HETEROCYCLES, Vol. 98, No. 2, 2019, pp. 304 - 311. © 2019 The Japan Institute of Heterocyclic Chemistry
Received, 18th December, 2018, Accepted, 23rd January, 2019, Published online, 8th February, 2019
DOI: 10.3987/COM-18-14025

SITE-SELECTIVE ACYLATION OF CARBOHYDRATES DIRECTED BY RECYCLABLE POLYMER-SUPPORTED ISOTHIOUREA CATALYSTS

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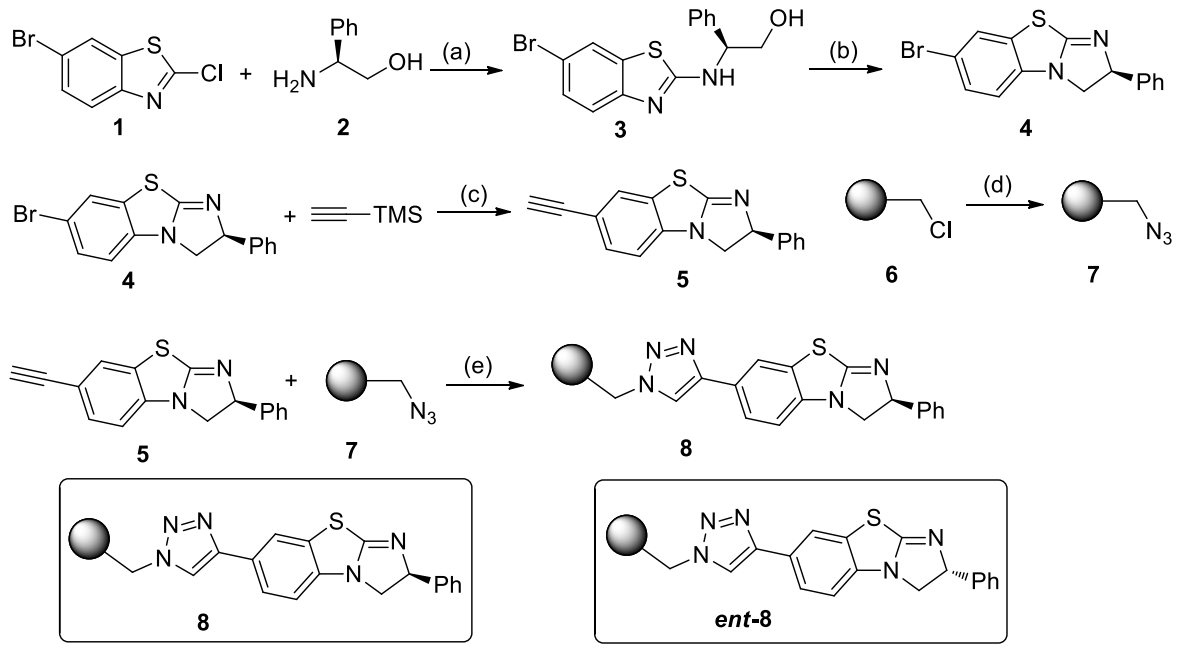
Abstract – The polystyrene-supported isothiourea catalysts, derived from the homogeneous catalyst BTMs, were synthesized and applied to the site-selective acylation of carbohydrates. The catalysts can be recovered and reused conveniently for 10 cycles without significantly loss in either activity or selectivity. It offers a sustainable and environmentally benign approach for the site-selective functionalization of carbohydrates.

Carbohydrates serve essential roles as energy reservoir and as resource of biomaterials.[1] They also provide the core scaffolds for pharmaceutical agents and vaccines.[2] However, the differentiation of hydroxyl groups in carbohydrates is a long-standing challenge due to more than one hydroxyl group inherently existing in the saccharides.[3] Although enzyme is demonstrated to be efficient for the selective activation of certain hydroxyl group in carbohydrates, it is still difficult to discriminate the hydroxyl groups of saccharides by non-enzymatic methods.[4] Recently, the chiral catalyst-directed selective functionalization of hydroxyl groups in carbohydrates has emerged as the breakthroughs to address above issue.[5] Therefore, the exploration of novel catalysts is urgent and critical for further developing the concise and protecting-group free synthesis of carbohydrates.

