A facile method for the preparation of sugar orthoesters promoted by anhydrous sodium bicarbonate

Shanqiao Wei, Jinzhong Zhao, and Huawu Shao

Abstract: A facile and eco-friendly method for the preparation of sugar orthoesters by using anhydrous sodium bicarbonate is described. Various sugar orthoesers, including sugar–sugar orthoesters, were synthesized in good-to-excellent yields by the reaction of a protected glycosyl bromide with an alcohol or sugar.

Key words: sugar orthoesters, anhydrous sodium bicarbonate, protected glycosyl bromide.

Résumé : On a développé une méthode facile et écologique de préparation d'orthoesters de sucres utilisant le bicarbonate de sodium anhydre. On a réalisé la synthèse de divers orthoesters de sucres, y compris des orthoesters de sucre-sucre, avec des rendements allant de bons à excellents en procédant à la réaction d'un bromure de glycosyle protégé avec un alcool ou un sucre.

Mots-clés : orthoesters de sucres, bicarbonate de sodium anhydre, bromure de glycosyle protégé.

[Traduit par la Rédaction]

Introduction

Sugar 1,2-orthoesters are some of the most important intermediates in organic synthesis,[1,2] especially in the oligosaccharide synthesis.[3–7] Sugar 1,2-orthoesters are classic glycosyl donors and can be efficiently converted to the corresponding 1,2-*trans*-glycosides by the action of protonic or Lewis acids, such as TMSOTf,[8] $BF_3{\cdot}Et_2O$,[9a] and TfOH.[9b] Sugar 1,2-orthoesters are also extremely practical for the selective protection of a pyranose ring while the other acetyl groups on the 3, 4, and 6 positions are converted to benzyl groups, and so forth. At present, there are several methods in the literature for the preparation of carbohydrate 1,2-orthoesters.[10,11] The well-known method involves the treatment of peracetylated or perbenzoylated glycosyl bromides with alcohols in the presence of a quaternary ammonium salt[12] or silver triflate[5,13] and an organic base, usually *syn*-collidine or 2,6-lutidine.[14] It is necessary to utilize two kinds of reagents, quaternary ammonium salt and bulky amine compound, for the reaction to occur.[11a,15] Although the method has been extensively used, there is one large disadvantage: the use of a smelly, toxic, and eco-unfriendly organic base. Knowing the broad spectrum of the significant applications of sugar orthoesters, we have focused our interest on improving the synthesis of sugar orthoesters. Herein, a facile, less toxic, and efficient procedure for the synthesis of 1,2-orthoesters, including sugar–sugar orthoesters, by using anhydrous sodium bicarbonate instead of an organic base is reported.[15,16]

Received 21 May 2009. Accepted 4 September 2009. Published on the NRC Research Press Web site at canjchem.nrc.ca on 28 November 2009.

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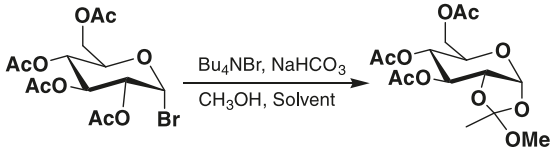
Result and discussion

Our studies started with the reaction of peracetylated glucopyranosyl bromide with methanol in the presence of tetrabutylammonium bromide, anhydrous sodium bicarbonate, and a 4 Å molecular sieve in dry acetonitrile solvent (Scheme 1). The reaction was carried out at room temperature for 4 h, affording the glucopyranosyl methyl orthoester in an 86% yield (Table 1, entry 1). To optimize the method, we used toluene, 1,2-dichlorethane, *N*,*N*-dimethylformamide (DMF), and tetrahydrofuran (THF), respectively, as the solvent, and afforded the target product **2** in various yields (Table 1, entries 2–5).

