Tetrahedron Letters 53 (2012) 4929–4932

Contents lists available at SciVerse ScienceDirect

Tetrahedron Letters

journal homepage: www.elsevier.com/locate/tetlet

Deoxygenation/dimerization of sugar derivatives with $BF_3{\cdot}Et_2O$–Et_3SiH: synthesis of a β-isonucleoside

Subhrangshu Mukherjee *, Biswajit G. Roy, Soumendra N. Das, Sukhendu B. Mandal

Chemistry Division, CSIR-Indian Institute of Chemical Biology, 4, Raja S.C. Mullick Road, Jadavpur, Kolkata 700 032, India

ARTICLE INFO

Article history:
Received 1 June 2012
Revised 25 June 2012
Accepted 27 June 2012
Available online 3 July 2012

Keywords:
Boron trifluoride-etherate
Triethylsilane
Deoxygenation
Dimerization
Synthesis
Isonucleosides

ABSTRACT

Lewis acid-Et_3SiH induced deoxygenation of anomeric carbon of sugars generates tetrahydrofuran derivatives, accompanied by hitherto unknown dimeric products. If the reagent addition steps are reversed, tetrahydrofuran derivatives are obtained as the sole products, while only the dimeric products are isolated if Et_3SiH is excluded. One of the deoxygenated products has been transformed into a β-isonucleoside.

Self-glycosylation reaction for the generation of disaccharides is scarcely reported. Formation of di-D-fructose dianhydrides via acid catalyzed dimerization[1] of D-fructose, sucrose or inulin through a fructosyl oxocarbenium cation and in situ glycosylation into the respective disaccharide has been demonstrated by Mellet and García Fernández group.[2] Very recently, a report by Uriel et al.[3] disclosed the use of self-glycosylation for stereoselective formation of disaccharides from mannose-derived orthoesters by treatment with $BF_3{\cdot}Et_2O$. The role of $BF_3{\cdot}Et_2O$ for the cleavage of acetonide protection and as promoter in glycosylation reaction in a tandem manner has been clearly revealed in these reactions. It appeared that during the self-glycosylation reaction occurring through oxocarbenium ion, in situ addition of a hydride donor that could act in the presence of the Lewis acid to reduce the double bond would prevent glycosylation and generate solely 3-hydroxytetrahydrofuran derivatives (deoxygenated products), which could be transformed to bioactive isonucleosides[4–7] via nucleophilic displacement of 3-OH group by nucleobases (Fig. 1). However, if glycosylation and hydride addition compete with each other, the reaction could afford both deoxygenated and dimerized products. This realization has encouraged us to exploit this strategy for the stereoselective preparation of D-glucose-based chiral 3-hydroxytetrahydrofuran derivatives and di-D-glucose 1,2′:1′,2-dianhydrides (dimeric products), and the results are described herein.

The starting sugar based precursor **5** was derived from 3-*O*-benzyl xylose,[8] whereas **6** and **9** were obtained from the corresponding dihydroxymethyl derivatives[9,10] via benzylation. Compounds **7**,[11] **8**,[12] **10**,[13] and **11**[14] were prepared following the literature methods. For the deoxygenation of the anomeric carbon, the starting synthons (type **A**, Scheme 1) **5–11** (Table 1) were treated with Et_3SiH in the presence of $BF_3{\cdot}Et_2O$.[15,16] Interestingly, treatment of $BF_3{\cdot}Et_2O$ at first followed by Et_3SiH (Method I)[17] furnished the normal tetrahydrofuran derivatives (type **B**) **12**, **14**, **16**, **18**, **20**, **22**, and **24** (27–45% yields) along with the hitherto unknown dimeric products (type **C**) **13**, **15**, **17**, **19**, **21**, **23,** and **25** (32–38% yields) (Table 1). However, reversal of the addition schedule to employ Et_3SiH first and then $BF_3{\cdot}Et_2O$ ensured exclusive formation of the deoxygenated products in 67–78% yields (Method II).[17] On the other hand,