Birman and Shiina's group first developed the kinetic resolution of secondary alcohols using benzotetramisoles (BTMs) as chiral catalysts.[6] Later, Tang and Liu's group found a pair of BTM as catalysts could differentiate *trans*-1,2-diols of carbohydrates in acylation by a cation-*n* interaction.[7] Recently, Pericàs and Smith's group disclosed a polymer-supported isothiourea-catalyzed acylative kinetic resolution of secondary alcohols.[8] The polymer resins own excellent chemical stability and efficient swelling in organic solvents, which are very suitable for the organocatalysis in mild conditions.

In addition, it facilitates the catalyst recovery by a simple filtration and washing sequence. Although some solid-supported organocatalysts have been successfully applied in organic synthesis, it is still rare to be utilized in the functionalization of hydroxyl groups in carbohydrates.[9] Herein we reported the polystyrene-supported isothiourea catalysts, derived from the homogeneous catalyst BTMs, were synthesized and applied to the site-selective acylation of carbohydrates.

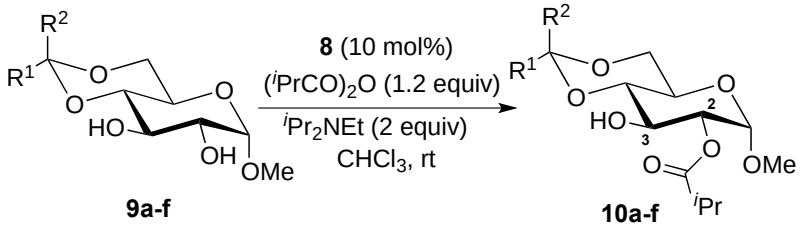
We first synthesized the polystyrene-supported BTM **8** following a slight modification of the literatures.[8] 6-Bromo-2-chlorobenzo[*d*]thiazole **1** and (*S*)-2-amino-2-phenylethanol **2** were used as starting materials. Compound **3** was afforded *via* a selective C-N bond formation in the first step. Then the cyclization occurred to give (*S*)-7-bromo-2-phenyl-2,3-dihydrobenzo[*d*]imidazo[2,1-*b*]thiazole **4**. Treating **4** with ethynyltrimethylsilane, the Sonogashira coupling product **5** was acquired after *in situ* deprotection. The commercially available (chloromethyl)polystyrene resin **6** (*f* = 1.20 mmol/g) could be transferred to (azidomethyl)polystyrene **7** (*f* = 1.10 mmol/g) efficiently.[8] The polystyrene-supported BTM **8** was prepared by the copper-catalyzed azide-alkyne cycloaddition (CuAAC) reaction between **5** and **7**. The functionalization of **8** was determined by elemental analysis of the nitrogen content (*f* = 0.89 mmol/g), which was used to confirm catalyst loading in site-selective acylation.[8] The polystyrene-supported *ent*-BTM ***ent*-8** could be prepared from (*R*)-2-amino-2-phenylethanol in the same sequence with similar yields and functionalization (*f* = 0.88 mmol/g) (Scheme 1).



(a) $^{i}Pr_2NEt$ (4 equiv), *o*-dichlorobenzene, reflux, 78%; (b) MsCl (1.5 equiv), NEt_3 (4 equiv), DCM, 0 °C-reflux, 46%; (c) $PdCl_2(PPh_3)_2$ (10 mol%), CuI (10 mol%), NEt_3 (10 equiv), THF, 50 °C, then TBAF (1.1 equiv), rt, 62%; (d) NaN_3, DMSO, 60 °C; (e) CuI (5 mol%), $^{i}Pr_2NEt$ (3.5 equiv), THF:DMF = 1:1

Scheme 1. Synthesis of the polystyrene-supported BTMs

With a pair of chiral catalysts in hand, the substrate scope of site-selective acylation of carbohydrates was investigated. The acylation preferred to occur at C2 position rather than C3 position using polystyrene-supported (*S*)-BTM **8** as catalyst (Scheme 2). The site-selectivities for C2 acylation were generally excellent (more than 20:1 ratio).[10] The yield for the dimethyl protecting substrate **9b** was slightly lower than the benzyl protecting one **9a**. To our delight, 4,6-*O*-methylidene substrate could achieve this transformation smoothly and gave **10c** in good yield and site-selectivity. If the 2-naphthalenyl group was used instead of the benzyl one, the yield for **10d** was increased to 81% with excellent selectivity. The yields for **10e** and **10f** were similar, which hinted the electronic effect was not obvious for the C2 acylation reaction, albeit the site-selectivity for **10f** was decreased to 16:1.