To establish the feasibility of this reaction as a general method for the preparation of 1,2-orthoesters (Scheme 2), we carried out the synthesis of 3,4,6-tri-*O*-acetyl mannose, 3,4,6-tri-*O*-acetyl galactose, 3,4-di-*O*-acetyl rhamnose orthoesters, and 3,4,6-tri-*O*-benzoyl mannose orthoester in good to excellent yields, and the results are shown in Table 2 (entries 1–4). Since 6-*O*-tosyl and 6-*O*-mesyl of these orthoesters can be easily substituted by other groups, the library of sugar orthoesters is greatly expanded. However, the synthesis of 6-*O*-tosyl and 6-*O*-mesyl orthoesters has not been reported in the literature. Herein, with the suitable protocol in hand, 6-*O*-mesyl and 6-*O*-tosyl mannopyranosyl bromide were treated by using various alcohols such as methanol, isopropyl alcohol, and allyl alcohol, and the corresponding orthoesters (Table 2, entries 5–10). 6-*O*-Mesyl orthosters **13** and **14** (Table 2, entries 5 and 6) and 6-*O*-tosyl orthoster **19** (Table 2, entry 11) were obtained in good yields. Whereas 6-*O*-mesyl orthoesters **15–18** (Table 2, entries 7–10) and 6-*O*-tosyl orthoesters **20** and **21** (Table 2, entries 12 and 13) were obtained in modest yields. The

Scheme 1. The synthesis of glucopyranosyl methyl orthoester.



1 2

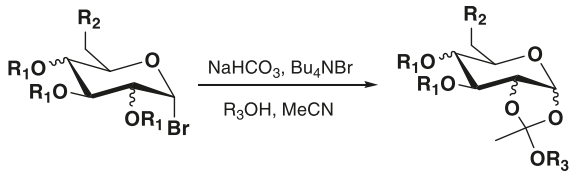
Table 1. Optimization of the synthesis of glucopyranosyl methyl orthoester.

Entry	Slovent	Time (h)	Yield (%)
1	MeCN	3	86
2	Toluene	6	69
3	$ClCH_2CH_2Cl$	6	71
4	DMF	4	60
5	THF	8	75

sugar–sugar orthoesters are extremely important intermediates for oligosaccharide synthesis. Comparing simple sugar orthoesters, the reaction pathways of sugar–sugar orthoesters are relatively simplified for oligosaccharide preparation; the consideration is mainly focused on intra- and inter-molecular rearrangement of the alkoxide.[8a] Sugar–sugar orthoesters are usually synthesized by the reaction of a glycosyl bromide donor with a glycosyl acceptor with only one free hydroxyl group in dichloromethane in the presence of silver triflate and 2,4-lutidine.[8a] Although this method is efficient, both silver triflate and 2,4-lutidine are toxic and expensive. We hoped that our newly developed method could be applied to the synthesis of sugar–sugar orthoesters. Hence, **3** and **22** were treated in the presence of tetrabutylammonium bromide and anhydrous sodium bicarbonate, the reaction was completed at room temperature for 12 h, and readily afforded the sugar–sugar orthoester **24** in an excellent yield (90%). Encouraged by the success in synthesizing **24**, we subsequently prepared sugar–sugar orthoesters **25**–**28** in good yields (Table 2, entries 15–18).

In summary, we developed a facile and effective protocol for the synthesis of various sugar 1,2-orthoesters and sugar–sugar orthoesters by using anhydrous sodium bicarbonate as an inexpensive and environmentally friendly base. The approach, in terms of low toxicity of reagents, simplicity, economy, and efficiency, will be a general, useful, and attractive strategy for the synthesis of sugar 1,2-orthoesters.

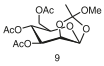
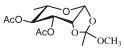
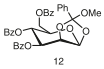
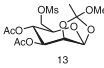
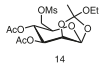
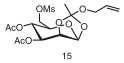
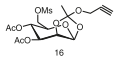
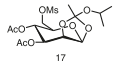
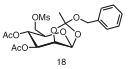
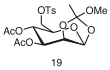
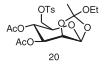
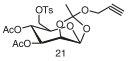
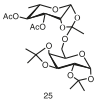
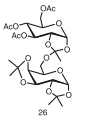
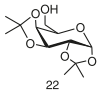
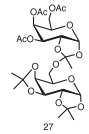
Scheme 2. The synthesis of glucopyranosyl various orthoester.



