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Synthesis and structural analysis of a series of D-glucose derivatives as low molecular weight gelators

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ABSTRACT

Low molecular weight gelators are an interesting new type of compounds that are important in supramolecular chemistry and advanced materials. Previously, we had synthesized several acyl derivatives of methyl 4,6-*O*-benzylidene-α-D-glucopyranoside and found that a number of terminal acetylene-containing esters are good gelators. To understand the structure requirement of the acyl chains, we synthesized a series of analogs containing different functional groups including aryl, alkenyl, and halogen derivatives. X-ray crystal structures of a monoester and a diester derivative were also obtained to help understand the relationship between structure and gelation. For good gelation properties, the carboxyl derivatives should possess alkyl groups containing a terminal acetylene group and aryl derivatives.

1. Introduction

Low molecular weight organogelators and hydrogelators are an interesting new class of compounds that have drawn great attention over the past few decades.[1–4] The gelation properties of these compounds are determined by their structures and modes of self-organization in various solvents. The driving forces for the formation of the physical gels are non-covalent intermolecular forces. These include hydrogen bonding, electrostatic interactions, van der Waals interaction, and π–π stacking. The potential applications of these compounds in various fields have also propelled their further development. These include their uses in enzyme immobilization,[5] drug-delivery systems,[6–9] and advanced nanomaterials.[3,4,10–12] There is a great diversity among the structures of organogelators and hydrogelators. Amino acids and carbohydrates are often used as the building blocks for low molecular weight gelators. Many research efforts have been devoted to the preparation and characterization of effective hydrogelators[13–27] and to their potential applications.[28–32] Low molecular weight hydrogelators are particularly interesting because they can form hydrogels that lend themselves to many applications. Among the different types of organo/hydrogelators, carbohydrate-derived gelators are of particular interest to us because of their unique nature. Sugar-based systems have been used by many research groups in the preparation of low molecular weight gelators.[33–47] Sugars contain polar hydroxyl groups that can be utilized as hydrogen bond donors or be functionalized to form useful self-assembling aggregates. Carbohydrate-based hydrogelators have intrinsic chirality, which could lend themselves to applications in ferroelectric liquid crystals or separation of biologically important agents such as proteins and DNA. Furthermore, hydrogels formed by carbohydrate derivatives are biocompatible. This is important for potential biomedical applications.

Previously, we had synthesized several sugar derivatives and found that short chain esters of methyl 4,6-*O*-benzylidene-α-D-glucopyranoside are good gelators for hexane, ethanol, and an ethanol–water mixture.[46] These esters were synthesized by an acylation reaction of the sugar headgroup with α,ω alkynyl acids. Compounds **1**–**3** are representative structures of the three classes of organo/hydrogelators we have synthesized. These compounds contain a short alkynyl chain, which is 5-carbons in length. These are effective gelators for the tested solvents including hexane, ethanol, and aqueous solutions. The 5–7 carbon monoalkynyl esters are good hydrogelators. Several carbamoyl derivatives containing 5 or 7 carbon alkyl chains were also synthesized, and the monocarbamates are also excellent gelators.[46]

In addition to the short chain derivatives, we had also prepared a series of long chain ester derivatives containing diacetylene functional groups and found that these compounds can form gels in ethanol–water mixtures.[47] To understand the structural requirements of the acyl chains for good gelators and gelation properties of these simple carbohydrate derivatives, we synthesized and characterized a series of additional compounds containing different functional groups, including methacryloyl, alkenyl, halogen, and aryl derivatives. Methacrylate-containing gelators can be polymerized and lead to potentially new materials.[48–52]

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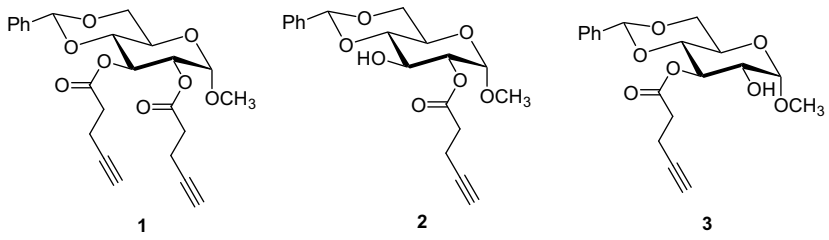


2. Results and discussion

To understand the structure and gelation property correlations, especially the tolerance of acyl chain substituents of these simple sugar derivatives (**1–3**), we synthesized a series of ester analogs by a one-pot reaction using conditions similar to those reported before.[46] The structures of these compounds are shown in Figure 1. To determine the role of the terminal acetylene group in the self-assembly process, we synthesized several analogs with similar chain lengths as those in the good gelators **1**–**3**. These include compounds **5a–8c** with chloro-substituents, terminal alkenyl, saturated hydrocarbon, and branched alkyl chains. Compounds **9** and **10** contain 8 and 10 carbon acyl chains, and compound **11** contains polymerizable methacrylate group. Compounds **12–13** contain aromatic substituents.

After obtaining purified compounds, their gelation properties in several solvents (hexane, water, ethanol and 1:1 water–ethanol) were tested. The results for various ester derivatives of **4** are shown in Table 1. These are listed according to their derivatization patterns on the sugar ring so that we can compare the influence of the acyl chains.