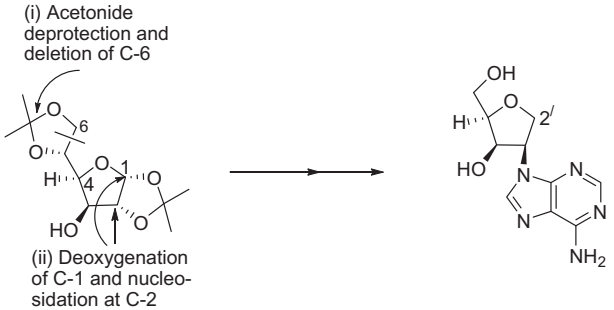
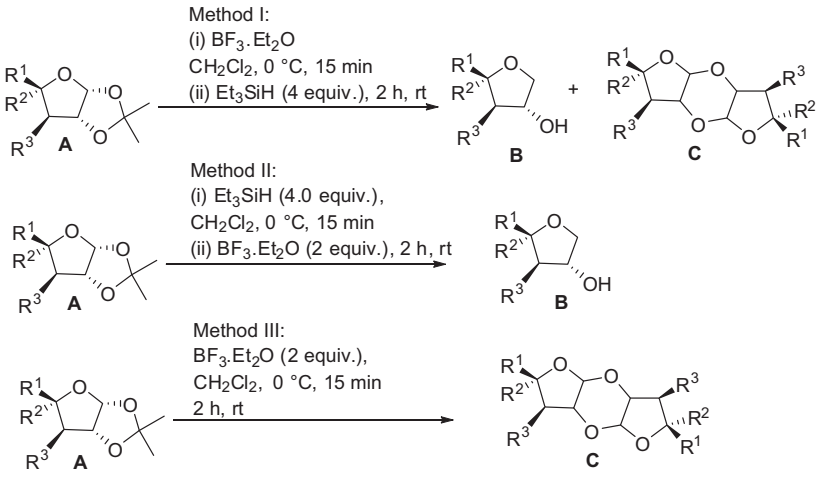


Figure 1. A strategy to generate isonucleosides.

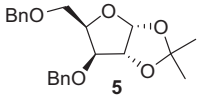
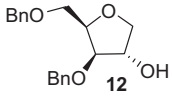
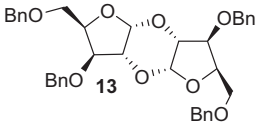
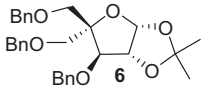
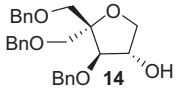
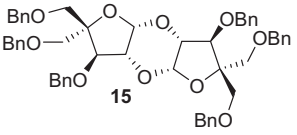
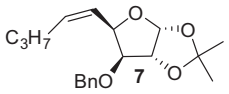
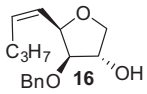
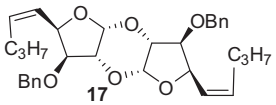
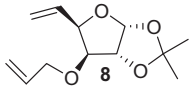
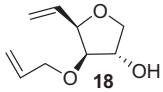
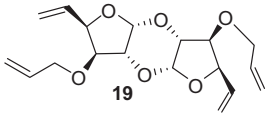
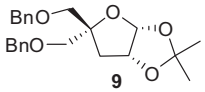
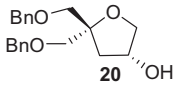
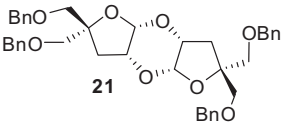
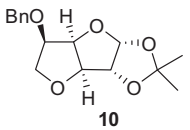
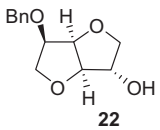
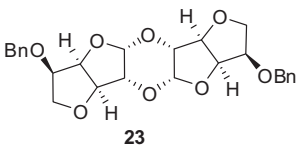
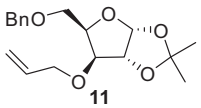
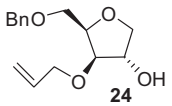
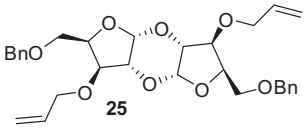
* Corresponding author.
E-mail address: bantim_2006@rediff.com (S. Mukherjee).

0040-4039/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.tetlet.2012.06.121



Scheme 1. Deoxygenation of anomeric carbon and dimerization of sugar.

Table 1
Reaction of sugar derivatives with $BF_3{\cdot}Et_2O$–Et_3SiH

Entry	Starting sugar	Deoxygenated product	Yield (%)		Dimeteric product	Yield (%)	
			Method I	Method II		Method I	Method II
1	 **5**	 **12**	42	78	 **13**	33	75
2	 **6**	 **14**	27	67	 **15**	37	72
3	 **7**	 **16**	35	72	 **17**	35	80
4	 **8**	 **18**	38	72	 **19**	36	78
5	 **9**	 **20**	42	75	 **21**	32	73
6	 **10**	 **22**	45	71	 **23**	36	79
7	 **11**	 **24**	44	69	 **25**	38	70

the use of $BF_3{\cdot}Et_2O$ as the sole reagent furnished the dimeric products exclusively in 70–80% yields (Method III).[17] All the products were characterized by ^1H and ^{13}C NMR besides MS analyses.[18] The presence of an extra CH_2 signal ($\sim\delta$ 70.0) and absence of the anomeric carbon signal in the ^{13}C NMR spectra, coupled with the absence of signals for isopropylidene methyl and the anomeric proton in the ^1H NMR spectra of the deoxygenated products indicated the successful reduction of the anomeric position. However,

the anomeric proton and carbon signals appeared at ~δ 5.2 and ~δ 98.0, respectively, as expected, in the NMR spectra of the dimeric products, which showed peaks for half the number of nuclei due to C_2 symmetric nature of the molecules. Mass spectral analyses of the dimeric products showed the appropriate molecular ion peaks.