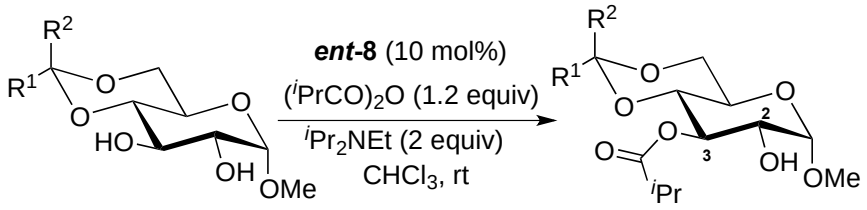


10a R^1 = Ph, R^2 = H, C2/C3 > 20:1, 70%
10b R^1 = Me, R^2 = Me, C2/C3 > 20:1, 64%
10c R^1 = H, R^2 = H, C2/C3 > 20:1, 73%
10d R^1 = 2-naphthalenyl, R^2 = H, C2/C3 > 20:1, 81%
10e R^1 = 4-MeO-C_6H_4-, R^2 = H, C2/C3 > 20:1, 76%
10f R^1 = 4-NO_2-C_6H_4-, R^2 = H, C2/C3 = 16:1, 75%

Scheme 2. C2-Selective acylation of carbohydrates

If the polystyrene-supported (*R*)-BTM ***ent*-8** was used as catalyst, the acylation reaction occurred at C3 position instead of the C2 position (Scheme 3). But the site-selectivities for the ***ent*-8** were slightly lower than **8** as catalyst. The yield of **11a** was similar to **10a** but with reversed site-selectivity. The yield and selectivity for the dimethyl protecting product **11b** were decreased to 60% and 7:1 respectively. The yield and selectivity could not be further improved for the 4,6-*O*-methylidene product **11c**. However, when 2-naphthalenyl substrate was used, good yield and excellent site-selectivity were afforded for **11d**. The electronic effect was obvious for the polystyrene-supported (*R*)-BTM-catalyzed acylation reaction. The yield and selectivity for the electron-donating product **11e** were much higher than the electron-withdrawing product **11f**. The catalysts, **8** and ***ent*-8**, can be recovered and reused conveniently for 10 cycles without significantly loss in either activity or selectivity. The yield for **10a** was 65% after 10 cycles of catalyst **8** with excellent site-selectivity (C2/C3 > 20:1).[11] The yield for **11a** was 70% after 10 cycles of catalyst ***ent*-8** with reversed site-selectivity (C3/C2 > 20:1).[11] According to previous study, the the cation-*n* interaction between the BTM catalyst and carbohydrate may be the key factor to control the site-selectivity.[7] Herein, the mechanism using polymer-supported BTMs as catalysts should be similar

with previous reported because the supporting site cannot influence the transition states for the acylation process. For the details, please see the supporting information.



9a-f **11a-f**

11a R^1 = Ph, R^2 = H, C3/C2 > 20:1, 78%
11b R^1 = Me, R^2 = Me, C3/C2 = 7:1, 60%
11c R^1 = H, R^2 = H, C3/C2 = 8:1, 65%
11d R^1 = 2-naphthalenyl, R^2 = H, C3/C2 > 20:1, 76%
11e R^1 = 4-MeO-C_6H_4-, R^2 = H, C3/C2 > 20:1, 85%
11f R^1 = 4-NO_2-C_6H_4-, R^2 = H, C3/C2 = 11:1, 66%

Scheme 3. C3-Selective acylation of carbohydrates

In conclusion, we have developed a site-selective acylation of carbohydrates using the polystyrene-supported isothiourea catalysts, which were derived from the homogeneous catalyst BTMs. The catalysts can be recovered and reused conveniently for 10 cycles without significantly loss in either activity or selectivity. It offers a sustainable and environmentally benign approach for the site-selective functionalization of carbohydrates. Efforts to further expand the substrate scope and the investigation of the mechanism are underway in our laboratories.