Previously, we had found that compounds containing long diacetylene chains and short mono acetylene chains exhibit good gelation properties in organic solvents or water. Here, we found that the straight-chain derivatives and compounds with double bonds, branched alkyl group, and chloro substituents are generally not gelators in the same solvents tested: hexane, water, and an ethanol–water mixture. Among the diesters with aliphatic acyl chains (**5a–11a**), except **6a**, none showed gelation in any of the four solvents. The saturated alkyl chains tend to pack in a tighter order compared to the alkynyl chains, thus leading to precipitation from solution. The alkyne group disrupts the packing order, thereby hindering the precipitation. However, for the benzoate and naphthoate derivatives, they were able to gelate in an 1:1 ethanol–water mixture at 5 and 7 mg/mL, respectively. Aromatic π–π stacking plays an important role here, and presumably, hydrogen bonding between the diester and the solvent hydroxyl groups also contributed to the gelation. These resemble the behavior of long chain diacetylene-containing compounds, which were also able to form gels in the ethanol–water mixture. The dimethacrylate **11a** did not form gels in the solvents tested. However, we were able to obtain a single crystal X-ray structure of the dimethacrylate (recrystallized from ethanol and acetone mixture) as shown in Figure 2. The two acyl chains are extending from the six-membered ring and the phenyl group appears to occupy the equatorial position. When the acyl chains are longer or contain aromatic substituents, they can affect the gelation properties by hydrophobic interaction and π−π stacking. However, when they are short chain derivatives, they are not able to form gels in aqueous solution.

For the 2-monoesters **5b**–**13b**, and 3-monoesters **5c**–**12c**, the compounds with C=C bonds and aryl substituents showed promising gelation results. Compound **6b** contains a terminal alkene group and it also does not gelate hexane or ethanol. However, it can form unstable gels in water. The terminal double bond is less structurally rigid compared to a triple bond. This may have accounted for the observed gelation differences. The 3-chloro-butanoate **5c** was able to form opaque gels in pure water. The 2-methacrylate **11b** can gelate in pure water at about 2 wt %, and the 3-ester **11c** can form gels in an ethanol–water mixture at ~1 wt %. This follows the same trend as we observed in the monoacetylene lipids that short acyl chains lead to good gelators. For aryl derivatives, the mono benzoates **12b** and **12c** do not form gels in the solvents tested. However, the 2-naphthoate monoester **13b** can form gels in aqueous mixtures, perhaps due to the fact that π–π stacking among the naphthoyl groups is the main driving force for gelation. There may also be hydrogen bonding between the hydroxyl group of the solvents with the oxygen from compound **13b**. If the 3-naphthalene derivative **13c** can be prepared, it is expected to be able to gelate ethanol water as well. However, during the esterification reaction, the reaction is quite regioselective favoring the 2-position.

To understand the structural requirements of 2-monoesters as hydrogelators, we obtained a single crystal X-ray structure of the analogous sugar lipid, the 2-chloro-butanoate derivative **5b**. The crystal structure is shown in Figure 3. Hydrogen bonding between the 3-hydroxyl group and the anomeric oxygen forms a one-dimensional array (Fig. 3b). In organic solvents, hydrogen bonding is important for gelation. In aqueous solutions, hydrogen bonding becomes unimportant, the hydrophobic interaction is the driving

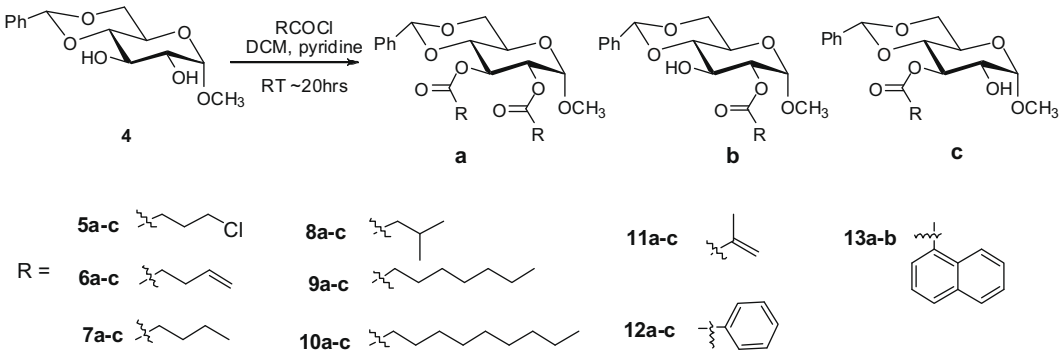
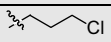
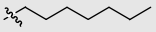
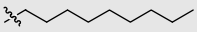
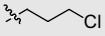
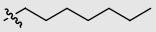
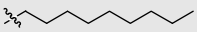
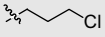
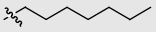
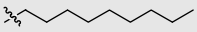


Figure 1. Structures of the synthesized diesters (a) and monoesters (b, c) .

Table 1
Gelation results of diesters (a), mono esters (b), and mono esters (c), the numbers shown are positive gelation concentrations in mg/mL[a]

Compound	R=	Hexane	H_2O	EtOH	EtOH/H_2O (1:1)
5a		P	I	S	P
6a		P	I	S	G* 10
7a		P	I	P	P
8a		S	I	S	P
9a		S	I	S	P
10a		S	I	S	I
11a		S	I	S	P
12a		P	I	S	G 5
13a		P	I	S	G 7
5b		P	P	S	S
6b		P	G* 12	S	S
7b		G 15	P	S	S
8b		P	S	S	S
9b		S	P	S	P
10b		P	P	S	P
11b		P	G* 20	S	S
12b		P	P	S	P
13b		I	I	S	G 10
5c		P	G 7	S	P
6c		P	P	S	P
7c		S	P	S	P
8c		P	P	S	P
9c		P	P	S	P
10c		S	P	S	P
11c		I	I	S	G* 9
12c		P	P	P	P

[a] G: stable gel, G*: unstable gel, I: insoluble, P: precipitate, S: soluble at 20 mg/mL.

force for gelation. The crystal structure can help us to understand the gelation properties of the alkynyl esters. It is safe to estimate that the terminal acetylene derivatives would also assemble in a similar fashion and form one-dimensional hydrogen bonded arrays, as in **5b** as they are very similar in structure. However, the packing of the alkynyl chains is not as ordered as in **5b**, therefore they do not crystallize or precipitate, and form gels instead.