Experimental

Reactions were monitored by thin layer chromatography (TLC) using silica gel HSGF254 plates. Flash chromatography was performed using silica gel HG/T2354–92. ^1H and ^{13}C NMR (600 and 150 MHz, respectively) spectra

Table 2. Preparation for various orthoesters using anhydrous sodium bicarbonate.

Entry	Glycosyl bromide	ROH	Product	Yield (%)
1	 3	methanol	 9	84
2	 4	methanol	 10	80
3	 5	methanol	 11	66
4	 6	methanol	 12	91
5	 7	methanol	 13	88
6	 7	ethanol	 14	83
7	 7	allyl alcohol	 15	77
8	 7	propynol	 16	70
9	 7	isopropyl alcohol	 17	60
10	 7	benzylalcohol	 18	69
11	 8	methanol	 19	80
12	 8	ethanol	 20	78
13	 8	propynol	 21	71
14	 3	 22	 24	90
15	 5	 22	 25	76
16	 1	 22	 26	78
17	 4	 22	 27	78
18	3	23	28	80

were recorded in $CDCl_3$. ^1H NMR chemical shifts are reported in ppm (δ) relative to tetramethylsilane (TMS) with the solvent resonance employed as the internal standard ($CDCl_3$, δ 7.26 ppm). Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, m = multiplet), integration, and coupling constants (Hz). ^{13}C NMR chemical shifts are reported in ppm from tetramethylsilane (TMS) with the solvent resonance as the internal standard ($CDCl_3$, δ 77.0 ppm). HR-MS (ESI) spectra were recorded on BioTOF Q. Optical rotations were acquired on a PerkinElmer M341 Digital Polarimeter.

General procedure for the synthesis of 1,2-orthoesters 2, 9–21

The acetobromo glycoside (1 mmol) was dissolved in dry acetonitrile (4 mL), then alcohol (10 mmol), tetrabutylammonium bromide (0.7 mmol), anhydrous sodium bicarbonate (2 mmol), and molecular sieves 4 Å; (400 mg) were added. The reaction mixture was vigorously stirred for 3–7 h at room temperature. TLC indicated when the reaction was complete. The solvent was evaporated to dryness and the residue was purified by silica gel column chromatrography.

General procedure for the synthesis of sugar–sugar orthoesters 24–28

The glycosyl acceptor (1 mmol) and acetobromo glycoside (2 mmol) were dissolved in dry acetonitrile (10 mL), then tetrabutylammonium bromide (1 mmol), anhydrous sodium bicarbonate (4 mmol), and molecular sieves 4 Å; (600 mg) were added. The reaction mixture was vigorously stirred at room temperature for 12–15 h. TLC indicated when the reaction was complete. The solvent was evaporated to dryness and the residue was purified by silica gel column chromatrography.

Characterization data

Compound 2

Yield: 86%. Syrup. $[\alpha]_D^{25}$ +31 (*c* 0.8, EtOAc). ^1H NMR ($CDCl_3$) δ: 5.72 (d, 1H, *J* = 5.1 Hz), 5.19 (dd, 1H, *J* = 2.8, 3.0), 4.90 (dd, 1H, *J* = 2.8, 9.6), 4.32 (m, 1H), 4.20 (m, 2H), 3.95 (m, 1H), 3.29 (s, 3H), 2.11 (s, 3H), 2.10 (s, 3H,), 2.09 (s, 3H), 1.71 (s, 3H).

Compound 9

Yield: 84%. White needle, mp 107–108 °C. $[\alpha]_D^{25}$ –24 (*c* 0.2, EtOAc). ^1H NMR ($CDCl_3$) δ: 5.49 (d, 1H, *J* = 2.5), 5.30 (dd, 1H, *J* = 9.7, 9.8), 5.15 (dd, 1H, *J* = 4.0, 10.0), 4.61 (dd, 1H, *J* = 2.9, 3.5), 4.24 (dd, 1H, *J* = 5.0, 12.2), 4.14 (dd, 1H, *J* = 1.9, 11.7), 3.68 (m, 1H), 3.28 (s, 3H), 2.12 (s, 3H), 2.07 (s, 3H), 2.05 (s, 3H), 1.74 (s, 3H).

