An Efficient Method for the Synthesis of 2,6-Branched Galacto-Oligosaccharides and Its Applications to the Synthesis of Three Tetrasaccharides and a Hexasaccharide Related to the Arabinogalactans (AGs)

Jun Ning,* Yuetao Yi, Zhe Yao

Research Center for Eco-Environmental Sciences, Academia Sinica, P. O. Box 2871, Beijing 100085, P. R. China
Fax +86(10)62923563; E-mail: jning@mail.rcees.ac.cn

Received 15 September 2003

Abstract: An efficient method for the synthesis of 2,6-branched galacto-oligosaccharides has been developed by using 6-*O*-Ac-2,3,4-tri-*O*-Bz-α-D-galactopyranosyl trichloroacetimidate, 2,6-di-*O*-Ac-3,4-di-*O*-Bz-α-D-galactopyranosyl trichloroacetimidate and 2-*O*-Ac-3,4,6-tri-*O*-Bz-α-D-galactopyranosyl trichloroacetimidate as synthons. Three tetrasaccharides and a hexasaccharides related to AGs from plants were readily prepared using this method.

Key words: arabinogalactan, oligosaccharides, synthesis, glycosides, glycosylations

Increased appreciation of the role of carbohydrates in the biological and pharmaceutical science resulted in a revival of interest in carbohydrate chemistry. However, compared with other biopolymers such as peptides and nucleic acids, the role of saccharide structure in function has been minimally studied. This can be attributed mainly to the difficulty of synthesizing saccharides. Unlike peptides and nucleic acids, oligosaccharides are typically branched rather than linear. In addition, the monosaccharide units can be connected by α or β linkages. Furthermore, oligosaccharide synthesis requires multiple selective protection and deprotection steps. Although over the past few decades, considerable progress has been made in this field,[1] there still is no general solution for oligosaccharide synthesis. Maybe, owing to this structural complexity, the preparation of saccharides will never achieve the same level of ease as the preparation of peptides and nucleic acids, but we can create relatively general procedures which are effective for certain types of oligosaccharide. As our continuous efforts dedicated to the synthesis of oligosaccharides, we have developed highly efficient strategies for the construction of 3,6-branched gluco-oligosaccharides,[2] 2,6-branched manno-oligosaccharides,[3] 3,6-branched and 5,6-branched galacto-oligosaccharides.[4,5]

2,6-Branched D-Gal*p* residues like 2-*O*-arabinofuranosylated-β-D-(1→6)-linked galacto-oligosaccharides are common structural components of AGs from plants including traditional herbal medicines such as *Acer pseudoplatanus*,[6] *Angelica acutiloba* and *Bupleurum falcatum*.[7] Researches shown that the pharmacological activities of these herbal plants are mainly attributed to AGs. So far, the presence of 2,6-branched β-D-Gal*p* residues in AGs is well defined, however, the exact structure of these saccharides remains to be established. For detailed characterization of AGs, especially, for further elucidation of the molecular structure responsible for their biological activity, it would be necessary to synthesize 2,6-branched galacto-oligosaccharides. Several methods for preparation of 2,6-branched galacto-oligosaccharides have been described in literatures.[8] Here we disclose an efficient strategy for synthesis of this kind of oligosaccharides. Constructions of three tetrasaccharides and a hexasaccharide related to AGs from plants have been presented as typical examples using the method developed (Figure 1).

In our synthesis, 6-*O*-Ac-2,3,4-tri-*O*-Bz-α-D-galactopyranosyl trichloroacetimidate (**8**), 2-*O*-Ac-3,4,6-tri-*O*-Bz-α-D-galactopyranosyl trichloroacetimidate (**13**) and 2,6-di-*O*-Ac-3,4-di-*O*-Bz-α-D-galactopyranosyl trichloroacetimidate (**17**) were the key synthons. Tritylation of galactose (**5**) followed by benzoylation in a one-pot manner gave 1,2,3,4-tetra-*O*-Bz-6-*O*-Tr-D-galactoyranose, selective acetolysis of which using CH_2Cl_2–AcOH–Ac_2O–

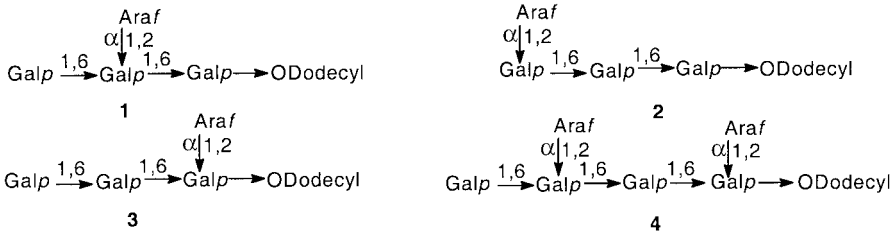


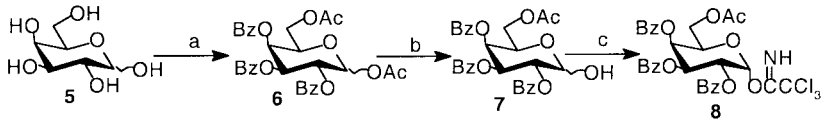
Figure 1

SYNLETT 2003, No. 14, pp 2208–2212
Advanced online publication: 29.10.2003
DOI: 10.1055/s-2003-42109; Art ID: U13303ST