The proposed mechanism for the formation of two products involves the cleavage of the acetonide ring aided by complexation with BF_3, producing an oxocarbenium intermediate that either undergoes reduction with triethylsilyl hydride to produce the C-1-deoxygenated product or dimerizes. However, addition of Et_3SiH before $BF_3{\cdot}Et_2O$ ensures that the initially formed silicon–complex intermediate can facilitate the transfer of hydride ion on to the anomeric carbon, leading to the formation of deoxygenated product only (Fig. 2). Formation of the dimer as the sole product using only $BF_3{\cdot}Et_2O$ is also in full agreement with the mechanism.

Subsequently, to support the formation of dimers, one of the dimeric products, the diallyl-divinyl-1,4-dioxane derivative **19**, was treated with 1st generation Grubbs catalyst in CH_2Cl_2 to isolate the bis(pyranofuro)dioxane derivative **26**[19] in 82% yield upon ring closing metathesis reaction (Scheme 2).

Since 3-hydroxytetrahydrofuran derivatives are key intermediates for some important isonucleosides, we exploited the tetrahydrofuran derivative **12** as a representative example for isonucleoside synthesis. Thus, insertion of 6-chloropurine base on **12** under Mitsunobu reaction condition using DEAD-Ph_3P in THF produced the protected nucleoside **27**[19] in 56% yield (Scheme 3). Substitution of chloro group by amine upon treatment with methanolic ammonia followed by hydrogenolytic cleavage of the benzyl groups furnished in 51% yield (in two steps) the targeted β-isonucleoside **28** as foam, $[\alpha]_D^{25}$ +27.2 (*c* 0.24, MeOH) {lit[4b] $[\alpha]_D^{25}$ for its enantiomer −26.6 (*c* 0.27, MeOH)}; ESIMS, *m/z*: 274 $(M+Na)^+$. Inclusion of the chloropurine ring was evident from the presence of two singlets at δ 8.33 and 8.64 in the ^1H NMR spectrum, and the signals at δ 130.9, 144.9, 150.7, 151.5, and 151.7 in the ^{13}C NMR spectrum of **27**.

In conclusion, this work describes a method for the deoxygenation of anomeric carbon using Lewis acid catalyzed reduction with triethylsilane. Tinkering with the reagent addition order also generated dimeric products, which became the exclusive products by avoiding the silane reagent. Subsequent inclusion of a nucleobase on one of the deoxygenated products under Mitsunobu reaction condition and shedding of the protecting groups provided an isonucleoside. This strategy could be used to other systems.

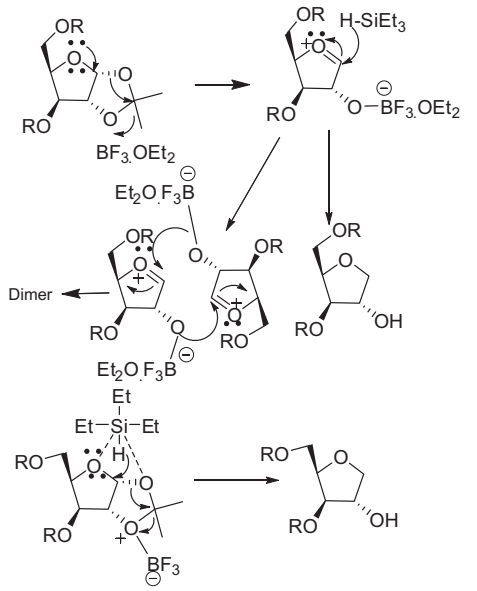
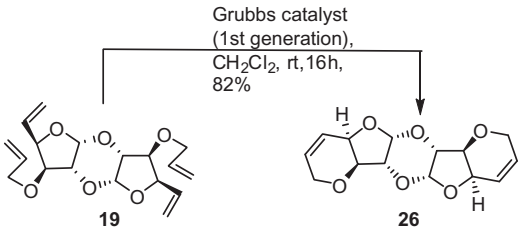
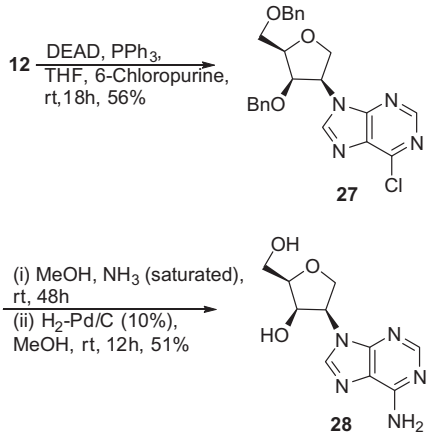


Figure 2. Mechanism for the formation of the products.