Compound 10

Yield: 80%. Syrup. $[\alpha]_D^{25}$ +80 (*c* 0.2, EtOAc). ^1H NMR [$(CD_3)_2CO$] δ: 5.87 (d, 1H, *J* = 4.6), 5.40 (dd, 1H, *J* = 2.9, 3.1), 5.06 (dd, 1H, *J* = 3.4, 6.5), 4.42–4.40 (m, 2H), 4.17 (dd, 1H, *J* = 7.0, 11.3), 4.10 (dd, 1H, *J* = 5.8, 11.3), 3.23 (s, 3H), 2.08 (s, 3H), 2.01 (s, 3H), 2.00 (s, 3H), 1.60 (s, 3H).

Compound 11

Yield: 66%. $[\alpha]_D^{25}$ +20 (*c* 0.4, EtOAc). ^1H NMR ($CDCl_3$) δ: 5.41 (d, 1H, *J* = 2.3), 5.06 (m, 2H), 4.59 (dd, 1H, *J* = 2.3, 3.9), 3.51 (m, 1H), 3.27 (s, 3H), 2.12 (s, 3H), 2.06 (s, 3H), 1.73 (s, 3H), 1.23 (d, 3H, *J* = 6.2).

Compound 12

Yield: 91%. White solid, mp 150–152 °C. $[\alpha]_D^{25}$ –129 (*c* 0.7, EtOAc). ^1H NMR ($CDCl_3$) δ: 8.01 (d, 2H, *J* = 7.6), 7.90–7.89 (m, 4H), 7.71–7.69 (m, 2H), 7.53–7.47 (m, 3H), 7.42–7.32 (m, 6H), 7.30–7.26 (m, 3H), 5.88 (dd, 1H, *J* = 9.5, 9.6), 5.80 (d, 1H, *J* = 2.9), 5.66 (dd, 1H, *J* = 4.1, 10.0), 5.08 (dd, 1H, *J* = 3.3, 3.7), 4.51 (dd, 1H, *J* = 3.1, 11.9), 4.35 (dd, 1H, *J* = 4.7, 12.1), 4.14–4.09 (m, 1H), 3.23 (s, 3H).

Compound 13

Yield: 88%. White solid, mp 128–129 °C. $[\alpha]_D^{25}$ –2.5 (*c* 0.2, EtOAc). ^1H NMR ($CDCl_3$) δ: 5.51 (d, 1H, *J* = 2.5), 5.25 (dd, 1H, *J* = 9.4, 9.8), 5.17 (dd, 1H, *J* = 3.8, 10.0), 4.63 (dd, 1H, *J* = 3.1, 3.1), 4.3 (dd, 1H, *J* = 5.5, 11.1), 4.28 (dd, 1H, *J* = 2.7, 11.1), 3.79 (m, 1H), 3.28 (s, 3H), 3.05 (s, 3H), 2.12 (s, 3H), 2.08 (s, 3H), 1.73 (s, 3H). ^{13}C NMR ($CDCl_3$) δ: 170.3, 169.6, 124.3, 97.5, 76.2, 71.6, 70.2, 67.2, 65.5, 50.1, 37.7, 24.0, 20.7, 20.6. HR-MS (ESI) anal. calcd. for $C_{14}H_{22}NaO_{11}S$ [M + Na]: 421.0775; found: 421.0772.

Compound 14

Yield: 83%. White solid, mp 145–146 °C. $[\alpha]_D^{25}$ –1 (*c* 0.2, EtOAc). ^1H NMR ($CDCl_3$) δ: 5.49 (d, 1H, *J* = 2.5), 5.25 (dd, 1H, *J* = 9.5, 9.7), 5.17 (dd, 1H, *J* = 3.9, 9.9), 4.61 (dd, 1H, *J* = 3.1, 3.5), 4.33 (dd, 1H, *J* = 5.5, 11.1), 4.28 (dd, 1H, *J* = 2.7, 11.0), 3.78 (m, 1H), 3.59–3.50 (m, 2H), 3.05 (s, 3H), 2.12 (s, 3H), 2.08 (s, 3H), 1.73 (s, 3H), 1.18 (t, 3H, *J* = 7.0). ^{13}C NMR ($CDCl_3$) δ: 170.3, 169.6, 124.0, 97.5, 76.0, 71.6, 70.2, 67.3, 65.6, 58.4, 37.7, 24.3, 20.7, 20.6, 15.1. HR-MS (ESI) anal. calcd. for $C_{15}H_{24}NaO_{11}S$ [M + Na]: 435.0932; found: 435.0936.