Because a balance between hydrophilicity and hydrophobicity is necessary for gelation, we compared the CLogP (partition coefficient in water and octanol) values of several compounds with the same chain length; these are shown in Chart 1. This analysis shows an interesting trend versus gelation properties in water. Compounds **2b**, **6b**, and **11b** are able to form gels in water, and their CLogP values are below 1.2; here, **2b** has the lowest CLogP and is

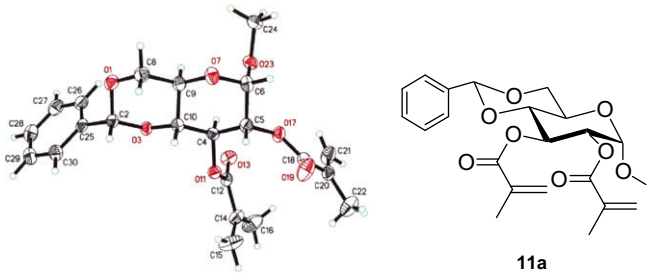


Figure 2. X-ray crystal structure of compound **11a**.

the most efficient hydrogelator among these three. The saturated alkyl derivatives **8b** and **7b** have higher CLogP values (>1.5), and they are not gelators in water. This trend indicates that, for similar structures, when considering structural modifications on the alkyl chains, the CLogP values can perhaps be used to help predict the gelation possibility in water.

We also characterized the morphologies of the dried gels formed by several compounds; some of these are shown in Figure 4. The morphology showed dependence on the structure of the gelators. The methacrylate derivatives **11b** and **11c** generally formed a long fibrous network type of structures as shown in Figures 4a–e; the fibers are narrow, long and curved slightly. The SEM image of part of the tubular-shaped rod showed that it is formed by a bundle of much smaller fibers (Fig. 4c). Compound **11c** formed similar morphologies (Figs. 4d–e), somewhat more uniform in width than the other ester **11b**. The di-naphthalene derivative **13a** formed more rigid and larger tubular type of structures in wider diameter and straight manner (Fig. 4f). The mono-naphthalene derivative **13b** formed a softer fibrous assembly, which has smaller diameters and is somewhat softer and showed bending when a few strands of fibrous cross path (Fig. 4g–i). This reflects that in compound **13b**, which has only one naphthalene group, the $\pi-\pi$ stacking interaction is not as strong as in **13a**, therefore it forms a less rigid tubular network in aqueous solution.

3. Conclusions

We have synthesized a series of acyl derivatives of a simple sugar headgroup and analyzed the influence of the acyl chains on the gelation properties. For ester derivatives with similar chain length, the acyl chains give the best gelation results when they contain a terminal acetylene function. Halide and saturated alkyl chains do not gelate in hexane, ethanol, or ethanol–water mixture; aryl and alkenyl derivatives give favorable gelation results in aqueous solutions. X-ray crystal structures of a diester and a monoester gave some insight into how they assemble in solution phase. The trends observed here for gelation properties can be used in the design of other hydrogelators.

4. Experimental

4.1. General methods

4.1.1. Gelation testing

The compounds were tested in a 1 dram vial with a rubber-lined screw cap from Kimble. Approximately 2–4 mg of each purified product and solvent were added into the vial. A starting concentration of ~20 mg/mL was used. The mixture was heated to dissolve the compound (to give a homogeneous solution) and was sonicated, if necessary. The solution was allowed to cool for 15–20 min. Then the vial was inverted, if no liquid flowed and if the gels stayed at the bottom end of the upside down vial, the gel was said to be stable. If a stable gel formed, serial dilution was performed to find the minimum gelation concentration (MGC).

4.1.2. Optical microscopy

A small amount of the gel was placed on a clean glass slide and was air-dried overnight. The xerogels were observed with an Olympus BX60M optical microscope using a DSP Color Hi-Res EXvision camera and an Olympus U-TV1X lens. The program used to acquire and store the photos was Corel Photo-Paint 7.

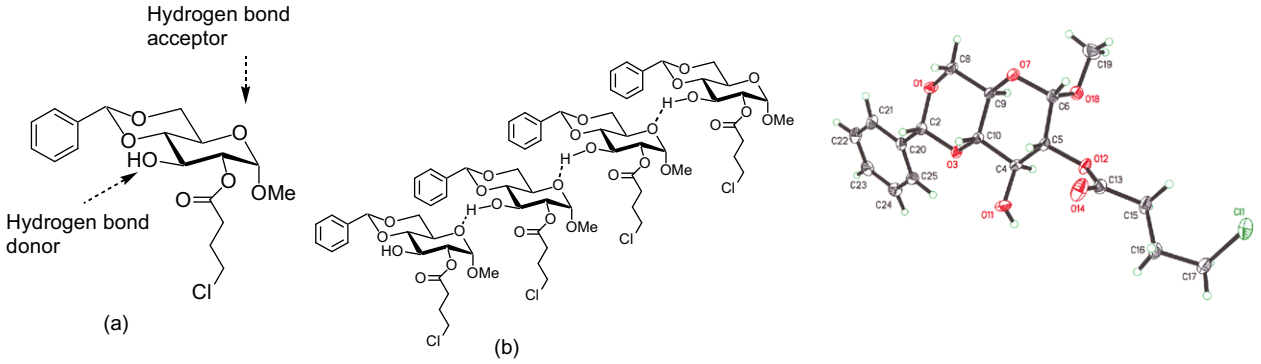


Figure 3. X-ray crystal structure of 4-chlorobutanoate monoester **5b**. The monoester derivative (a) contains a hydrogen bond acceptor and donor, which enables them to form one-dimensional bonding networks (b).