Scheme 2. Ring closing metathesis of the olefin **19**–**26**.



Scheme 3. Conversion of **12** to the isonucleoside **28**.

Acknowledgments

The authors (S.M. and B.G.R.) gratefully acknowledge CSIR for providing them with Senior Research Fellowships, and B. Achari, ex-scientist of the institute for helping to edit the manuscript.

References and notes

1. (a) Defaye, J.; Garcia Fernández, J. M. *Carbohydr. Res.* **1994**, *251*, 17–31; (b) Garcia Fernández, J. M.; Schnelle, R. R.; Defaye, J. *Tetrahedron: Asymmetry* **1995**, *6*, 307–312; (c) Kennedy, I. A.; Hemscheidt, T.; Britten, J. F.; Spenser, I. D. *Can. J. Chem.* **1995**, *73*, 1329–1337.
2. (a) Benito, J. M.; Gomez Garcia, M.; Mellet, C. O.; Garcia Fernández, J. M.; Defaye, J. *Org. Lett.* **2001**, *3*, 549–552; (b) Rubio, E. M.; Mellet, C. O.; Garcia Fernández, J. M. *Org. Lett.* **2003**, *5*, 873–876; (c) Garcia Fernández, J. M.; Mellet, C. O.; Defaye, J. *J. Org. Chem.* **1998**, *63*, 3572–3580.
3. Uriel, C.; Ventura, J.; Gómez, A. M.; Cristóbal López, J.; Fraser-Reid, B. *J. Org. Chem.* **2012**, *77*, 795–800.
4. (a) Kakefuda, A.; Shute, S.; Nagahata, T.; Sek, J.; Sasaki, T.; Matsuda, A. *Tetrahedron* **1994**, *50*, 10167–10182; (b) Bravo, F.; Diaz, Y.; Castillón, S. *Tetrahedron: Asymmetry* **2001**, *12*, 1635–1643.
5. (a) Nair, V.; Nuesca, Z. M. *J. Am. Chem. Soc.* **1992**, *114*, 7951–7953; (b) Diaz, Y.; Bravo, F.; Castillón, S. *J. Org. Chem.* **1999**, *64*, 6508–6511.
6. Lei, Z.; Zhang, L. H. *Tetrahedron: Asymmetry* **2000**, *11*, 2899–2906.
7. Yoshimura, Y.; Asami, K.; Matsui, H.; Tanaka, H.; Takahata, H. *Org. Lett.* **2006**, *8*, 6015–6018.
8. Yoshimura, Y.; Kitano, K.; Satoh, H.; Watanabe, M.; Miura, S.; Sakata, S.; Sasaki, T.; Matsuda, A. *J. Org. Chem.* **1996**, *61*, 822–823.
9. Roy, A.; Achari, B.; Mandal, S. B. *Tetrahedron Lett.* **2006**, *47*, 3875–3879.
10. (a) Prokop, J.; Murray, D. H. *J. Pharm. Sci.* **1965**, *54*, 359–365; (b) Leyland, D. L.; Kotick, M. P. *Carbohydr. Res.* **1974**, *38*, C9–C11.
11. Chandrasekhar, S.; Prakash, S. J.; Rao, C. L. *J. Org. Chem.* **2006**, *71*, 2196–2199.
12. Haque, A.; Panda, J.; Ghosh, S. *Indian J. Chem.* **1999**, *38B*, 8–9.
13. Maity, J. K.; Mukherjee, S.; Drew, M. G. B.; Achari, B.; Mandal, S. B. *Carbohydr. Res.* **2007**, *342*, 2511–2521.
14. Khan, A. R.; Tripathi, R. P.; Bhaduri, A. P. *Indian J. Chem* **1996**, *35B*, 405–408.
15. Rosenthal, A.; Sprinzl, M. *Carbohydr. Res.* **1971**, *16*, 337–342.
16. Acton, E. M.; Goerner, R. N.; Uh, H. S.; Ryan, K. J.; Henry, D. W. *J. Med. Chem.* **1979**, *22*, 518–525.