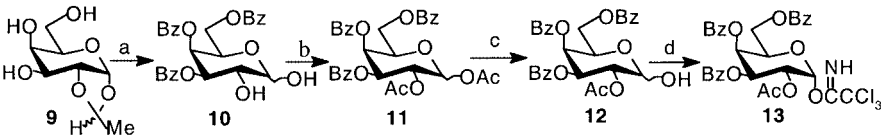
H_2SO_4 in a ratio of 1:1:0.6:0.175 afforded the corresponding 1,6-diacetate **6** in 70% yield (for three steps). The diacetate **6** was selectively deacetylated at the anomeric position with benzylamine in THF in high yield to give the corresponding 6-*O*-Ac-2,3,4-tri-*O*-Bz-D-galactopyranose (**7**). Subsequent reaction of **7** with CCl_3CN/DBU in CH_2Cl_2 afforded the glycosyl donor **8** (Scheme 1). Benzoylation of 1,2-*O*-ethylidene-α-D-galactopyranose[9] (**9**) followed by hydrolysis with 90% CF_3COOH afforded 3,4,6-tri-*O*-Bz-D-galactopyranose (**10**), subsequent acetylation with Ac_2O in pyridine furnished the diacetate **11**. Selective 1-*O*-deacetylation of **11** and then treatment with CCl_3CN/DBU in CH_2Cl_2 afforded the glycosyl donor **13** (Scheme 2). Tritylation of 1,2-*O*-ethylidene-β-D-galactopyranose (**9**) followed by benzoylation in a one-pot manner gave the 3,4-di-*O*-Bz-6-*O*-Tr-1,2-*O*-ethylidene-D-galactopyranose (**14**) (Scheme 3). Acetolysis of **14** afforded 1,2,6-tri-*O*-Ac-3,4-di-*O*-Bz-D-galactopyranose (**15**). The triacetate **15** was selectively deacetylated at the anomeric position with benzylamine in THF in high yield to give the corresponding 2,6-di-*O*-Ac-3,4-di-*O*-Bz-D-galactoyranose (**16**). Subsequent reaction of **16** with CCl_3CN/DBU in CH_2Cl_2 afforded the glycosyl donor **17**.

Coupling of **8** with dodecyl alcohol followed by selective 6-*O*-deacetylation in MeOH solution containing 0.5% HCl gave the glycosyl acceptor **19** in 87% yield for two steps.[3] The disaccharide glycosyl acceptor **21** was obtained from condensation of **17** and **19** followed by 2,6-di-*O*-deacetylation in 71% yield (Scheme 4). Coupling of **21** with 2,3,4,6-tetra-*O*-Bz-α-D-galactopyranosyl trichloroacetimidate[10] using TMSOTf as catalyst and 4 Å molecular sieves in CH_2Cl_2 at –45 °C regio- and stereospecifically afforded the trisaccharides **22** in 82% yield. No (1→2)-linked trisaccharide was detected from ^{1}H NMR and TLC. Condensation of **22** with 2,3,5-tri-*O*-Bz-α-L-arabinofuranosyl trichloroacetimidate[4] afforded the tetrasaccharide block **23** in 84% yield. Coupling of compound **8** with the glycosyl acceptor **19** followed by 6-*O*-deacetylation gave the disaccharide glycosyl acceptor **25** in 87% yield. The trisaccharide glycosyl acceptor **27** was obtained from condensation of **25** and **13** followed by 2-*O*-deacetylation in 72% yield. Condensation of **27** with 2,3,5-tri-*O*-Bz-α-L-arabinofuranosyl trichloroacetimidate afforded the tetrasaccharide block **28** in 85% yield. Deprotection of **23** and **28** using NH_3 in CH_3OH gave the free tetrasaccharides **1** and **2** as amorphous white solids in high yields.

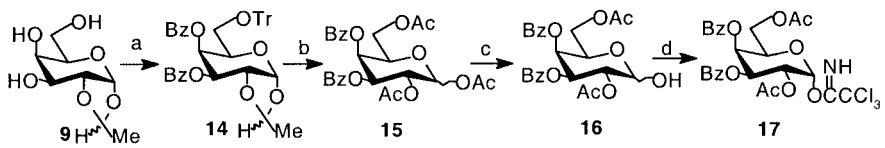
The glycosyl acceptor **30** was obtained from coupling of compound **17** with dodecyl alcohol followed by 2,6-di-*O*-deacetylation with MeOH solution containing 0.5% HCl in 76% yield for two steps (Scheme 5). Coupling of **30** with **8** using TMSOTf as catalyst and 4Å molecular sieves in CH_2Cl_2 at –45 °C regio- and stereospecifically afforded the disaccharide **31** in 84% yield. Condensation of **31** with 2,3,5-tri-*O*-Bz-α-L-arabinofuranosyl trichloroacetimidate afforded the trisaccharide **32** in 85% yield. Selective removal of the 6-*O*-acetyl group of the trisaccharide **32** gave the glycosyl acceptor **33** in 93% yield. Coupling of **17** with **33** gave the tetrasaccharide **34**. Selective removal of the acetyl group of **34** gave the glycosyl acceptor **35** in 94% yield. Coupling of **35** with 2,3,4,6-tetra-*O*-Bz-α-D-galactopyranosyl trichloroacetimidate regio- and stereo-