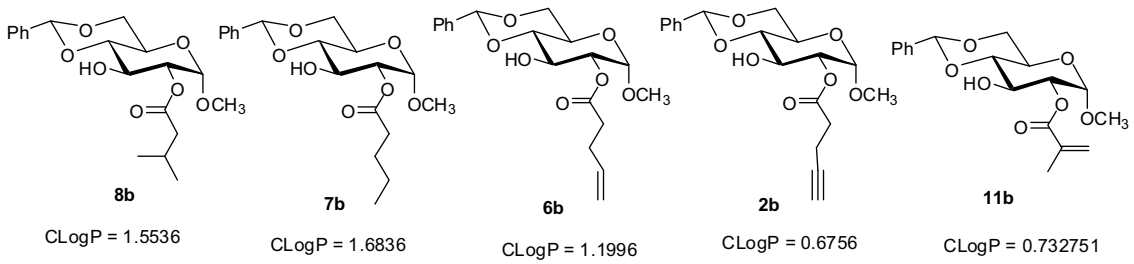


Chart 1. The CLogP values of several monoesters with similar chain length.

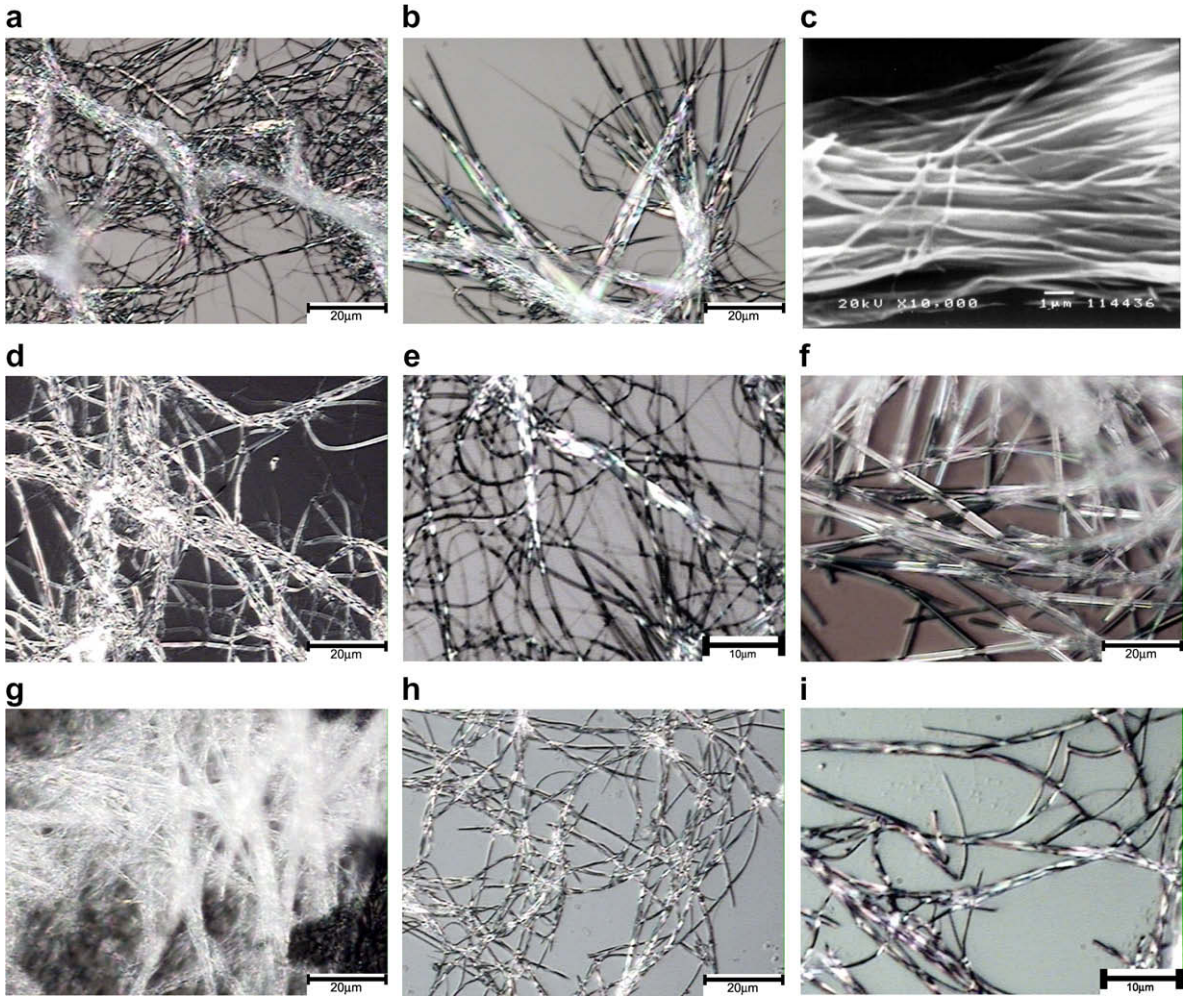


Figure 4. Optical micrographs (a, b, d–i) and scanning electron micrograph (c) of dried gels formed by compounds **11b**, **11c**, **13a**, **13b**. (a–c) Gels by **11b** in water, 20 mg/mL, (d, e) gels by **11c** from EtOH–H_2O, 1:1 at 9 mg/mL; (f) gels by **13a** from EtOH–H_2O, 1:1 at 7 mg/mL; (g–i) gels formed by **13b** in EtOH–H_2O, 1:1 at 10 mg/mL.

