.09 (d, 2H, $J_{1''',2'''} = J_{1'',2''} = 1.4$ Hz, H-1''', H-1''), 4.93 (d, 1H, $J_{1',2'} = 1.6$ Hz, H-1'), 4.87 (d, 1H, $J_{1,2} = 1.6$ Hz, H-1), 4.41–3.48 (m, 18H, 4H-5, 8H-6, $2CH_2Cl\mathit{C}O$, $-C\mathit{H}_2-CH{=}CH_2$), 2.18 (s, 3H, $C\mathit{H}_3CO$), 2.09 (s, 3H, $C\mathit{H}_3CO$); ^{13}C NMR (100 MHz, $CDCl_3$): δ 170.13, 169.68 ($CH_3\mathit{C}O$), 166.69, 166.79 ($CH_2Cl\mathit{C}O$), 165.94, 165.50, 165.49, 165.46, 165.34, 165.32, 165.30, 165.25, 165.23 ($Ph\mathit{C}O$), 97.89, 97.86, 97.16, 96.29 (C-1), 71.62, 71.29, 70.17, 70.12, 70.03, 69.89, 69.83, 69.71, 69.66, 68.88, 68.82, 66.61, 66.56, 66.20, 66.13, 66.06, 65.93, 65.69, 62.87, 40.80, 20.72, 20.68. Anal. Calcd for $C_{98}H_{88}Cl_2O_{34}$: C 68.59; H 4.72. Found: C 68.88; H 4.66.

3.21. Allyl 2-*O*-acetyl-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-3,4-di-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-2-*O*-acetyl-3,4-di-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-3,4-di-*O*-benzoyl-α-D-mannopyranoside (27)

Dechloroacetylation of **26** (208 mg, 0.1 mmol) using the same conditions as those used for preparation of **8** from **7** gave a residue that was purified by flash chromatography (2:1 petroleum ether–EtOAc) to furnish **27** (157 mg, 82.3%) as a foamy solid: $[\alpha]_D$ +37.5 (*c* 1.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 8.10–7.23 (m, 45H, 9*Ph*), 6.14–6.06 (m, 2H, H-4''', $-CH_2-C\mathit{H}{=}CH_2$), 5.70–5.96 (m, 7H, 4H-3, 3H-4), 5.55–5.33 (m, 2H, $-CH_2-CH{=}C\mathit{H}_2$), 5.52–5.50 (m, 2H, H-2', H-2'''), 5.21 (d, 2H, $J_{1''',2'''} = J_{1'',2''} = 1.4$ Hz, H-1''', H-1''), 5.03 (d, 1H, $J_{1',2'} = 1.5$ Hz, H-1'), 4.91 (d, 1H, $J_{1,2} = 1.6$ Hz, H-1), 4.72–3.50 (m, 16H, 2H-2, 4H-5, 8H-6, $-C\mathit{H}_2-CH{=}CH_2$), 2.15 (s, 3H, $C\mathit{H}_3CO$), 2.10 (s, 3H, $C\mathit{H}_3CO$); ^{13}C NMR (100 MHz, $CDCl_3$): δ 170.09, 169.75 ($CH_3\mathit{C}O$), 166.04, 166.01, 165.73, 165.64, 165.61, 165.59, 165.58, 165.57, 165.34 ($Ph\mathit{C}O$), 98.80, 98.68, 97.75, 96.74 (C-1), 72.94, 72.58, 70.24, 70.04, 69.97, 69.85, 69.78, 69.49, 69.14, 68.75, 68.72, 68.27, 67.70, 67.07, 66.83, 66.74, 66.41, 66.35, 66.29, 20.80, 20.73. Anal. Calcd for $C_{94}H_{86}O_{32}$: C 65.35; H 5.02. Found: C 65.07; H 4.98.

3.22. Allyl 2-*O*-acetyl-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-[2,3,4,6-tetra-*O*-benzoyl-α-D-mannopyranosyl-(1 → 2)]-3,4-di-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-2-*O*-acetyl-3,4-di-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-[2,3,4,6-tetra-*O*-benzoyl-α-D-mannopyranosyl-(1 → 2)]-3,4-di-*O*-benzoyl-α-D-mannopyranoside (28)