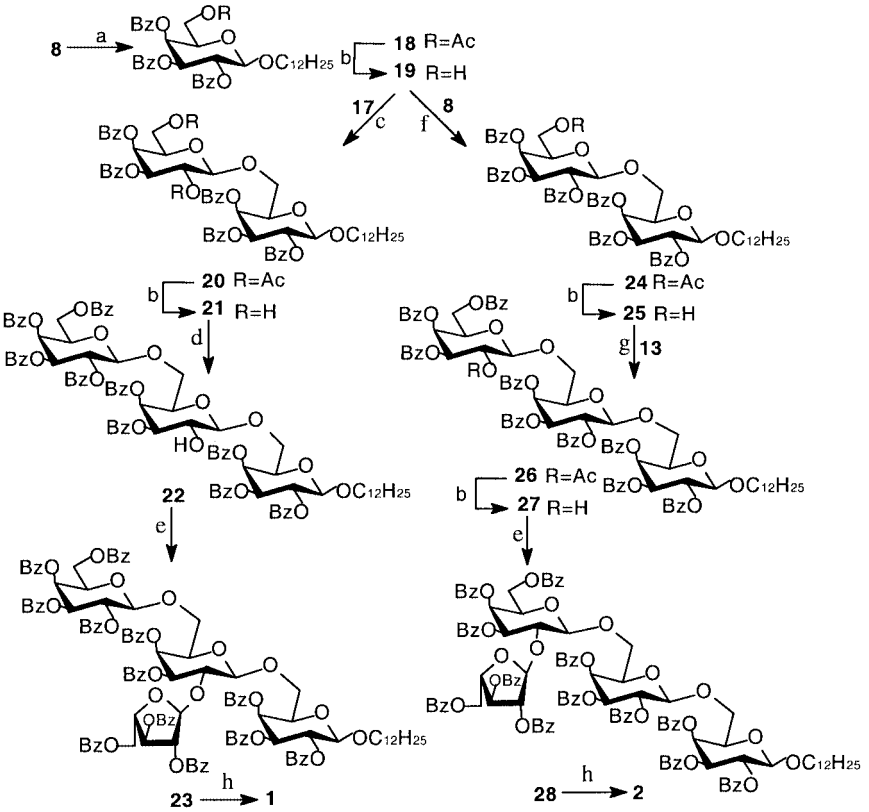
Scheme 1 Reagents and conditions: (a) i. Trityl chloride (1.2 equiv), pyridine, 50 °C, 32 h; ii. PhCOCl (4.8 equiv), < 40 °C, 24 h; iii. CH_2Cl_2–HOAc–Ac_2O–H_2SO_4 = 1:1:0.6:0.175 (v/v), r.t., 20 h, 70% (for three steps). (b) Benzylamine (3.2 equiv.), THF, r.t., 24 h, 85%. (c) CCl_3CN (2.3 equiv), DBU (0.18 equiv), CH_2Cl_2, r.t., 5 h, 84%.