EXPERIMENTAL

Thin layer chromatography was performed using precoated silica gel plates and visualized with UV light at 254 nm. Flash column chromatography was performed with silica gel (40-60 μm). ^{1}H and ^{13}C nuclear magnetic resonance spectra (NMR) were obtained on a Bruker Avance II 400 MHz or Bruker Avance III 500 MHz recorded in ppm (δ) downfield of TMS (δ=0) in $CDCl_3$ unless noted otherwise. Signal splitting patterns were described as singlet (s), doublet (d), triplet (t), quartet (q), quintet (quint), multiplet (m), and broad (br) with coupling constants (*J*) in hertz (Hz). High resolution mass spectra (HRMS) were performed by Agilent apparatus on an Electron Spray Injection (ESI) mass spectrometer. Melting points were determined by XP-4 melting point apparatus.

Starting Materials. The carbohydrates substrates were prepared by the appropriate literature reported.[12] All other chemicals used in this study were commercially available.

Typical Procedure for the Preparation of Methyl 4,6-*O*-Benzylidene-2-*O*-isobutyryl-α-D-glucopyranoside (10a): To a stirred solution of **9a** (0.1 mmol, 1 equiv, 28.2 mg) in $CHCl_3$ (1 mL,

0.1 M), was added catalyst **8** (0.01 mmol, 0.1 equiv, 11.2 mg), DIPEA (0.2 mmol, 2 equiv, 25.8 mg) and isobutyric anhydride (0.12 mmol, 1.2 equiv, 19 mg). Then the mixture was stirred for 24 h at ambient temperature. The resin was filtered from the mixture. Evaporation the filter liquor and purification by flash chromatography (gradient elution, 50% EtOAc/PE) afforded C2-acylation product **10a** (24.6 mg, 70%).

Methyl 4,6-*O*-benzylidene-2-*O*-isobutyryl-α-D-glucopyranoside (10a): Colorless oil. $[\alpha]_D^{22}$ +53.6 (*c* 0.25, CH_2Cl_2). ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 7.50-7.48 (m, 2H), 7.38-7.36 (m, 3H), 5.55 (s, 1H), 4.94 (d, *J* = 3.6 Hz, 1H), 4.78 (dd, *J* = 9.6, 4.0 Hz, 1H), 4.29 (dd, *J* = 10.0, 4.8 Hz, 1H), 4.18 (t, *J* = 9.6 Hz, 1H), 3.85-3.73 (m, 2H), 3.56 (t, *J* = 9.6 Hz, 1H), 3.39 (s, 3H), 2.68-2.64 (m, 1H), 1.21 (d, *J* = 2.4 Hz, 3H), 1.19 (d, *J* = 2.4 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 177.2, 137.2, 129.5, 128.6, 126.5, 102.3, 97.8, 81.6, 73.6, 69.1, 69.0, 62.3, 55.6, 34.0, 19.3, 19.0. The spectra are identical to the literature data.[7]

Methyl 4,6-*O*-isopropylidene-2-*O*-isobutyryl-α-D-glucopyranoside (10b): White solid, mp 133-135 °C. $[\alpha]_D^{22}$ +73.8 (*c* 1.2, CH_2Cl_2). ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 4.91 (d, *J* = 3.6 Hz, 1H), 4.73 (dd, *J* = 10.0, 4.0 Hz, 1H), 4.03 (dt, *J* = 9.6, 2.8 Hz, 1H), 3.90-3.86 (m, 1H), 3.76 (t, *J* = 10.0 Hz, 1H), 3.67-3.61 (m, 1H), 3.61-3.56 (m, 1H), 3.36 (s, 3H), 2.67-2.64 (m, 1H), 2.41 (d, *J* = 2.8 Hz, 1H), 1.52 (s, 3H), 1.45 (s, 3H), 1.20 (d, *J* = 2.0 Hz, 3H), 1.19 (d, *J* = 2.0 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 177.2, 100.1, 97.8, 74.3, 73.8, 69.4, 63.1, 62.5, 55.6, 34.0, 29.3, 19.4, 19.3, 19.0. HRMS (ESI) *m/z* calcd for $C_{14}H_{24}O_7$ $(M+Na)^+$ 327.1414, found 327.1414.