4.1.3. Scanning electron microscopy

Samples were prepared by drying the gel (20–30 μL) on an aluminum pellet in a desiccator under reduced pressure for several days. A thin layer of platinum was deposited onto the pellet by a Denton Vacuum (model Desk II) at a reduced pressure of ~30 mtorr and a current of 45 mA for 60 s. The sample was analyzed using a JEOL JSM 5410 scanning microscope with an EDAX Detecting Unit PV9757/05.

4.2. Synthesis of compounds 5–13a–c

4.2.1. General procedure

Compound **4** (1–4 mmol) and 3–4 equiv of anhydrous pyridine, and anhydrous dichloromethane (DCM, 5–10 mL) were mixed in a round-bottom flask. The flask was protected with a calcium chloride drying tube and was cooled to 0–5 °C in an ice bath. The acid chloride (1.3 equiv) was added to the reaction mixture. If the acid chloride was not commercially available, it was prepared by treating the corresponding carboxylic acid with oxalyl chloride. The temperature was warmed to room temperature and stirred for 20 h. The reactions were quenched by dilution with ~10 mL of DCM, and then washed with water (2 × 5 mL) and 5% cold $NaHCO_3$ solution. The combined aqueous phase was extracted with 2 mL of DCM, and the combined organic phase was dried over anhydrous Na_2SO_4. The crude reaction mixtures were purified by flash chromatography on silica gel using various gradients of hexanes and acetone (19–9:1). The products are generally eluted in the order of diester, 2-monoester, and 3-monoester. The characterization data for the compounds synthesized are listed below.

4.2.2. Methyl 4,6-*O*-benzylidene-2,3-di-*O*-(4′-chlorobutanoyl)–α-D-glucopyranoside (5a)

Compound **5a** was isolated in 16% yield as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41–7.46 (m, 2H), 7.32–7.37 (m, 3H), 5.61 (t, 1H, J = 9.9 Hz), 5.51 (s, 1H), 4.96 (d, 1H, J = 3.7 Hz), 4.92 (dd, 1H, J = 3.7, 9.9 Hz), 4.31 (dd, 1H, J = 4.8, 10.3 Hz), 3.93 (ddd~dt, 1H, J = 4.8, 9.5, 10.3 Hz), 3.78 (t, 1H, J = 10.3 Hz), 3.66 (dd~t, 1H, J = 9.5, 9.9 Hz), 3.59 (t, 2H, J = 6.4 Hz), 3.53 (t, 2H, J = 6.4 Hz), 3.42 (s, 3H), 2.44–2.60 (m, 4H), 2.00–2.14 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 171.9, 171.4, 136.7, 128.9, 128.0, 125.9, 101.3, 97.3, 78.9, 71.4, 68.8, 68.5, 62.1, 55.2, 43.7, 43.6, 30.8, 30.7, 27.2, 27.1. HRMS calcd for $C_{22}H_{29}O_8Cl_2$ $[M+H]^+$ 491.1239, found 491.1243.

4.2.3. Methyl 4,6-*O*-benzylidene-2-*O*-(4′-chlorobutanoyl)–α-D-glucopyranoside (5b)

Compound **5b** was isolated as off-white crystals in 62% yield. Mp 75.2–76.1 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46–7.51 (m, 2H), 7.34–7.40 (m, 3H), 5.52 (s, 1H), 4.93 (d, 1 H, J = 3.9 Hz), 4.80 (dd, 1H, J = 3.9, 9.8 Hz), 4.28 (dd, 1H, J = 3.9, 9.8 Hz), 4.13 (t, 1H, J = 9.8 Hz), 3.82 (dt, 1H, J = 4.9, 9.8 Hz), 3.73 (dd~t, 1H, J = 9.8, 10.7 Hz), 3.59 (t, 2H, J = 6.4 Hz), 3.51 (t, 1H, J = 9.8 Hz), 3.38 (s,

3H), 2.86 (br s, 1H), 2.58 (t, 2H, J = 7.3 Hz), 2.09 (p, 2H, J = 6.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.3, 136.8, 129.2, 128.2, 126.2, 101.8, 97.3, 81.2, 73.4, 68.7, 68.4, 61.9, 55.3, 43.8, 31.0, 27.4. HRMS calcd for $C_{18}H_{24}O_7Cl$ $[M+H]^+$ 387.1211, found 387.1205.