Compound 15

Yield: 77%. White solid, mp 127–129 °C. $[\alpha]_D^{25}$ +11 (*c* 0.1, EtOAc). ^1H NMR ($CDCl_3$) δ: 5.87 (m, 1H), 5.51 (d, 1H, *J* = 2.8), 5.27–5.24 (m, 2H), 5.18–5.14 (m, 2H), 4.62 (dd, 1H, *J* = 3.1, 3.8), 4.33 (dd, 1H, *J* = 5.6, 11.3), 4.28 (dd, 1H, *J* = 3.0, 11.3), 4.06–4.00 (m, 2H), 3.79 (m, 1H), 3.05 (s, 3H), 2.12 (s, 3H), 2.08 (s, 3H), 1.75 (s, 3H). ^{13}C NMR ($CDCl_3$) δ: 170.2, 169.6, 133.9, 124.1, 116.8, 97.6, 76.0, 71.7, 70.1, 67.3, 65.5, 64.0, 37.7, 24.4, 20.7, 20.6. HR-MS (ESI) anal. calcd. for $C_{16}H_{24}NaO_{11}S$ [M + Na]: 447.0932; found: 447.0925.

Compound 16

Yield: 70%. White solid, mp 130-132 °C. $[\alpha]_D^{25}$ +1 (*c* 0.2, EtOAc). ^1H NMR ($CDCl_3$) δ: 5.53 (d, 1H, *J* = 2.9), 5.25 (dd, 1H, *J* = 9.4, 9.7), 5.18 (dd, 1H, *J* = 4.0, 10.0), 4.68 (dd, 1H, *J* = 3.2, 3.2), 4.33 (dd, 1H, *J* = 5.6, 11.5), 4.29 (dd, 1H, *J* = 2.8, 11.2), 4.18 (d, 2H, *J* = 2.1), 3.80 (m, 1H), 3.05 (s, 3H), 2.38 (t, 1H, *J* = 1.9), 2.12 (s, 3H), 2.08 (s, 3H), 1.77 (s, 3H). ^{13}C NMR ($CDCl_3$) δ: 170.2, 169.6, 123.9, 97.6, 79.4, 76.0, 73.7, 71.8, 69.9, 67.2, 65.4, 51.1, 37.7, 24.0, 20.7. HR-MS (ESI) anal. calcd. for $C_{16}H_{22}NaO_{11}S$ [M + Na]: 445.0775; found: 445.0783.

Compound 17

Yield: 60%. White solid, mp 109–111 °C. $[\alpha]_D^{25}$ +1 (*c* 0.4,

EtOAc). ^{1}H NMR ($CDCl_3$) δ: 5.48 (d, 1H, *J* = 2.7), 5.25 (dd, 1H, *J* = 9.5, 9.5), 5.17 (dd, 1H, *J* = 4.1, 9.9), 4.62 (dd, 1H, *J* = 2.9, 3.7), 4.33 (dd, 1H, *J* = 5.8, 11.3), 4.28 (dd, 1H, *J* = 2.9, 11.2), 3.95 (m, 1H), 3.79 (m, 1H), 3.05 (s, 3H), 2.11 (s, 3H), 2.08 (s, 3H), 1.73 (s, 3H), 1.15 (d, 3H, *J* = 6.2), 1.14 (d, 3H, *J* = 9.1). ^{13}C NMR ($CDCl_3$) δ: 170.2, 169.6, 124.1, 97.4, 75.5, 71.7, 70.1, 67.4, 66.6, 65.6, 37.7, 24.4, 23.7, 20.7. HR-MS (ESI) anal. calcd. for $C_{16}H_{26}NaO_{11}S$ [M + Na]: 449.1088; found: 449.1011.