17. *General procedure for the preparation of deoxygenated and dimeric products*: *Method I*: To a solution of **5** (1.0 g, 2.70 mmol) in CH_2Cl_2 (20 mL) at 0 °C was added freshly distilled $BF_3{\cdot}Et_2O$ (0.68 mL, 2.0 equiv) and the mixture was allowed to stir for 15 min under N_2 atmosphere. Et_3SiH (1.7 mL, 4.0 equiv) was added to it and the reaction was allowed to continue for 2 h. The mixture was diluted with water (10 mL); the CH_2Cl_2 was separated, washed with water (2 × 5 mL), dried (Na_2SO_4) and evaporated to yield a mixture of two products. These were separated by column chromatography on silica gel (60–120 mesh) using EtOAc–petroleum ether (1:49) and EtOAc–petroleum ether (1:4) to furnish **13** (556 mg, 33%) and **12** (356 mg, 42%), respectively as viscous liquids. *Method II*: Et_3SiH was added to the substrate solution followed by $BF_3{\cdot}Et_2O$, using the same protocol as described in Method I. The products identified were **12** (78%), **14** (67%), **16** (72%), **18** (72%), **20** (75%), **22** (71%) and **24** (69%) with the respective sugar derivatives **5**–**11**. *Method III*: $BF_3{\cdot}Et_2O$ (2 equiv) was added to the well stirred substrate solution at 0 °C. After 15 min more at 0 °C, the stirring was continued for 2 h at room temperature. A cold solution of 5% $NaHCO_3$ (10 mL) was then added. Usual work-up and purification afforded the dimeric products **13** (75%), **15** (72%), **17** (80%), **19** (78%), **21** (73%), **23** (79%) and **25** (70%), respectively with **5**–**11**.