4.2.4. Methyl 4,6-*O*-benzylidene-3-*O*-(4′-chlorobutanoyl)–α-D-glucopyranoside (5c)

Compound **5c** was isolated as off-white crystals in 10% yield. Mp 154.4–155.1 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41–7.46 (m, 2H), 7.33–7.38 (m, 3H), 5.50 (s, 1H), 5.34 (t, 1H, J = 9.9 Hz), 4.81 (d, 1H, J = 3.7 Hz), 4.31 (dd, 1H, J = 4.8, 10.3 Hz), 3.87 (dt, 1H, J = 4.8, 9.9 Hz), 3.75 (t, 1H, J = 10.3 Hz), 3.70–3.63 (m, 1H), 3.59 (t, 1H, J = 9.5 Hz), 3.55 (t, 2H, J = 6.4 Hz), 3.47 (s, 3H), 2.57 (t, 2H, J = 7.1 Hz), 2.20 (d, 1H, J = 11.7 Hz), 2.10 (p, 2H, J = 6.6 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 172.7, 136.9, 129.1, 128.2, 126.1, 101.5, 100.1, 78.6, 72.4, 71.7, 68.9, 62.7, 55.6, 43.8, 31.4, 27.8. HRMS calcd for $C_{18}H_{24}O_7Cl$ $[M+H]^+$ 387.1213, found 387.1211.

4.2.5. Methyl 4,6-*O*-benzylidene-2,3-di-*O*-(4′-pentenoyl)–α-D-glucopyranoside (6a)

The diester **6a** was obtained as a clear oil in 50% yield. ^{1}H NMR, (250 MHz, $CDCl_3$) δ 7.41–7.51 (m, 2H), 7.30–7.40 (m, 3H), 5.79 (m, 2H), 5.64 (t, 1H, J = 9.6 Hz), 5.51 (s, 1H), 5.02–5.12 (m, 2H), 4.87–5.01 (m, 4H), 4.31 (dd, 1H, J = 4.7, 10.1 Hz), 3.94 (dt, 1H, J = 4.7, 9.9 Hz), 3.77 (t, 1H, J = 10.1 Hz), 3.66 (t, 1H, J = 9.6 Hz), 3.40 (s, 3H), 2.26–2.51 (m, 8H); ^{13}C NMR (62.5 MHz, $CDCl_3$) δ 172.2, 171.5, 136.8, 136.2, 136.1, 128.9, 128.0, 126.0, 115.5, 115.4, 101.4, 97.5, 79.1, 71.4, 68.7, 62.2, 55.2, 33.3, 33.1, 28.6, 28.5. HRMS calcd for $C_{24}H_{31}O_8$ $[M+H]^+$ 447.2019, found 447.1976.

4.2.6. Methyl 4,6-*O*-benzylidene-2-*O*-(4′-pentenoyl)–α-D-glucopyranoside (6b)

The ester **6b**[53] was isolated as viscous oil in a yield of 35%. ^{1}H NMR (250 MHz, $CDCl_3$) δ 7.45–7.55 (m, 2H), 7.33–7.43 (m, 3H), 5.85 (m, 1H), 5.55 (s, 1H), 5.98–5.14 (m, 2H), 4.94 (d, 1H, J = 3.9 Hz), 4.80 (dd, 1H, J = 3.9, 9.6 Hz), 4.30 (m, 1H), 4.18 (dd∼t, 1H, J = 9.6 Hz), 3.85 (m, 1H), 3.76 (dd∼t, 1H, J = 9.1, 10.1 Hz), 3.56 (t, 1H, J = 9.1 Hz), 3.39 (s, 3H), 2.46–2.58 (m, 2H), 2.34–2.46 (m, 2H); ^{13}C NMR (62.5 MHz, $CDCl_3$) δ 172.7, 137.0, 136.5, 129.3, 128.3, 126.3, 115.6, 102.0, 97.6, 81.3, 73.6, 68.8, 68.6, 62.0, 55.4, 33.3, 28.8. HRMS calcd for $C_{19}H_{24}O_7Na$ $[M+Na]^+$ 387.1420, found 387.1407.

4.2.7. Methyl 4,6-*O*-benzylidene-3-*O*-(4′-pentenoyl)–α-D-glucopyranoside (6c)

The ester **6c** was isolated as a white solid in a yield of 9%. Mp 152.0–154.3 °C. ^{1}H NMR (250 MHz, $CDCl_3$) δ 7.40–7.47 (m, 2H), 7.31–7.38 (m, 3H), 5.80 (m, 1H), 5.49 (s, 1H), 5.34 (t, 1H, J = 9.6 Hz), 5.02 (m, 1H), 4.91 (m, 1H), 4.81 (d, 1H, J = 4.1 Hz), 4.31 (dd, 1H, J = 4.1, 9.6 Hz), 3.87 (m, 1H), 3.76 (m, 1H), 3.68 (m, 1H), 3.58 (dd∼t, 1H, J = 9.1, 9.6 Hz), 3.47 (s, 3H), 2.31–2.53 (m, 4H), 2.20 (d, 1H, J = 11.4 Hz); ^{13}C NMR (62.5 MHz, $CDCl_3$) δ 173.0, 136.9, 136.4, 128.9, 128.1, 126.1, 115.4, 101.4, 100.1, 78.6, 72.1, 71.7, 68.8, 62.7, 55.5, 33.5, 28.8. HRMS calcd for $C_{19}H_{25}O_7$ $[M+H]^+$ 365.1600, found 365.1593.