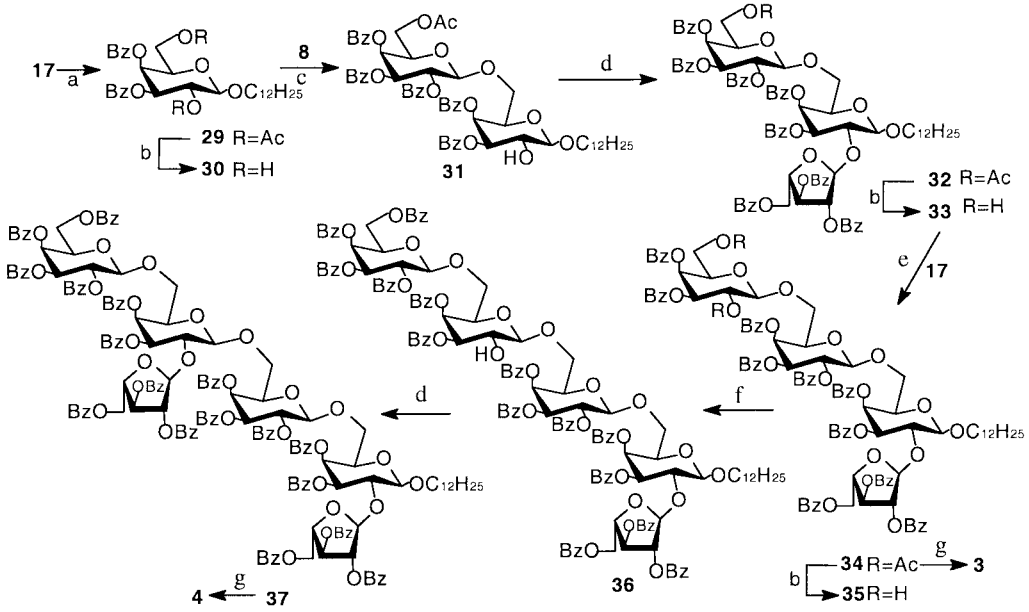
Scheme 2 Reagents and conditions: (a) i. PhCOCl (3.3 equiv), pyridine, <40 °C, 24 h, 95%; ii. F_3CCOOH (90%), r.t., 4 h, 89%. (b) Ac_2O, pyridine, r.t., 5 h, 100%. (c) Benzylamine (4.0 equiv), THF, r.t., 24 h, 88%. (d) CCl_3CN (3.3 equiv), DBU (0.3 equiv), CH_2Cl_2, r.t., 5 h, 86%.



Scheme 3 Reagents and conditions: (a) i. Trityl chloride (1.2 equiv), pyridine, 50 °C, 32 h; ii. PhCOCl (4.8 equiv), < 40 °C, 24 h; 71% (for two steps). (b) CH_2Cl_2–HOAc–Ac_2O–H_2SO_4 = 1:1:0.6:0.175, r.t., 20 h, 83%. (c) Benzylamine (4.0 equiv), THF, r.t., 24 h, 88%. (d) CCl_3CN (3.3 equiv), DBU (0.3 equiv), r.t., 5 h, 86%.



Scheme 4 Reagents and conditions: (a) Dodecyl alcohol (2 equiv), TMSOTf (0.05 equiv), CH_2Cl_2, r.t., 3 h, 89%. (b) MeOH–0.5% HCl, r.t., 12–14 h, 93–96%. (c) **17** (1.4 equiv), TMSOTf (0.02 equiv), MS 4 Å, CH_2Cl_2, r.t., 2 h, 86%. (d) 2,3,4,6-Tetra-*O*-Bz-α-D-galactopyranosyl trichloroacetimidate (1.0 equiv), TMSOTf (0.02 equiv), MS 4 Å, CH_2Cl_2, –45 °C, 2 h, 82%. (e) 2,3,5-Tri-*O*-Bz-α-L-arabinofuranosyl trichloroacetimidate (1.3 equiv), CH_2Cl_2, TMSOTf (0.02 equiv), r.t., 2 h, 84% for **23**, 85% for **28**. (f) **8** (1.4 equiv), TMSOTf (0.02 equiv), MS 4 Å, CH_2Cl_2, r.t., 2 h. 87%. (g) **13** (1.4 equiv.), TMSOTf (0.02 equiv.), MS 4 Å, CH_2Cl_2, r.t., 2 h. 85%. (h) CH_3OH sat. with anhyd NH_3, r.t., 72 h, 95% for **1**, 96% for **2**.



Scheme 5 Reagents and conditions: (a) Dodecyl alcohol (2 equiv), TMSOTf (0.05 equiv), CH_2Cl_2, r.t., 3 h, 91%. (b) MeOH–0.5% HCl, r.t., 12–14 h, 93–96%. (c) **8** (1.0 equiv), TMSOTf (0.02 equiv), MS 4 Å, CH_2Cl_2, –45 °C, 2 h, 84%. (d) 2,3,5-Tri-*O*-Bz-α-L-arabinofuranosyl trichloroacetimidate (1.3 equiv), CH_2Cl_2, TMSOTf (0.02 equiv), r.t., 2 h, 85% for **32**, 81% for **37**. (e) **17** (1.3 equiv), TMSOTf (0.02 equiv), MS 4 Å, CH_2Cl_2, r.t., 2 h, 86%. (f) 2,3,4,6-Tetra-*O*-Bz-α-D-galactopyranosyl trichloroacetimidate (1.0 equiv), TMSOTf (0.02 equiv.), MS 4 Å, CH_2Cl_2, –45 °C, 2 h, 83%. (g) CH_3OH sat. with anhyd NH_3, r.t., 72 h, 94% for **3**, 97% for **4**.

specifically afforded the pentasaccharide **36** in 83% yield. Condensation of **36** with 2,3,5-tri-*O*-Bz-α-L-arabinofuranosyl trichloroacetimidate afforded the blocked hexasaccharide **37** in 81% yield. Deprotection of **34** and **37** gave the free tetrasaccharides **3** and hexasaccharide **4** as amorphous white solids.