18. *Characterization data of the deoxygenated products*: Compound **12**: $[\alpha]_D^{25}$ −19.8 (*c* 0.96, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2.29 (br s, 1H), 3.62–3.76 (m, 3H), 3.89 (br d, 1H, *J* = 2.4 Hz), 4.12 (dd, 1H, *J* = 3.9, 9.9 Hz), 4.31 (br s, 2H), 4.50 (br d, 2H, *J* = 11.4 Hz), 4.61 (d, 2H, *J* = 11.7 Hz), 7.30–7.32 (m, 10H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 68.6 (CH_2), 72.2 (CH_2), 73.4 (CH_2), 73.5 (CH_2), 75.0 (CH), 79.2 (CH), 84.3 (CH), 127.5–128.5 (10 × CH), 137.9 (C), 138.1(C); ESIMS, *m*/*z*: 337 $(M+Na)^+$. Compound **14**: $[\alpha]_D^{25}$ +49.3 (*c* 0.76, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 3.56 (d, 1H, *J* = 10.3 Hz), 3.63 (d, 1H, *J* = 10.3 Hz), 3.72 (d, 1H, *J* = 10.0 Hz), 3.80 (d, 1H, *J* = 10.0 Hz), 3.87 (d, 1H, *J* = 9.7 Hz), 3.99 (partially merged dd, 1H, *J* = 3.2, 9.7 Hz), 4.02 (br s, 1H), 4.15 (br d, 1H, *J* = 7.7 Hz), 4.28 (br d, 1H, *J* = 10.8 Hz), 4.45 (d, 1H, *J* = 11.8 Hz), 4.50 (d, 1H, *J* = 11.8 Hz), 4.53 (d, 1H, *J* = 12.0 Hz), 4.58 (d, 1H, *J* = 12.0 Hz), 4.66 (d, 2H, *J* = 12.0 Hz), 7.23–7.35 (m, 15H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 69.5 (CH_2), 72.7 (CH_2), 73.2 (CH_2), 73.5 (CH_2), 73.8 (CH_2), 74.0 (CH_2), 75.4 (CH), 86.1 (C), 87.1 (CH), 127.3 (2 × CH), 127.4 (CH), 127.5 (2 × CH), 127.6 (CH), 127.8 (2 × CH), 127.9 (CH), 128.2 (2 × CH), 128.3 (2 × CH), 128.5 (2 × CH), 136.9 (C), 137.8 (C), 138.1(C); ESIMS, *m*/*z*: 457 $(M+Na)^+$. Compound **16**: $[\alpha]_D^{25}$ −12.8 (*c* 0.81, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 0.91 (t, 3H, *J* = 7.3 Hz), 1.35–1.47 (m, 2H), 1.73 (br s, 1H), 2.03–2.16 (m, 2H), 3.67 (d, 1H, *J* = 9.8 Hz), 3.79 (d, 1H, *J* = 3.2 Hz), 4.21 (dd, 1H, *J* = 4.4, 9.8 Hz), 4.40 (s, 1H), 4.60 (s, 2H), 4.83 (br t-like, 1H), 5.65–5.71 (m, 2H), 7.32 (br s, 5H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 13.6 (CH_3), 22.6 (CH_2), 29.7 (CH_2), 71.9 (CH_2), 73.2 (CH_2), 75.2 (CH), 75.8 (CH), 85.5 (CH), 124.6 (CH), 127.3 (2 × CH), 127.5 (CH), 128.2 (2 × CH), 134.5 (CH), 137.8 (C); ESIMS, *m*/*z*: 285 $(M+Na)^+$, 301 $(M+K)^+$. Compound **18**: $[\alpha]_D^{25}$ −14.0 (*c* 0.64, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2.30 (br s, 1H), 3.70 (dd, 1H, *J* = 1.8, 11.6 Hz), 3.80 (br dd-like, 1H), 4.04–4.13 (m, 2H), 4.17 (dd, 1H, *J* = 4.3, 9.7 Hz), 4.36 (br dd-like, 1H), 4.50 (dd, 1H, *J* = 4.0, 7.0 Hz), 5.18 (dd, 1H, *J* = 1.4, 10.3 Hz), 5.25–5.31 (m, 2H), 5.37 (dd, 1H, *J* = 1.0, 17.2 Hz), 5.86–6.04 (m, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 71.6 (CH_2), 73.8 (CH_2), 75.7 (CH), 82.1 (CH), 86.0 (CH), 117.4 (CH_2), 118.6 (CH_2), 134.0 (CH), 134.7 (CH); ESIMS, *m*/*z*: 193 $(M+Na)^+$. Compound **20**: $[\alpha]_D^{25}$ +21.9 (*c* 0.22, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 1.99 (d, 1H, *J* = 15.0 Hz), 2.08 (d, 1H, *J* = 15.0 Hz), 3.32 (d, 1H, *J* = 9.8 Hz), 3.39 (d, 1H, *J* = 9.8 Hz), 3.53 (d, 1H, *J* = 9.8 Hz), 3.67 (d, 1H, *J* = 9.8 Hz), 3.76 (d, 1H, *J* = 9.5 Hz), 3.94 (d, 1H, *J* = 9.5 Hz), 4.26 (s, 2H), 4.50 (d, 1H, *J* = 12.0 Hz), 4.56 (d, 1H, *J* = 11.7 Hz), 4.57 (d, 1H, *J* = 12.0 Hz), 4.70 (d, 1H, *J* = 11.7 Hz), 7.29–7.34 (m, 10H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 35.2 (CH_2), 65.9 (CH_2), 66.1 (CH_2), 71.0 (CH_2), 72.5 (CH_2), 73.0 (CH_2), 74.4 (CH), 89.2 (C), 127.5–128.4 (10 × CH), 137.3 (C), 138.0 (C); ESIMS, *m*/*z*: 351 $(M+Na)^+$. Compound **22**: $[\alpha]_D^{25}$ −16.8 (*c* 0.53, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 1.77 (br s, 1H), 3.61 (t, 1H, *J* = 8.4 Hz), 3.86 (dd, 1H, *J* = 6.6, 8.4 Hz), 3.95 (d, 1H, *J* = 10.2 Hz), 4.00 (d, 1H, *J* = 3.0 Hz), 4.03–4.11 (m, 1H), 4.32 (br s, 1H), 4.42 (d, 1H, *J* = 4.2 Hz), 4.57 (d, 1H, *J* = 12.0 Hz), 4.72 (t, 1H, *J* = 4.5 Hz), 4.78 (d, 1H, *J* = 12.0 Hz), 7.29–7.37 (m, 5H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 70.2 (CH_2), 72.4 (CH_2), 74.5 (CH_2), 76.7 (CH), 79.1 (CH), 80.1 (CH), 88.2 (CH), 127.9–128.4 (5 × CH), 137.6 (C); ESIMS, *m*/*z*: 259 $(M+Na)^+$. Anal. Calcd for $C_{13}H_{16}O_4$: C, 66.09; H, 6.83; Found: C, 66.26; H, 6.91. Compound **24**: $[\alpha]_D^{25}$ −20.4 (*c* 0.93, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2.46 (d, 1H, *J* = 2.4 Hz), 3.63–3.74 (m, 3H), 3.83 (d. 1H, *J* = 3.6 Hz), 3.96 (dd, 1H, *J* = 5.4, 12.9 Hz), 4.08 (t-like, 1H, *J* = 9.6, 10.8 Hz), 4.09 (t, 1H, *J* = 9.6 Hz), 4.28–4.31 (m, 2H), 4.52 (d, 1H, *J* = 12.0 Hz), 4.62 (d, 1H, *J* = 12.0 Hz), 5.16 (d, 1H, *J* = 10.5 Hz), 5.24 (d, 1H, *J* = 17.4 Hz), 5.77–5.90 (m, 1H), 7.27–7.35 (m, 5H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 68.5 (CH_2), 70.9 (CH_2), 73.3 (CH_2), 73.4 (CH_2), 74.6 (CH), 79.1 (CH), 83.9 (CH), 116.9 (CH_2), 127.5 (CH), 127.7 (2 × CH), 128.3 (2 × CH), 134.2 (CH), 137.9 (C); ESIMS, *m*/*z*: 287 $(M+Na)^+$.