4.2.8. Methyl 4,6-*O*-benzylidene-2,3-di-*O*-pentanoyl–α-D-glucopyranoside (7a)

Compound **7a** was isolated as an oil in 5% yield. ^{1}H NMR (250 MHz, $CDCl_3$) δ 7.39–7.47 (m, 2H) 7.30–7.37 (m, 3H), 5.61 (t, 1H, J = 9.6 Hz), 5.50 (s, 1H), 4.86–4.96 (m, 2H), 4.30 (dd, 1H, J = 4.7, 9.9 Hz), 3.93 (dt, 1H, J = 4.7, 9.6 Hz), 3.77 (dd∼t, 1H, J = 10.3 Hz), 3.64 (t, 1H, J = 9.6 Hz), 3.40 (s, 3H), 2.31 (m, 4H), 1.58 (m, 4H), 1.31 (m, 4H), 0.91 (t, 3H, J = 7.3 Hz), 0.83 (t, 3H, J = 7.3 Hz); ^{13}C NMR (62.5 MHz, $CDCl_3$) δ 173.2, 172.5, 136.9, 129.0, 128.1, 126.1, 101.5, 97.7, 79.3, 71.4, 68.8, 68.5, 62.3, 55.4, 33.8, 27.1, 26.9, 22.1, 22.0, 13.6. HRMS calcd for $C_{24}H_{35}O_8$ $[M+H]^+$ 451.2332, found 451.2327.

4.2.9. Methyl 4,6-*O*-benzylidene-2-*O*-pentanoyl–α-D-glucopyranoside (7b)

Compound **7b** was isolated as white crystals in a 44% yield. Mp 124.3–125.2 °C. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.45–7.53 (m, 2H) 7.33–7.42 (m, 3H), 5.54 (s, 1H), 4.95 (d, 1H, J = 3.6 Hz), 4.79 (dd, 1H, J = 3.6, 9.6 Hz), 4.29 (dd, 1H, J = 3.9 Hz, 9.8), 4.16 (t, 1H, J = 9.6 Hz), 3.84 (m, 1H), 3.75 (dd∼t, 1H, J = 10.1Hz), 3.54 (dd∼t, 1H, J = 9.2 Hz), 3.39 (s, 3H), 2.56 (br s, 1H), 2.41 (t, 2H, J = 7.5 Hz), 1.64 (p, 2H, J = 7.4 Hz), 1.36 (h, 2H, J = 7.4 Hz), 0.92 (t, 3H, J = 7.3 Hz); ^{13}C NMR (62.5 MHz, $CDCl_3$) δ 173.5, 136.9, 129.2, 128.3, 126.2, 101.9, 97.5, 81.3, 73.3, 68.8, 68.6, 61.9, 55.3, 33.8, 26.9, 22.0, 13.6. HRMS calcd for $C_{19}H_{27}O_7$ $[M+H]^+$ 367.1757, found 367.1752.

4.2.10. Methyl 4,6-*O*-benzylidene-3-*O*-pentanoyl–α-D-glucopyranoside (7c)

Compound **7c** was isolated as white needles in 11% yield. Mp 178.1–178.7 °C. ^{1}H NMR (250 MHz, $CDCl_3$) δ 7.39–7.47 (m, 2H), 7.30–7.38 (m, 3H), 5.49 (s, 1H), 5.33 (t, 1H J = 9.6 Hz,), 4.80 (d, 1H, J = 4.1 Hz), 4.30 (dd, 1H, J = 4.6, 10.1 Hz), 3.86 (m, 1H), 3.75 (t, 1H, J = 10.1 Hz), 3.66 (m, 1H), 3.59 (dd∼t, 1H, J = 9.1, 9.6 Hz), 3.47 (s, 3H), 2.37 (t, 2H, J = 7.6 Hz), 2.26 (br s, 1H), 1.61 (p, 2H, J = 7.6 Hz), 1.31 (h, 2H, J = 7.8 Hz), 0.85 (t, 3H, J = 7.3 Hz); ^{13}C NMR (62.5 MHz, $CDCl_3$) δ 174.0, 137.0, 129.0, 128.2, 126.1, 101.4, 100.1, 78.7, 72.0, 71.8, 68.9, 62.7, 55.6, 34.1, 27.1, 22.0, 13.6. HRMS calcd for $C_{19}H_{27}O_7$ $[M+H]^+$ 367.1757, found 367.1746.

4.2.11. Methyl 4,6-*O*-benzylidene-2,3-di-*O*-(3′-methylbutanoyl)–α-D-glucopyranoside (8a)

Diester **8a** was isolated as a clear oil in 3% yield. ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.40–7.46 (m, 2H), 7.31–7.37 (m, 3H), 5.63 (t, 1H, J = 9.9 Hz), 5.50 (s, 1H), 4.97 (d, 1H, J = 3.7 Hz), 4.89 (dd, 1H, J = 3.7, 9.9 Hz), 4.31 (dd, 1H, J = 4.8, 10.3 Hz), 3.93 (dt, 1H, J = 4.8, 9.9 Hz), 3.77 (t, 1H, J = 10.3 Hz), 3.64 (t, 1H, J = 9.5 Hz), 3.39 (s, 3H), 2.14-2.25 (m, 4H), 2.00–2.14 (m, 2H), 0.94 (d, 6H, J = 6.6 Hz), 0.89 (d, 6H, J = 6.2 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 172.5, 171.7, 137.0, 128.9, 128.1, 126.0, 101.4, 97.6, 79.4, 71.4, 68.8, 68.3, 62.3, 55.3, 43.3, 43.1, 25.8, 25.7, 22.2. HRMS calcd for $C_{24}H_{35}O_8$ $[M+H]^+$ 451.2332, found 451.2315.