All new compounds involved in this study were identified by optical rotations, ^{1}H NMR or/and ^{13}C NMR spectroscopy, and elemental analyses or MALDI–TOF MS. Selected physical data for some key compounds are given in references.[11]

In summary, an efficient method for the preparation of 2,6-branched galacto-oligosaccharides has been developed by regio- and stereoselective glycosylation using glycosyl trichloroacetimidates as the donors and partially protected sugars as the acceptor. This method can be used to synthesize both homo- and hetero- saccharide structures, which are used for the further assembly of advanced bioactive sugar chains. The sole use of acyl groups in the synthesis substantially simplified the procedure.

Acknowledgment

This work was supported by the Beijing Natural Science Foundation (6021004) and by The Ministry of Science and Technology (2001AA246014).

References

(1) (a) Plante, O. J.; Palmacci, E. R.; Seeberger, P. H. *Science* **2001**, *291*, 1523. (b) Sears, P.; Wong, C. H. *Science* **2001**, *291*, 2344.
(2) Ning, J.; Yi, Y.; Kong, F. *Tetrahedron Lett.* **2002**, *43*, 5545.
(3) (a) Xing, Y.; Ning, J. *Tetrahedron: Asymmetry* **2003**, *14*, 1275. (b) Ning, J.; Heng, L.; Kong, F. *Tetrahedron Lett.* **2002**, *43*, 673.
(4) Ning, J.; Wang, H.; Yi, Y. *Tetrahedron Lett.* **2002**, *43*, 7349.
(5) Wang, H.; Ning, J. *J. Org. Chem.* **2003**, *68*, 2521.
(6) Puhlmann, J.; Bucheli, E.; Swain, M. J.; Dunning, N.; Albersheim, P.; Darvill, A. G.; Hahn, M. *Plant Physiol.* **1994**, *104*, 699.
(7) (a) Yamada, H.; Kiyohara, H.; Cyong, J.-C.; Otsuka, Y. *Carbohydr. Res.* **1987**, *159*, 275. (b) Yamada, H. *Carbohydr. Polym.* **1994**, *25*, 269.
(8) (a) Timmers, C. M.; Wigchert, S. C. M.; Leeuwenburgh, M. A.; van der Marel, G. A.; van Boom, J. H. *Eur. J. Org. Chem.* **1998**, 91. (b) Borbás, A.; Jánossy, L.; Lipták, A. *Carbohydr. Res.* **1999**, *318*, 98. (c) Csávas, M.; Borbás, A.; Jánossy, L.; Lipták, A. *Tetrahedron Lett.* **2003**, *44*, 631.
(9) Ning, J.; Kong, F. *Carbohydr. Res.* **2001**, *330*, 165.
(10) Rio, S.; Beau, J. M.; Jacquinet, J. C. *Carbohydr. Res.* **1991**, *219*, 71.
(11) All new compounds gave satisfactory elemental analysis results. Selected physical data for some key compounds are as follows:
For **8**: $[\alpha]_D$ +20.9 (*c* 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.66 (s, 1 H, $CNHCCl_3$), 8.08–7.26 (m, 15 H, 3 × PhH), 6.89 (d, $J_{1,2}$ = 3.6 Hz, 1 H, H-1), 6.06 (dd, 1 H, H-4), 6.05 (dd, 1 H, H-3), 5.94 (dd, 1 H, H-2), 4.72 (m, 1 H, H-5), 4.28–4.26 (m, 2 H, H-6a,6b), 1.99 (s, 3 H, CH_3CO). Anal. Calcd for $C_{31}H_{26}NO_{10}CI_3$: C, 54.84; H, 3.86. Found: C, 54.69; H, 3.98.
For **13**: $[\alpha]_D$ +21.2 (*c* 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.71 (s, 1 H, $CNHCCl_3$), 8.06–7.33 (m, 15 H, 3 × PhH), 6.79 (d, $J_{1,2}$ = 3.6 Hz, 1 H, H-1), 6.11 (dd, 1 H, H-4), 5.86 (dd, 1 H, H-3), 5.72 (dd, 1 H, H-2), 4.80 (m, 1 H, H-5), 4.58 (dd, 1 H, H-6a), 4.40 (dd, 1 H, H-6b), 1.98 (s, 3 H, CH_3CO). Anal. Calcd for $C_{31}H_{26}NO_{10}CI_3$: C, 54.84; H, 3.86. Found: C, 54.72; H, 3.90.
For **17**: $[\alpha]_D$ +55 (*c* 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.73 (s, 1 H, $CNHCCl_3$), 8.04–7.31 (m, 10 H, 2 × PhH), 6.76 (d, $J_{1,2}$ = 3.6 Hz, 1 H, H-1), 6.00 (dd, 1 H, H-4), 5.81 (dd, 1 H, H-3), 5.68 (dd, 1 H, H-2), 4.65 (m, 1 H, H-5), 4.22 (m, 2 H, H-6a,b), 1.98, 1.97 (2 × s, 6 H, 2 CH_3CO). Anal. Calcd for $C_{26}H_{24}Cl_3NO_{10}$: C, 50.63; H, 3.92. Found: C, 50.79; H, 3.85.