Compound 18

Yield: 68%. White solid, mp 141–142 °C. $[\alpha]_D^{25}$ +10 (*c* 0.2, EtOAc). ^{1}H NMR ($CDCl_3$) δ: 7.37–7.26 (m, 5H), 5.52 (d, 1H, *J* = 2.7), 5.26 (dd, 1H, *J* = 9.5, 9.7), 5.16 (dd, 1H, *J* = 3.9, 9.9), 4.64–4.54 (m, 3H), 4.35–4.28 (m, 2H), 3.80 (m, 1H), 3.05 (s, 3H), 2.10 (s, 3H), 2.08 (s, 3H), 1.81 (s, 3H). ^{13}C NMR ($CDCl_3$) δ: 170.2, 169.6, 137.4, 128.6, 128.4, 127.7, 127.5, 127.0, 124.2, 97.6, 76.0, 71.7, 70.0, 67.3, 65.5, 65.0, 37.7, 24.4, 20.7; HR-MS (ESI) anal. calcd for $C_{20}H_{26}NaO_{11}S$ [M + Na]: 497.1088; found: 497.1079.

Compound 19

Yield: 80%. Syrup. $[\alpha]_D^{25}$ +30.5 (*c* 0.2, EtOAc). ^{1}H NMR ($CDCl_3$) δ: 7.78 (d, 2H, *J* = 8.3), 7.34 (d, 2H, *J* = 7.9), 5.41 (d, 1H, *J* = 2.7), 5.16 (dd, 1H, *J* = 9.2, 9.6), 5.11 (dd, 1H, *J* = 3.8, 9.8), 4.56 (dd, 1H, *J* = 2.9, 3.7), 4.11 (m, 2H), 3.72 (m, 1H), 3.24 (s, 3H), 2.45 (s, 3H), 2.10 (s, 3H), 2.03 (s, 3H), 1.59 (s, 3H). ^{13}C NMR ($CDCl_3$) δ: 170.3, 169.5, 145.0, 132.5, 129.8, 128.1, 124.3, 97.4, 76.3, 71.3, 70.2, 67.9, 65.9, 50.0, 24.0, 21.6, 20.7, 20.6; HR-MS (ESI) anal. calcd for $C_{20}H_{26}NaO_{11}S$ [M + Na]: 497.1088; found: 497.1081.

Compound 20

Yield: 78%. Syrup. $[\alpha]_D^{25}$ +19.7 (*c* 0.6, EtOAc). ^{1}H NMR ($CDCl_3$) δ: 7.78 (d, 2H, *J* = 7.3), 7.34 (d, 2H, *J* = 7.7), 5.40 (m, 1H), 5.27–5.11 (m, 2H), 4.55 (m, 1H), 4.13–4.07 (m, 2H), 3.72 (m, 1H), 3.51 (m, 2H), 2.44 (s, 3H), 2.10 (s, 3H), 2.02 (s, 3H), 1.60 (s, 3H), 1.16 (t, 3H, *J* = 6.72). ^{13}C NMR ($CDCl_3$) δ: 170.3, 169.5, 145.0, 132.5, 129.8, 128.1, 124.0, 97.4, 76.1, 71.3, 70.2, 68.0, 65.9, 58.2, 24.3, 21.6, 20.7, 20.6, 15.0 HR-MS (ESI) anal. calcd for $C_{21}H_{28}NaO_{11}S$ [M + Na]: 511.1245; found: 511.1268.