Methyl 4,6-*O*-methylidene-2-*O*-isobutyryl-α-D-glucopyranoside (10c): White solid, mp 118-120 °C. $[\alpha]_D^{22}$ +105.0 (*c* 1.03, CH_2Cl_2). ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 5.09 (d, *J* = 6.4 Hz, 1H), 4.91 (d, *J* = 3.6 Hz, 1H), 4.71 (dd, *J* = 9.6, 3.6 Hz, 1H), 4.65 (d, *J* = 6.4 Hz, 1H), 4.18-4.10 (m, 2H), 3.76-3.69 (m, 1H), 3.49 (t, *J* = 10.4 Hz, 1H), 3.38 (s, 3H), 3.30 (t, *J* = 9.6 Hz, 1H), 2.69-2.62 (m, 1H), 2.45 (d, *J* = 3.2 Hz, 1H), 1.21 (d, *J* = 1.6 Hz, 3H), 1.19 (d, *J* = 1.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 177.2, 97.8, 94.1, 81.3, 73.8, 69.0, 68.9, 62.4, 55.8, 34.1, 19.3, 19.0. The spectra are identical to the literature data.[7]

Methyl 4,6-*O*-(2-naphthalenylidene)-2-*O*-isobutyryl-α-D-glucopyranoside (10d): White solid, mp 50-52 °C. $[\alpha]_D^{22}$ +18.9 (*c* 1.45, CH_2Cl_2). ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 7.97 (s, 1H), 7.86-7.82 (m, 3H), 7.60 (d, *J* = 6.8 Hz, 1H), 7.50-7.48 (m, 2H), 5.71 (s, 1H), 4.96 (d, *J* = 3.2 Hz, 1H), 4.80 (dd, *J* = 7.6, 2.8 Hz, 1H), 4.35 (dd, *J* = 8.0, 3.6 Hz, 1H), 4.23 (t, *J* = 7.6 Hz, 1H), 3.91-3.87 (m, 1H), 3.82 (t, *J* = 8.4 Hz, 1H), 3.62 (t, *J* = 7.2 Hz, 1H), 3.40 (s, 3H), 2.70-2.64 (m, 1H), 2.44 (s, 1H), 1.21 (d, *J* = 2.4 Hz, 3H), 1.20 (d, *J* = 2.0 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 177.2, 134.6, 134.0, 133.1, 128.6, 128.5, 127.9, 126.7, 126.5, 126.1, 123.9, 102.4, 97.9, 81.7, 73.6, 69.2, 69.1, 62.3, 55.8, 34.1, 19.3, 19.1. HRMS (ESI) *m/z* calcd for $C_{22}H_{26}O_7$ $(M+Na)^+$ 425.1570, found 425.1572.

Methyl 4,6-*O*-(4-methoxyphenyl)methylene-2-*O*-isobutyryl-α-D-glucopyranoside (10e): White solid, mp 126-128 °C. $[\alpha]_D^{22}$ +40.6 (*c* 0.65, CH_2Cl_2). ^{1}H NMR (500 MHz, $CDCl_3$, TMS): δ 7.42 (d, *J* = 9.0 Hz,

2H), 6.89 (d, *J* = 9.0 Hz, 2H), 5.52 (s, 1H), 4.94 (d, *J* = 4.0 Hz, 1H), 4.78 (dd, *J* = 9.5, 3.5 Hz, 1H), 4.28 (dd, *J* = 10.5, 5.0 Hz, 1H), 4.18 (t, *J* = 11.5 Hz, 1H), 3.87-3.81 (m, 1H), 3.81 (s, 3H), 3.75 (t, *J* = 10.0 Hz, 1H), 3.55 (t, *J* = 9.5 Hz, 1H), 3.40 (s, 3H), 2.68-2.65 (m, 1H), 2.35 (s, 1H), 1.21 (d, *J* = 3.0 Hz, 3H), 1.20 (d, *J* = 3.0 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 177.2, 160.5, 129.7, 127.9, 113.9, 102.2, 97.8, 81.6, 73.6, 69.1, 69.0, 62.3, 55.8, 55.6, 34.0, 19.3, 19.0. The spectra are identical to the literature data.[7]