    Characterization data of the dimeric products: Compound **13:** $[\alpha]_D^{25}$ −9.1 (*c* 0.32, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 3.72–3.74 (t-like, 2H, *J* = 2.8, 3.0 Hz), 4.00 (d, 1H, *J* = 2.9 Hz), 4.12 (d, 1H, *J* = 3.5 Hz), 4.47–4.54 (m, 3H), 4.61 (d, 1H, *J* = 12.0 Hz), 4.66 (d, 1H, *J* = 12.0 Hz), 5.16 (d, 1H, *J* = 3.6 Hz), 7.28–7.32 (m, 10H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 67.6 (CH_2), 71.8 (CH_2), 73.3 (CH_2), 76.6 (CH), 79.7 (CH), 82.5 (CH), 97.0 (CH), 127.5–128.3 (10 × CH), 137.4 (C), 138.0 (C); ESIMS, *m*/*z*: 647 $(M+Na)^+$. Compound **15:** $[\alpha]_D^{25}$ −23.4 (*c* 0.54, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 3.52 (d, 1H, *J* = 9.8 Hz), 3.65 (d, 1H, *J* = 9.8 Hz), 3.68 (partially merged d, 1H, *J* = 10.5 Hz), 3.72 (d , 1H, *J* = 10.5 Hz), 4.16–4.21 (m, 2H), 4.46 (d, 1H, *J* = 12.0 Hz), 4.49 (d, 1H, *J* = 10.7 Hz), 4.51–4.61 (m, 3H), 4.72 (d, 1H, *J* = 12.0 Hz), 5.13 (d, 1H, *J* = 3.9 Hz), 7.24–7.28 (m, 15H); ^{13}C NMR ($CDCl_3$, 75 MHz)): δ 69.4 (CH_2), 71.1 (CH_2), 72.2 (CH_2), 73.2 (CH_2), 73.4 (CH_2), 78.0 (CH), 83.9 (CH), 86.1(C), 96.3 (CH), 127.2–128.1 (15 × CH), 137.7 (C), 138.0 (C), 138.3 (C); ESIMS, *m*/*z*: 887 $(M+Na)^+$. Compound **17:** $[\alpha]_D^{25}$ −74.6 (*c* 0.21, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 0.89 (t, 3H, *J* = 7.4 Hz), 1.34–1.43 (m, 2H), 1.98–2.11 (m, 2H), 3.99 (d, 2H, *J* = 3.0 Hz), 4.53 (d, 1H, *J* = 12.1 Hz), 4.64 (d, 1H, *J* = 12. 1 Hz), 5.08 (dd, 1H, *J* = 3.4, 7.3 Hz), 5.19 (d, 1H, *J* = 3.8 Hz), 5.62–5.73 (m, 2H), 7.31 (brs, 5H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 14.1 (CH_3), 23.0 (CH_2), 30.5 (CH_2), 72.4 (CH_2), 77.5 (CH), 77.6 (CH), 84.7 (CH), 97.8 (CH), 123.9 (CH), 128.0 (2 × CH), 128.2 (CH), 128.8 (2 × CH), 135.6 (CH), 137.9 (C); ESIMS, *m*/*z*: 543 $(M+Na)^+$. Compound **19:** $[\alpha]_D^{25}$ −84.6 (*c* 0.46, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 600 MHz) : δ 3.98 (t, 2H, *J* = 3.6 Hz), 3.99 (partially merged dd, 1H, *J* = 6.0, 13.2 Hz), 4.11 (dd, 1H, *J* = 5.4, 13.2 Hz), 4.75 (dd, 1H, *J* = 3.6, 7.2 Hz), 5.18–5.21 (m, 2H), 5.28 (dd, 1H, *J* = 1.2, 17.4 Hz), 5.32 (d, 1H, *J* = 10.8 Hz), 5.43 (d, 1H, *J* = 17.4 Hz), 5.82–5.88 (m, 1H), 5.95–6.01(m, 1H); ^{13}C NMR ($CDCl_3$, 150 MHz): δ 71.0 (CH_2), 76.9 (CH), 82.2 (CH), 84.2 (CH), 97.3 (CH), 117.6 (CH_2), 119.4 (CH_2), 131.9 (CH), 133.8 (CH); ESIMS, *m*/*z*: 359 $(M+Na)^+$. Compound **21:** $[\alpha]_D^{25}$ −35.7 (*c* 0.31, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 2.11–2.15 (m, 2H), 3.45–3.55 (m, 2H), 3.62–3.66 (m, 2H), 4.44–4.59 (m, 4H), 4.72 (brd, 1H, *J* = 3.1 Hz), 5.85 (d, 1H, *J* = 3.7 Hz), 7.27-7.31 (m, 10H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 34.2 (CH_2), 64.8 (CH_2), 65.2 (CH_2), 72.5 (CH_2), 73.0 (CH_2), 81.4 (CH), 89.2 (C), 104.8 (CH),127.4 (4 × CH), 127.6 (2 × CH), 128.2 (4 × CH), 137.5 (C), 138.1 (C); ESIMS, *m*/*z*: 675 $(M+Na)^+$. Compound **23:** $[\alpha]_D^{25}$ −7.8 (*c* 0.46, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 3.63 (t, 1H, *J* = 8.4 Hz), 3.87 (dd, 1H, *J* = 6.6, 8.4 Hz), 3.98–4.05 (m, 2H,), 4.57 (d, 1H, *J* = 11.7 Hz), 4.64 (d, 1H, *J* = 3.9 Hz), , 4.74 (t, 1H, *J* = 11.7 Hz), 4.78 (d, 1H, *J* = 4.5 Hz), 5.31 (d, 1H, *J* = 3.6 Hz), 7.28–7.37 (m, 5H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 69.2 (CH_2), 72.5 (CH_2), 77.4 (CH), 78.2 (CH), 79.8 (CH), 86.0 (CH), 98.1 (CH), 128.0 (2 × CH), 128.5 (3 × CH), 137.4 (C); ESIMS, *m*/*z*: 491$(M+Na)^+$. Anal. Calcd for $C_{26}H_{28}O_8$: C, 66.66; H, 6.02; Found: C, 66.47; H, 6.11. Compound **25:** $[\alpha]_D^{25}$ −8.7 (*c* 0.33, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 3.67–378 (m, 2H), 3.94–3.98 (m, 2H), 4.05 (d, 1H, *J* = 3.9 Hz), 4.11 (dd, 1H, *J* = 5.1, 12.9 Hz), 4.47–4.54 (m , 1H), 4.52 (d, 1H, *J* = 12.0 Hz), 4.61 (d, 1H, *J* = 12.0 Hz), 5.15 (d, 1H, *J* = 3.6 Hz), 5.16 (d, 1H, 9.9 Hz), 5.25 (dd, 1H, *J* = 1.2, 17.1 Hz), 5.76–5.89 (m, 1H), 7.27–7.33 (m, 5H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 67.5 (CH_2), 70.7 (CH_2), 73.2 (CH_2), 77.2 (CH), 79.6 (CH), 82.4 (CH), 97.0 (CH), 117.3 (CH_2), 127.4 (CH), 127.5 (2 × CH), 128.2 (2 × CH), 133.8 (CH), 138.0 (C); ESIMS, *m*/*z*: 547 $(M+Na)^+$.