Compound 21

Yield: 71%. Syrup. $[\alpha]_D^{25}$ +23 (*c* 0.2, EtOAc). ^{1}H NMR ($CDCl_3$) δ: 7.78 (d, 2H, *J* = 8.2), 7.34 (d, 2H, *J* = 8.0), 5.43 (d, 1H, *J* = 2.8), 5.18–5.11 (m, 2H), 4.62 (dd, 1H, *J* = 3.2, 3.3), 4.15 (d, 2H, *J* = 1.8), 4.15–4.07 (m, 4H), 3.76 (m, 1H), 2.45 (s, 3H), 2.37 (t, 1H, *J* = 2.3), 2.10 (s, 3H), 2.03 (s, 3H), 1.63 (s, 3H). ^{13}C NMR ($CDCl_3$) δ: 170.2, 169.5, 145.1, 132.5, 130.0, 129.8, 128.1, 123.9, 97.5, 79.4, 76.0, 73.7, 71.6, 69.9, 68.0, 65.7, 51.0, 24.0, 21.6, 20.7, 20.6, 14.2; HR-MS (ESI) anal. calcd for $C_{22}H_{26}NaO_{11}S$ [M + Na]: 521.1088; found: 521.1065.

Compound 24

Yield: 90%. White solid, mp 121–123 °C. $[\alpha]_D^{25}$ –27.7 (*c* 0.3, EtOAc). ^{1}H NMR ($CDCl_3$) δ: 5.50 (m, 2H), 5.28 (dd, 1H, *J* = 9.4, 9.8), 5.18 (dd, 1H, *J* = 4.1, 10.0), 4.62 (dd, 1H, *J* = 3.1, 3.5), 4.58 (dd, 1H, *J* = 2.4, 7.9), 4.29 (dd, 1H, *J* = 2.4, 5.1), 4.24–4.22 (m, 2H), 4.15 (dd, 1H, *J* = 2.8, 11.9), 3.91 (dd, 1H, *J* = 5.5, 6.1), 3.74–3.69 (m, 2H), 3.60 (dd, 1H, *J* = 6.2, 9.2), 2.11 (s, 3H), 2.06 (s, 3H), 2.04 (s, 3H), 1.76 (s, 3H), 1.53 (s, 3H), 1.42 (s, 3H), 1.33 (s, 3H), 1.32 (s, 3H).

Compound 25

Yield: 76%. Syrup. $[\alpha]_D^{25}$ –34.3 (*c* 0.3, EtOAc). ^{1}H NMR [$(CD_3)_2CO$)] δ: 5.61 (d, 1H, *J* = 2.2), 5.44 (d, 1H, *J* = 5.0), 5.20 (dd, 1H, *J* = 4.0, 10.0), 4.97 (dd, 1H, *J* = 9.7, 9.8), 4.65 (dd, 1H, *J* = 2.4, 4.0), 4.60 (dd, 1H, *J* = 2.0, 7.9), 4.32 (dd, 1H, *J* = 2.2, 4.9), 4.23 (dd, 1H, *J* = 1.4, 7.9), 3.91 (m, 1H), 3.69 (m, 1H), 3.64 (dd, 1H, *J* = 5.6, 10.1), 3.56 (dd, 1H, *J* = 6.7, 9.8), 2.03 (s, 6H), 1.66 (s, 3H), 1.47 (s, 3H), 1.36 (s, 3H), 1.31 (s, 3H), 1.30 (s, 3H), 1.16 (d, 3H, *J* = 6.2). ^{13}C NMR ($CDCl_3$) δ: 169.6, 169.5, 123.8, 108.7, 108.1, 97.3, 96.3, 77.3, 71.0, 70.7, 70.5, 66.9, 61.4, 25.5, 24.8, 24.3, 23.8, 19.8, 16.9. HR-MS (ESI) anal. calcd. for $C_{24}H_{36}NaO_{13}$ [M + Na]: 555.2048; found: 555.2037.

Compound 26

Yield: 78%. Syrup. $[\alpha]_D^{25}$ –18.5 (*c* 0.2, EtOAc). ^{1}H NMR [$(CD_3)_2CO$] δ: 5.72 (d, 1H, *J* = 5.3), 5.44 (d, 1H, *J* = 4.9), 5.13 (dd, 1H, *J* = 2.8, 2.8), 4.86 (dd, 1H, *J* = 2.0, 9.5), 4.60 (dd, 1H, *J* = 2.4, 7.9), 4.45 (m, 1H), 4.32 (dd, 1H, *J* = 2.4, 5.2), 4.25 (dd, 1H, *J* = 1.8, 7.9), 4.15 (d, 2H, *J* = 4.4), 3.99 (m, 1H), 3.87 (m, 1H), 3.67 (dd, 1H, *J* = 6.3, 9.7), 3.52 (dd, 1H, *J* = 6.5, 9.7), 2.05 (s, 6H), 2.01 (s, 3H), 1.67 (s, 3H, CH_3), 1.45 (s, 3H), 1.37 (s, 3H), 1.31 (s, 3H), 1.30 (s, 3H).