Methyl 4,6-*O*-(4-nitrophenyl)methylene-2-*O*-isobutyryl-α-D-glucopyranoside (10f): White solid, mp 153-155 ºC. $[\alpha]_D^{22}$ +47.4 (*c* 1.55, CH_2Cl_2). ^{1}H NMR (500 MHz, $CDCl_3$, TMS): δ 8.24 (d, *J* = 9.0 Hz, 2H), 7.69 (d, *J* = 9.0 Hz, 2H), 5.64 (s, 1H), 4.96 (d, *J* = 4.0 Hz, 1H), 4.77 (dd, *J* = 10.0, 4.0 Hz, 1H), 4.33 (dd, *J* = 10.0, 4.5 Hz, 1H), 4.20 (t, *J* = 9.5 Hz, 1H), 3.88-3.83 (m, 1H), 3.79 (t, *J* = 10.0 Hz, 1H), 3.60 (t, *J* = 9.0 Hz, 1H), 3.41 (s, 3H), 2.68-2.64 (m, 1H), 2.39 (s, 1H), 1.22 (d, *J* = 2.5 Hz, 3H), 1.20 (d, *J* = 2.5 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 177.2, 148.6, 143.6, 127.7, 123.7, 100.5, 97.9, 81.6, 73.7, 69.2, 69.0, 62.1, 55.9, 34.1, 19.3, 19.1. The spectra are identical to the literature data.[7]

Methyl 4,6-*O*-benzylidene-3-*O*-isobutyryl-α-D-glucopyranoside (11a): White solid, mp 206-207 ºC. $[\alpha]_D^{22}$ +88.8 (*c* 0.25, CH_2Cl_2). ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 7.45-7.42 (m, 2H), 7.36-7.33 (m, 3H), 5.50 (s, 1H), 5.32 (t, *J* = 9.6 Hz, 1H), 4.80 (d, *J* = 4.0 Hz, 1H), 4.31 (dd, *J* = 10.0, 4.8 Hz, 1H), 3.87-3.83 (m, 1H), 3.75 (t, *J* = 10.0 Hz, 1H), 3.66 (s, 1H), 3.60 (t, *J* = 10.0 Hz, 1H), 3.47 (s, 3H), 2.64-2.60 (m, 1H), 2.25 (s, 1H), 1.19 (d, *J* = 6.8 Hz, 3H), 1.19 (d, *J* = 6.4 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 177.5, 137.3, 129.2, 128.4, 126.2, 101.5, 100.4, 79.0, 72.3, 72.1, 69.2, 62.9, 55.8, 34.3, 19.3, 19.1. The spectra are identical to the literature data.[7]

Methyl 4,6-*O*-isopropylidene-3-*O*-isobutyryl-α-D-glucopyranoside (11b): Colorless oil. $[\alpha]_D^{22}$ +112.5 (*c* 0.95, CH_2Cl_2). ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 5.12 (t, *J* = 9.6 Hz, 1H), 4.76 (d, *J* = 4.0 Hz, 1H), 3.91-3.87 (m, 1H), 3.76-3.58 (m, 4H), 3.44 (s, 3H), 2.63-2.59 (m, 1H), 2.18 (s, 1H), 1.44 (s, 3H), 1.37 (s, 3H), 1.19 (s, 3H), 1.17 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 177.5, 100.4, 99.8, 72.7, 72.1, 71.8, 63.8, 62.7, 55.7, 34.4, 29.3, 19.4, 19.3, 19.0. HRMS (ESI) *m/z* calcd for $C_{14}H_{24}O_7$ $(M+Na)^+$ 327.1414, found 327.1413.

Methyl 4,6-*O*-methylidene-3-*O*-isobutyryl-α-d-glucopyranoside (11c): White solid, mp 135-137 ºC. $[\alpha]_D^{22}$ +110.2 (*c* 1.18, CH_2Cl_2). ^{1}H NMR (500 MHz, $CDCl_3$, TMS): δ 5.23 (t, *J* = 9.5 Hz, 1H), 5.03 (d, *J* = 6.5 Hz, 1H), 4.76 (d, *J* = 4.0 Hz, 1H), 4.57 (d, *J* = 6.5 Hz, 1H), 4.17 (dd, *J* = 10.0, 4.5 Hz, 1H), 3.78-3.72 (m, 1H), 3.64-3.59 (m, 1H), 3.48-3.44 (m, 4H), 3.31 (t, *J* = 9.5 Hz, 1H), 2.66-2.59 (m, 1H), 2.14 (d, *J* = 11.5 Hz, 1H), 1.20 (d, *J* = 7.0 Hz, 3H), 1.19 (d, *J* = 6.5 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 177.6, 100.3, 93.9, 79.0, 72.2, 72.0, 68.9, 63.1, 55.8, 34.3, 19.2, 19.1. The spectra are identical to the literature data.[7]