Donor **11** (184 mg, 0.25 mmol) was coupled with acceptor **27** (143 mg, 0.08 mmol) as described in the general procedure, and the product was purified by chromatography with 3:2 petroleum ether–EtOAc as the eluent to give **28** (205 mg, 85.9%) as a foamy solid: $[\alpha]_D$ −18.7 (*c* 1.0, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): δ 8.16–6.81 (m, 85H, 17*Ph*), 6.28–5.90 (m, 15H, 2H-2, 6H-3, 6H-4, $-CH_2-C\mathit{H}{=}CH_2$), 5.77 (s, 1H, H-2'''), 5.70 (s, 1H, H-2'), 5.48–5.29 (m, 2H, $-CH_2-CH{=}C\mathit{H}_2$), 5.34 (s, 2H, H-1''', H-1''), 5.12 (s, 1H, H-1'), 4.99 (s, 1H, H-1), 4.81–3.54 (m, 22H, 2H-2, 6H-5, 12H-6, $-C\mathit{H}_2-CH{=}CH_2$), 2.10 (s, 3H, $C\mathit{H}_3CO$), 2.02 (s, 3H, $C\mathit{H}_3CO$); ^{13}C NMR (100 MHz, $CDCl_3$): δ 169.99, 169.50 ($CH_3\mathit{C}O$), 166.17, 165.99, 165.81, 165.79, 165.73, 165.54, 165.51, 165.19, 164.90, 164.84, 164.80, 164.77, 164.74, 164.68 ($Ph\mathit{C}O$), 99.93, 99.75, 98.32, 97.96, 97.89, 97.68 (C-1), 71.46, 70.81, 70.70, 70.43, 70.33, 70.19, 70.07, 69.96, 69.82, 69.74, 69.33, 68.72, 68.64, 67.10, 66.99, 66.76, 66.58, 66.46, 66.10, 65.76, 62.93, 62.66, 20.69, 20.65. Anal. Calcd for $C_{162}H_{138}O_{50}$: C 67.45; H 4.82. Found: C 67.63; H 4.78.

3.23. Allyl 3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-[2,3,4,6-tetra-*O*-benzoyl-α-D-mannopyranosyl-(1 → 2)]-3,4-di-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-3,4-di-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-[2,3,4,6-tetra-*O*-benzoyl-α-D-mannopyranosyl-(1 → 2)]-3,4-di-*O*-benzoyl-α-D-mannopyranoside (29)

Deacetylation of compound **28** (193 mg, 0.07 mmol) was carried out under the same conditions as those used for preparation of **13** from **12**, giving a crude product that was purified by flash chromatography (2:1 petroleum ether–EtOAc) to give **29** (144 mg, 76.8%) as a foamy solid: $[\alpha]_D$ +47.3 (*c* 1.0, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.07–6.90 (m, 85H, 17*Ph*), 6.37 (dd, 1H, $J_{3,4} = J_{4,5} = 9.9$ Hz, H-4), 6.15–5.76 (m, 14H, 2H-2, 6H-3, 5H-4, $-CH_2-CH{=}CH_2$), 5.48 (s, 1H, H-1), 5.36 (s, 1H, H-1), 5.34–5.15 (m, 2H, $-CH_2-CH{=}CH_2$), 5.30 (s, 1H, H-1), 5.24 (s, 1H, H-1), 5.15 (s, 1H, H-1), 5.04 (s, 1H, H-1), 4.88–3.58 (m, 24H, 4H-2, 6H-5, 12H-6, $-CH_2-CH{=}CH_2$); ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.17, 166.12, 166.03, 165.95, 165.73, 165.61, 165.51, 165.48, 165.40, 165.36, 165.08, 165.00, 164.78, 164.69, 164.60 (Ph*C*O), 100.28, 100.05, 99.29, 97.85, 97.82, 97.54 (C-1), 73.23, 72.72, 71.43, 70.59, 70.26, 69.93, 69.83, 69.72, 69.63, 69.54, 69.50, 69.20, 68.94, 68.57, 68.38, 67.17, 67.11, 66.85, 66.79, 66.67, 66.56, 66.52, 66.25, 66.90, 65.56, 63.66, 62.94, 62.86, 62.69. Anal. Calcd for $C_{158}H_{134}O_{48}$: C 67.76; H 4.82. Found: C 67.48; H 4.91.

3.24. Allyl [2,3,5-tri-*O*-benzoyl-α-D-arabinofuranosyl-(1 → 2)-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 2)]-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-[2,3,4,6-tetra-*O*-benzoyl-α-D-mannopyranosyl-(1 → 2)]-3,4-di-*O*-benzoyl-α-D-mannopyranosyl-(1→6)-[2,3,5-tri-*O*-benzoyl-α-D-arabinofuranosyl-(1 → 2)-3,4,6-tri-*O*-benzoyl-α-D-mannopyranosyl-(1 → 2)]-3,4-di-*O*-benzoyl-α-D-mannopyranosyl-(1 → 6)-[2,3,4,6-tetra-*O*-benzoyl-α-D-mannopyranosyl-(1 → 2)]-3,4-di-*O*-benzoyl-α-D-mannopyranoside (30)