For **19**: $[\alpha]_D$ +67.8° (*c* 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.13–7.25 (m, 15 H, 3 × PhH), 5.85 (dd, 1 H, H-2), 5.81 (dd, 1 H, H-4), 5.58 (dd, 1 H, H-3), 4.79 (d, $J_{1,2}$ = 7.9 Hz, 1 H, H-1), 4.03 (m, 1 H, H-5), 3.97–3.54 (m, 4 H, H-6a,6b, $CH_2C_{11}H_{23}$), 1.56–0.86 (m, 23 H, $CH_2C_{11}H_{23}$). Anal. Calcd for $C_{39}H_{48}O_9$: C, 70.89; H, 7.32. Found: C, 70.51; H, 7.39.
For **21**: $[\alpha]_D$ +85.3 (*c* 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.04–7.22 (m, 25 H, 5 × PhH), 6.00 (dd, 1 H, H-4), 5.74 (dd, 1 H, H-2), 5.62 (dd, 1 H, H-4), 5.56 (dd, 1 H, H-3), 5.29 (dd, 1 H, H-3), 4.77 (d, $J_{1,2}$ = 7.9 Hz, 1 H, H-1), 4.52 (d, $J_{1,2}$ = 7.6 Hz, 1 H, H-1), 1.60–0.81 (m, 23 H, $CH_2C_{11}H_{23}$). Anal. Calcd for $C_{59}H_{66}O_{16}$: C, 68.72; H, 6.45. Found: C, 68.49; H, 6.52.
For **22**: $[\alpha]_D$ +83.8 (*c* 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.10–7.22 (m, 45 H, 9 × PhH), 5.99 (dd, 1 H, H-4), 5.90 (dd, 1 H, H-4), 5.78–5.74 (m, 2 H, H-2,4), 5.68 (dd, 1 H, H-2), 5.59 (dd, 1 H, H-3), 5.53 (dd, 1 H, H-3), 5.24 (dd, 1 H, H-3), 4.79 (d, $J_{1,2}$ = 7.9 Hz, 1 H, H-1), 4.63 (d, $J_{1,2}$ = 7.8 Hz, 1 H, H-1), 4.46 (d, $J_{1,2}$ = 7.6 Hz, 1 H, H-1), 1.60–0.86 (m, 23 H, $CH_2C_{11}H_{23}$). Anal. Calcd for $C_{93}H_{92}O_{25}$: C, 69.39; H, 5.76. Found: C, 69.62; H, 5.81.
For **23**: $[\alpha]_D$ +48.6° (*c* 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.98–7.12 (m, 60 H, 12 × PhH), 6.02 (dd, 1 H, H-4), 5.86 (dd, 1 H, H-4), 5.77 (dd, 1 H, H-4), 5.70 (dd, 1 H, H-2), 5.64 (dd, 1 H, H-2), 5.58–5.52 (m, 3 H, 3 × H-3), 5.49 (s, 1 H, H-1), 5.37 (d, $J_{2,3}$ = 1.5 Hz, 1 H, H-2), 5.35 (dd, 1 H, H-3), 4.70 (d, $J_{1,2}$ = 8.0 Hz, 1 H, H-1), 4.59 (d, $J_{1,2}$ = 7.6 Hz, 1 H, H-1), 4.53 (d, $J_{1,2}$ = 7.9 Hz, 1 H, H-1), 1.36–0.86 (m, 23 H, $CH_2C_{11}H_{23}$). ^{13}C NMR (100 MHz, $CDCl_3$): δ = 166.19, 165.77, 165.48, 165.47, 165.41, 165.28, 165.23, 165.19, 165.16, 165.11, 165.0, 164.96 (12 PhCO), 106.51, 101.68, 101.44, 100.86 (4 C-1). Anal. Calcd for $C_{119}H_{112}O_{32}$: C, 69.58; H, 5.50. Found: C, 69.23; H, 5.59.
For **25**: $[\alpha]_D$ +75.5 (*c* 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.13–7.23 (m, 30 H, 6 × PhH), 5.92 (dd, 1 H, H-4), 5.80 (dd, 1 H, H-2), 5.76 (dd, 1 H, H-4), 5.68 (dd, 1 H, H-2), 5.53 (dd, 1 H, H-3), 5.50 (dd, 1 H, H-3), 4.83 (d, $J_{1,2}$ = 7.9 Hz, 1 H, H-1), 4.63 (d, $J_{1,2}$ = 8.0 Hz, 1 H, H-1), 1.39–0.87 (m, 23 H, $CH_2C_{11}H_{23}$). Anal. Calcd for $C_{66}H_{70}O_{17}$: C, 69.83; H, 6.21. Found: C, 69.91; H, 6.37.
For **27**: $[\alpha]_D$ +86.5 (*c* 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.05–7.15 (m, 45 H, 9 × PhH), 5.94 (dd, 1 H, H-4), 5.86 (dd, 1 H, H-4), 5.83 (d, 1 H, H-4), 5.77 (dd, 1 H, H-2), 5.68 (dd, 1 H, H-2), 5.55 (dd, 1 H, H-3), 5.52 (dd, 1 H, H-3), 5.32 (dd, 1 H, H-3), 4.87 (d, $J_{1,2}$ = 7.9 Hz, 1 H, H-1), 4.67 (d, $J_{1,2}$ = 7.9 Hz, 1 H, H-1), 4.52 (d, $J_{1,2}$ = 7.7 Hz, 1 H, H-1), 1.40–0.86 (m, 23 H, $CH_2C_{11}H_{23}$). Anal. Calcd for $C_{93}H_{92}O_{25}$: C, 69.39; H, 5.76. Found: C, 69.48; H, 5.81.
For **28**: $[\alpha]_D$ +56.0 (*c* 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.07–7.20 (m, 60 H, 12 × Ph*H*), 6.01 (dd, 1 H, H-4), 5.88 (dd, 1 H, H-4), 5.79 (dd, 1 H, H-4), 5.70 (dd, 1 H, H-2), 5.68 (dd, 1 H, H-2), 5.54–5.49 (m, 3 H, 3 × H-3), 5.46