Methyl 4,6-*O*-(2-naphthalenylidene)-3-*O*-isobutyryl-α-D-glucopyranoside (11d): White solid, mp 208-210 ºC. $[\alpha]_D^{22}$ +93.4 (*c* 1.58, CH_2Cl_2). ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 7.92 (s, 1H), 7.84-7.81

(m, 3H), 7.55-7.46 (m, 3H), 5.66 (s, 1H), 5.35 (t, *J* = 10.0 Hz, 1H), 4.82 (d, *J* = 4.0 Hz, 1H), 4.36 (dd, *J* = 10.2, 4.8 Hz, 1H), 3.93-3.88 (m, 1H), 3.82 (t, *J* = 10.0 Hz, 1H), 3.72-3.63 (m, 2H), 3.48 (s, 3H), 2.67-2.59 (m, 1H), 2.23 (d, *J* = 11.6 Hz, 1H), 1.20 (d, *J* = 5.2 Hz, 3H), 1.18 (d, *J* = 5.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 177.5, 134.7, 133.8, 133.1, 128.6, 128.3, 127.9, 126.6, 126.4, 125.8, 123.9, 101.7, 100.5, 79.1, 72.3, 72.2, 69.3, 63.0, 55.9, 34.4, 19.4, 19.1. HRMS (ESI) *m/z* calcd for $C_{22}H_{26}O_7$ $(M+Na)^+$ 425.1570, found 425.1573.

Methyl 4,6-*O*-(4-methoxyphenyl)methylene-3-*O*-isobutyryl-α-D-glucopyranoside (11e): White solid, mp 164-166 ºC. $[\alpha]_D^{22}$ +95.0 (*c* 1.21, CH_2Cl_2) ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 7.35 (d, *J* = 8.8 Hz, 2H), 6.86 (d, *J* = 8.8 Hz, 2H), 5.46 (s, 1H), 5.30 (t, *J* = 10.0 Hz, 1H), 4.80 (d, *J* = 3.6 Hz, 1H), 4.29 (dd, *J* = 10.0, 4.8 Hz, 1H), 3.88-3.81 (m, 1H), 3.80 (s, 3H), 3.73 (t, *J* = 10.0 Hz, 1H), 3.69-3.62 (m, 1H), 3.58 (t, *J* = 9.6 Hz, 1H), 3.46 (s, 3H), 2.64-2.57 (m, 1H), 2.20 (d, *J* = 11.6 Hz, 1H), 1.18 (d, *J* = 7.2 Hz, 3H), 1.20 (d, *J* = 8.0 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 177.5, 160.3, 129.8, 127.6, 113.8, 101.5, 100.4, 79.0, 72.3, 72.2, 69.1, 63.0, 55.8, 55.5, 34.3, 19.3, 19.1. The spectra are identical to the literature data.[7]

Methyl 4,6-*O*-(4-nitrophenyl)methylene-3-*O*-isobutyryl-α-D-glucopyranoside (11f): White solid, mp 212-214 ºC. $[\alpha]_D^{22}$ +70.0 (*c* 0.90, CH_2Cl_2) ^{1}H NMR (500 MHz, $CDCl_3$, TMS): δ 8.21 (d, *J* = 9.0 Hz, 2H), 7.60 (d, *J* = 8.5 Hz, 2H), 5.56 (s, 1H), 5.32 (t, *J* = 10.0 Hz, 1H), 4.81 (d, *J* = 3.5 Hz, 1H), 4.34 (dd, *J* = 10.0, 4.5 Hz, 1H), 3.88-3.84 (m, 1H), 3.77 (t, *J* = 10.0 Hz, 1H), 3.70-3.65 (m, 1H), 3.62 (t, *J* = 9.5 Hz, 1H), 3.48 (s, 3H), 2.65-2.62 (m, 1H), 2.18 (d, *J* = 11.5 Hz, 1H), 1.20 (d, *J* = 7.0 Hz, 3H), 1.18 (d, *J* = 7.0 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 177.4, 148.5, 143.6, 127.4, 123.6, 100.4, 99.9, 79.1, 72.1, 72.0, 69.2, 62.7, 55.9, 34.3, 19.4, 19.1. The spectra are identical to the literature data.[7]

ACKNOWLEDGEMENTS

This work was supported by grants from the National Natural Science Foundation of China (21702025), the Natural Science Foundation of Liaoning Province (20180550576), and the Fundamental Research Funds for the Central Universities (DUT18LK25).

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