Donor **18** (130 mg, 0.12 mmol) was coupled with acceptor **29** (130 mg, 0.05 mmol) as described in the general procedure, and the product was purified by chromatography with 3:2 petroleum ether–EtOAc as the eluent to give **30** (143 mg, 66.7%) as a foamy solid: $[\alpha]_D$ −13.7 (*c* 1.0, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.08–6.50 (m, 145H, 29*Ph*), 6.38–5.86 (m, 19H, Man*p* 2H-2, 8H-3, 8H-4, $-CH_2-CH{=}CH_2$), 5.61 (s, 1H, Ara*f* H-2), 5.58 (s, 1H, Ara*f* H-2), 5.57 (s, 1H, Man*p* H-1), 5.52 (d, 1H, $J_{3,4} = 4.4$ Hz, Ara*f* H-3), 5.50 (d, 1H, $J_{3,4} = 5.0$ Hz, Ara*f* H-3), 5.49 (s, 2H, Ara*f* 2H-1), 5.46–5.27 (m, 2H, $-CH_2-CH{=}CH_2$), 5.44 (s, 1H, Man*p* H-1), 5.34 (s, 1H, Man*p* H-1), 5.33 (s, 1H, Man*p* H-1), 5.28 (s, 1H, Man*p* H-1), 5.27 (s, 1H, Man*p* H-1), 5.22 (s, 1H, Man*p* H-1), 5.11 (s, 1H, Man*p* H-1), 5.05 (s, 1H, Man*p* H-2), 4.97 (s, 1H, Man*p* H-2), 4.89 (s, 1H, Man*p* H-2), 4.82–3.47 (m, 35H, Man*p* 3H-2, 8H-5, 16H-6, Ara*f* 2H-4, 4H-5, $-CH_2-CH{=}CH_2$); ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.25, 166.13, 166.09, 166.06, 165.95, 165.88, 165.82, 165.67, 165.65, 165.60, 165.55, 165.50, 165.45, 165.21, 165.14, 165.07, 165.02, 164.90, 164.81, 164.45, 164.39 (Ph*C*O), 107.17, 106.71 (Ara*f* C-1), 100.72, 100.28, 99.99, 99.43, 99.25, 98.05, 98.65, 98.02 (C-1), 82.08, 81.98, 81.75, 81.62, 76.32, 75.96, 75.25, 74.07, 72.58, 72.36, 71.86, 71.35, 71.07, 70.56, 70.45, 70.25, 70.04, 69.84, 69.70, 69.51, 69.46, 69.37, 69.25, 68.61, 68.31, 67.80, 67.34, 67.21, 66.92, 66.63, 66.48, 66.37, 65.35, 64.27, 63.50, 63.31, 63.14, 63.01. Anal. Calcd for $C_{264}H_{218}O_{78}$: C 68.36; H 4.74. Found: C 68.69; H 4.73.

3.25. Allyl [α-D-arabinofuranosyl-(1 → 2)-α-D-mannopyranosyl-(1 → 2)]-α-D-mannopyranosyl-(1 → 6)-[α-D-mannopyranosyl-(1 → 2)]-α-D-mannopyranosyl-(1 → 6)-[α-D-arabinofuranosyl-(1 → 2)-α-D-mannopyranosyl-(1 → 2)]-α-D-mannopyranosyl-(1 → 6)-[α-D-mannopyranosyl-(1 → 2)]-α-D-mannopyranoside (31)

Decasaccharide **30** (133 mg, 0.03 mmol) was dissolved in satd NH_3–MeOH (30 mL). After 96 h at rt, the reaction mixture was concentrated, and the residue was purified by chromatography on Sephadex LH-20 (MeOH) to afford **31** (43 mg, 92.5%) as a foamy solid: $[\alpha]_D$ +64.6 (*c* 1.0, H_2O); ^{1}H NMR (400 MHz, D_2O): δ 5.91–5.81 (m, 1H, $-CH_2-CH{=}CH_2$), 5.25 (d, 1H, $J = 17.2$ Hz, $-CH_2-CH{=}CH_{trans}$), 5.18 (d, 1H, $J = 10.0$ Hz, $-CH_2-CH{=}CH_{cis}$), 5.09 (s, 1H, Man*p* H-1), 5.08 (s, 1H, Man*p* H-1), 5.07 (s, 2H, Ara*f* 2H-1), 5.02 (s, 1H, Man*p* H-1), 5.01 (s, 1H, Man*p* H-1), 4.99 (s, 2H, Man*p* 2H-1), 4.93 (s, 1H, Man*p* H-1), 4.91 (s, 1H, Man*p* H-1); ^{13}C NMR (100 MHz, D_2O): δ 109.36 (2C, Ara*f* 2C-1), 102.32, 102.19, 101.32, 101.30, 98.17, 98.03, 97.53 (8C, Man*p* 8C-1), 83.65, 83.62, 81.20, 78.85, 78.70, 78.55, 77.46, 77.43, 76.46, 73.33, 73.26, 73.18, 72.85, 71.28, 71.19, 71.01, 70.64, 70.57, 70.49, 70.44, 70.24, 70.08, 70.04, 68.44, 67.02, 66.81, 66.75, 66.67, 66.48, 65.75, 65.63, 61.18, 61.15, 61.10, 61.07, 60.94, 60.86. Anal. Calcd for $C_{61}H_{102}O_{49}$: C 45.24; H 6.35. Found: C 45.13; H 6.33.

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