(dd, 1 H, H-3), 5.45 (s, 1 H, H-1), 5.36 (d, $J_{2,3}$ = 1.2 Hz, 1 H, H-2), 4.65 (d, 1 H, $J_{1,2}$ = 8.2 Hz, H-1), 4.63 (d, 1 H, $J_{1,2}$ = 8.2 Hz, H-1), 4.51 (d, 1 H, $J_{1,2}$ = 7.6 Hz, 1 H, H-1). 1.35–0.85 (m, 23 H, $CH_2C_{11}H_{23}$). ^{13}C NMR (100 MHz, $CDCl_3$): δ = 166.21, 165.73, 165.47, 165.43, 165.40, 165.33,165.33, 165.29, 165.21, 165.07, 165.07, 164.98 (12 PhCO), 106.27, 101.46, 101.19, 100.93 (4 C-1). Anal. Calcd for $C_{119}H_{112}O_{32}$: C, 69.58; H, 5.50. Found: C, 69.74; H, 5.46.

For **1**: $[\alpha]_D$ –6.5 (*c* 1.0, H_2O). ^{1}H NMR (400 MHz, D_2O): δ = 5.26 (s, 1 H, H-1), 4.48 (d, $J_{1,2}$ = 6.0 Hz, 1 H, H-1), 4.39 (d, $J_{1,2}$ = 7.6 Hz, 1 H, H-1), 4.30 (d, $J_{1,2}$ = 6.0 Hz, 1 H, H-1), 1.58–0.83 (m, 23 H, $CH_2C_{11}H_{23}$). MALDI–TOF MS: *m*/*z* calcd for $C_{35}H_{64}O_{20}$: 804.88 [M] , found: 827.54 $(M + Na)^+$.

For **2**: $[\alpha]_D$ –8.6 (*c* 1.0, H_2O). ^{1}H NMR (400 MHz, D_2O): δ = 5.33 (s, 1 H, H-1), 4.55 (d, $J_{1,2}$ = 6.0 Hz, 1 H, H-1), 4.46 (d, $J_{1,2}$ = 6.0 Hz, 1 H, H-1), 4.38 (d, $J_{1,2}$ = 6.0 Hz, 1 H, H-1), 1.66–0.92 (m, 23 H, $CH_2C_{11}H_{23}$). MALDI–TOF MS: *m*/*z* calcd for $C_{35}H_{64}O_{20}$: 804.88 [M], found: 827.81 $(M + Na)^+$.

For **30**: $[\alpha]_D$ +82.7 (*c* 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.08–7.26 (m, 10 H, 2 × PhH), 5.71 (dd, 1 H, H-4), 5.38 (dd, 1 H, H-3), 4.51 (d, $J_{1,2}$ = 7.7 Hz, 1 H, H-1), 4.13 (dd, 1 H, H-2), 3.98(dd, 1 H, H-6a), 3.93 (m, 1 H, H-5), 3.78 (dd, 1 H, H-6b), 3.64–3.59 (m, 2 H, $CH_2C_{11}H_{23}$), 1.36–0.86 (m, 23 H, $CH_2C_{11}H_{23}$). Anal. Calcd for $C_{32}H_{44}O_8$: C, 69.04; H, 7.97. Found: C, 69.19; H, 8.04.

For **31**: $[\alpha]_D$ +88.3 (*c* 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.07–7.24 (m, 25 H, 5 × PhH), 5.83 (dd, 1 H, H-4), 5.78 (dd, 1 H, H-4), 5.73 (dd, 1 H, H-2), 5.50 (dd, 1 H, H-3), 5.29 (dd, 1 H, H-3), 4.84 (d, $J_{1,2}$ = 7.9 Hz, 1 H, H-1), 4.37 (d, $J_{1,2}$ = 7.7 Hz, 1 H, H-1), 1.35–0.86 (m, 23 H, $CH_2C_{11}H_{23}$). Anal. Calcd for $C_{61}H_{68}O_{17}$: C, 68.27; H, 6.39. Found: C, 68.19; H, 6.35.