19. *Spectral data*: Compound **26**: $[\alpha]_D^{25}$ −93.2 (*c* 0.61, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 300 MHz): δ 3.99 (d, 1H, *J* = 3.8 Hz), 4.04 (d, 1H, *J* = 2.3 Hz), 4.11 (d, 1H, *J* = 17.1 Hz), 4.23 (td, 1H, *J* = 1.4, 2.1, 17.1 Hz), 4.48 (br t, 1H, *J* = 2.1 Hz), 5.21 (d, 1H, *J* = 3.8 Hz), 6.02–6.07 (m, 1H), 6.11–6.16 (m, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz): δ 65.0 (CH_2), 71.8 (CH), 78.9 (CH), 80.1 (CH), 98.0 (CH), 121.4 (CH), 132.8 (CH); ESIMS, *m*/*z*: 303 $(M+Na)^+$. Compound **27**: viscous liquid; $[\alpha]_D^{25}$ +54.2 (*c* 0.43, $CHCl_3$); ^{1}H NMR ($CDCl_3$, 600 MHz): δ 3.78 (dd, 1H, *J* = 6.0, 9.6 Hz), 3.84 (dd, 1H, *J* = 6.0, 9.6 Hz), 4.04 (d, 1H, *J* = 11.4 Hz), 4.17 (dd, 1H, *J* = 7.8, 9.6 Hz), 4.24 (dd, 1H, *J* = 6.6, 9.6 Hz), 4.28 (dd, 1H, *J* = 6.0, 10.8 Hz), 4.32 (d, 1H, *J* = 11.4 Hz), 4.37 (t-like, 1H, *J* = 4.8, 5.4 Hz), 4.57 (d, 1H, *J* = 12.0 Hz), 4.63 (d, 1H, *J* = 12.0 Hz), 5.45 (q, 1H, *J* = 6.6 Hz), 7.29–7.37 (m, 10H), 8.33 (s, 1H), 8.64 (s, 1H); ^{13}C NMR ($CDCl_3$, 150 MHz): δ 55.6 (CH), 67.8 (CH_2), 69.5 (CH_2), 73.6 (CH_2), 74.1 CH_2), 77.3 (CH), 80.9 (CH), 127.8–128.5 (10 × CH), 130.9 (C), 135.8 (C), 137.5 (C), 144.9 (CH), 150.7 (C), 151.5 (CH), 151.7 (C); ESIMS, *m*/*z*: 473 $(M+Na)^+$, 475 $(M+Na)^+$.