Compound 27

Yield: 78%. Syrup. $[\alpha]_D^{25}$ +9.5 (*c* 0.2, EtOAc). ^{1}H NMR [$(CD_3)_2CO$] δ: 5.87 (d, 1H, *J* = 4.9), 5.45 (dd, 1H, *J* = 4.9), 5.40 (dd, 1H, *J* = 2.5, 2.9), 5.07 (dd, 1H, *J* = 3.5, 6.4), 4.61 (dd, 1H, *J* = 2.2, 7.8), 4.43–4.40 (m, 2H), 4.27 (m, 1H), 4.18 (dd, 1H, *J* = 7.2, 11.5), 4.10 (dd, 1H, *J* = 5.5, 11.3), 4.04 (dd, 1H, *J* = 7.2, 14.1), 3.90 (dd, 1H, *J* = 4.9, 6.7), 3.68 (m, 1H), 3.55 (m, 1H), 2.13–2.01 (m, 9H), 1.63 (s, 3H), 1.46 (s, 3H), 1.37 (s, 3H), 1.31 (s, 3H), 1.30 (s, 3H).

Compound 28

Yield: 80%. Syrup. $[\alpha]_D^{25}$ +10 (*c* 0.3, EtOAc). ^{1}H NMR ($CDCl_3$) δ: 7.34–7.26 (m, 15H), 5.39 (d, 1H, *J* = 2.5), 5.27 (dd, 1H, *J* = 9.6, 9.6), 5.12 (dd, 1H, *J* = 3.9, 9.8), 4.90 (dd, 2H, *J* = 7.8, 10.9), 4.82 (d, 1H, *J* = 11.0), 4.77 (d, 1H, *J* = 11.0), 4.69 (d, 1H, *J* = 11.0), 4.62 (d, 1H, *J* = 10.9), 4.48 (dd, 1H, *J* = 2.9, 3.3), 4.28 (d, 1H, *J* = 7.8), 4.23 (dd, 1H, *J* = 5.1, 12.3), 4.14 (dd, 1H, *J* = 2.6, 12.2), 3.75 (d, 1H, *J* = 8.8), 3.68–3.60 (m, 3H), 3.55 (s, 3H), 3.51 (d, 1H, *J* = 9.2), 3.41 (m, 2H), 2.07 (s, 3H), 2.04 (s, 3H), 2.00 (s, 3H), 1.74 (s, 3H). ^{13}C NMR ($CDCl_3$) δ: 170.6, 170.3, 169.4, 138.6, 138.5, 138.3, 128.5, 128.4, 128.1, 128.0, 127.9, 127.8, 127.7, 127.6, 124.2, 104.6, 97.4, 84.6, 82.3, 77.7, 76.4, 75.6, 74.9, 74.7, 73.8, 71.5, 70.3, 65.7, 62.5, 61.8, 57.0, 24.4, 20.7, 20.6. HR-MS (ESI) anal. calcd. for $C_{42}H_{50}NaO_{15}$ [M + Na]: 817.3042; found: 817.3018.

Supplementary data

Supplementary data for this article are available on the journal Web site (canjchem.nrc.ca) or may be purchased from the Depository of Unpublished Data, Document Delivery, CISTI, National Research Council Canada, Ottawa, ON K1A 0R6, Canada. DUD 5297. For more information on ob-

taining material, refer to cisti-icist.nrc-cnrc.gc.ca/cms/unpub_e.shtml.

Acknowledgment

We are grateful for financial support from the Chinese Academy of Sciences (Hundreds of Talents Program).

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