For **33**: $[\alpha]_D$ +73.4 (*c* 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.01–7.13 (m, 40 H, 8 × PhH), 5.87 (dd, 1 H, H-4), 5.78 (dd, 1 H, H-2), 5.74 (dd, 1 H, H-4), 5.52–5.47 (m, 3 H, 3 × H-3), 5.36 (s, 1 H, H-1), 5.21 (d, $J_{1,2}$ = 0.9 Hz, 1 H, H-2), 4.80 (d, $J_{1,2}$ = 7.9 Hz, 1 H, H-1), 4.51 (d, $J_{1,2}$ = 7.8 Hz, 1 H, H-1), 1.4–0.86 (m, 23 H, $CH_2C_{11}H_{23}$). Anal. Calcd for $C_{85}H_{86}O_{23}$: C, 69.19; H, 5.87. Found: C, 69.44; H, 5.91.

For **34**: $[\alpha]_D$ +77.6 (*c* 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.01–7.13 (m, 50 H, 10 × PhH), 5.89 (dd, 1 H, H-4), 5.85 (dd, 1 H, H-4), 5.72 (dd, 1 H, H-4), 5.70 (dd, 1 H, H-2), 5.55-5.47 (m, 3 H, 3 × H-3), 5.43 (s, 1 H, H-1), 5.36 (d, $J_{1,2}$ = 1.1 Hz, 1 H, H-2), 5.35 (dd, 1 H, H-3), 5.25 (dd, 1 H, H-3), 4.82 (d, $J_{1,2}$ = 7.8 Hz, 1 H, H-1), 4.52 (d, $J_{1,2}$ = 7.8 Hz, 1 H, H-1), 4.46 (d, $J_{1,2}$ = 7.9 Hz, 1 H, H-1), 1.89, 1.88 (2 × s, 6 H, 2 × CH_3CO), 1.36–0.86 (m, 23 H, $CH_2C_{11}H_{23}$). ^{13}C NMR (100 MHz, $CDCl_3$): δ = 170.18, 169.23 (2 × CH_3CO), 166.08, 165.57, 165.44, 165.44, 165.40, 165.27, 165.20, 165.11, 165.04, 164.87 (10 × PhCO), 106.03, 101.98, 100.94, 100.22 (4 × C-1) 20.53, 20.44 (2 × CH_3CO). Anal. Calcd for $C_{109}H_{108}O_{32}$: C, 67.83; H, 5.64. Found: C, 67.68; H, 5.69.

For **37**: $[\alpha]_D$ +37.5 (*c* 1.0, $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 5.41 (s, 1 H, H-1), 5.30 (s, 1 H, H-1), 4.65 (d, $J_{1,2}$ = 7.6 Hz, 1 H, H-1), 4.47 (d, $J_{1,2}$ = 7.7 Hz, 1 H, H-1), 4.39 (d, $J_{1,2}$ = 7.7 Hz, 1 H, H-1), 4.32 (d, $J_{1,2}$ = 7.5 Hz, 1 H, H-1). ^{13}C NMR (100 MHz, $CDCl_3$): δ = 106.17, 106.02, 101.92, 101.22, 100.90, 100.82 (6 × C-1). Anal. Calcd for $C_{165}H_{150}O_{46}$: C, 69.08; H, 5.27. Found: C, 69.54; H, 5.17.

For **3**: $[\alpha]_D$ –17.5 (*c* 1.0, H_2O). ^{1}H NMR (400 MHz, D_2O): δ = 5.22 (s, 1 H, H-1), 4.38, 4.36, 4.11 (d, 3 H, 3 × H-1), 1.54–0.79 (m, 23 H, $CH_2C_{11}H_{23}$). MALDI–TOF MS: *m*/*z* calcd for $C_{35}H_{64}O_{20}$: 804.88 [M], found: 827.65 $(M + Na)^+$.

For **4**: $[\alpha]_D$ –6.8 (*c* 1.0, H_2O). ^{1}H NMR (400 MHz, D_2O): δ = 5.25 (s, 1 H, H-1), 5.23 (s, 1 H, H-1), 4.52 (d, $J_{1,2}$ = 6.8 Hz, 1 H, H-1), 4.01–4.39 (m, 3 H, H-1), 1.56–0.84 (m, 23 H, $CH_2C_{11}H_{23}$). ^{13}C NMR (100 MHz, D_2O): δ = 108.23, 108.23, 103.45, 103.45, 103.25, 102.17 (6 × C-1). MALDI-TOF MS: *m*/*z* calcd for $C_{46}H_{82}O_{29}$: 1099.14 [M], found: 1122.26 $(M + Na)^+$.