4.2.12. Methyl 4,6-*O*-benzylidene-2-*O*-(3′-methyl-butanoyl)–α-D-glucopyranoside (8b)

Compound **8b** was isolated as a crystalline white solid in 41% yield. Mp 113.1–113.8 °C. ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.45–7.52 (m, 2H), 7.32–7.40 (m, 3H), 5.52 (s, 1H), 4.94 (d, 1H, J = 3.7 Hz), 4.78 (dd, 1H, J = 3.7, 9.5 Hz), 4.27 (dd, 1H, J = 4.4, 9.9 Hz), 4.14 (t, 1H, J = 9.5 Hz), 3.82 (m, 1H), 3.73 (t, 1H, J = 10.3 Hz), 3.52 (dd∼t, 1H, J = 9.2, 9.5 Hz), 3.37 (s, 3H), 2.92 (br s, 1H), 2.28 (d, 2H, J = 7.0 Hz), 2.13 (m, 1H), 0.98 (d, 6H, J = 6.6 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 172.7, 136.9, 129.2, 128.2, 126.2, 101.8, 97.5, 81.3, 73.2, 68.7, 68.4, 61.9, 55.2, 43.1, 25.7, 22.1. HRMS calcd for $C_{19}H_{27}O_7$ $[M+H]^+$ 367.1757, found 367.1742.

4.2.13. Methyl 4,6-*O*-benzylidene-3-*O*-(3′-methyl-butanoyl)–α-D-glucopyranoside (8c)

Compound **8c** was isolated as a white solid in 14% yield. Mp 161.7–162.8 °C. ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.38–7.46 (m, 2H), 7.30–7.36 (m, 3H), 5.48 (s, 1H), 5.32 (t, 1H, J = 9.5 Hz), 4.79 (d, 1H, J = 3.7 Hz), 4.29 (dd, 1H, J = 4.8, 9.9 Hz), 3.85 (m, 1H, J = 4.8, 9.9 Hz), 3.74 (t, 1H, J = 10.3 Hz), 3.64 (m, 1H, J = 3.7, 9.5 Hz), 3.57 (t, 1H, J = 9.5 Hz), 3.45 (s, 3H), 2.23 (d, 2H, J = 7.0 Hz), 2.08 (m, 1H), 0.91 (d, 6H, J = 6.6 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 173.3, 136.9, 129.0, 128.1, 126.0, 101.4, 100.2, 78.7, 71.9, 71.6, 68.9,

62.6, 55.6, 43.5, 25.9, 22.2. HRMS calcd for $C_{19}H_{26}O_7Na$ $[M+Na]^+$ 389.1576, found 389.1570.

4.2.14. Methyl 4,6-*O*-benzylidene-2,3-di-*O*-octanoyl–α-D-glucopyranoside (9a)

Compound **9a** was isolated as a white powder in 35% yield. Mp 46.9–48.7 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40–7.46 (m, 2H), 7.30–7.36 (m, 3H), 5.61 (t, 1H, J = 9.8 Hz), 5.50 (s, 1H), 4.94 (d, 1H, J = 2.9 Hz), 4.91 (dd, 1H, J = 4.8, 9.8 Hz), 4.30 (dd, 1H, J = 4.9 Hz, 10.7), 3.92 (dt, 1H, J = 4.8, 9.8 Hz), 3.76 (dd∼t, 1H, J = 9.8, 10.7 Hz), 3.64 (t, 1H, J = 9.8 Hz), 3.39 (s, 3H), 2.30 (m, 4H), 1.59 (m, 4H), 1.10–1.36 (m, 16H), 0.84 (m, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.1, 172.4, 136.8, 128.9, 128.0, 126.0, 101.3, 97.6, 79.2, 71.3, 68.7, 68.5, 62.2, 55.2, 34.2, 34.0, 31.6, 31.5, 28.9, 28.8, 25.0, 24.8, 22.5, 13.9. HRMS calcd for $C_{30}H_{46}O_8Na$ $[M+Na]^+$ 557.3090, found 557.3066.

4.2.15. Methyl 4,6-*O*-benzylidene-2-*O*-octanoyl–α-D-glucopyranoside (9b)

Compound **9b**[54] was isolated as white crystals in 50% yield. Mp 59.7–60.8 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.47–7.52 (m, 2H), 7.33–7.40 (m, 3H), 5.51 (s, 1H), 4.94 (d, 1H, J = 3.9 Hz), 4.77 (dd, 1H, J = 3.9, 9.8 Hz), 4.27 (dd, 1H, J = 4.9, 9.8 Hz), 4.13 (t, 1H, J = 9.8 Hz), 3.81 (m, 1H), 3.72 (dd∼t, 1H, J = 9.8, 10.7 Hz), 3.50 (dd∼t, 1H, J = 8.8, 9.8 Hz), 3.36 (s, 3H), 2.94 (br s, 1H), 2.39 (t, 2H, J = 7.3 Hz), 1.64 (m, 2H), 1.20–1.38 (m, 8H), 0.88 (t, 3H, J = 6.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.4, 136.9, 129.1, 128.1, 126.2, 101.8, 97.4, 81.2, 73.2, 68.7, 68.4, 61.9, 55.2, 33.9, 31.5, 28.8, 24.8, 22.4, 13.9. HRMS calcd for $C_{22}H_{33}O_7$ $[M+H]^+$ 409.2226, found 409.2207.

4.2.16. Methyl 4,6-*O*-benzylidene-3-*O*-octanoyl–α-D-glucopyranoside (9c)

Compound **9c** was isolated as a white powder in 15% yield. Mp 117.1–118.2 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40–7.47 (m, 2H), 7.32–7.38 (m, 3H), 5.49 (s, 1H), 5.34 (t, 1H, J = 9.8 Hz), 4.80 (d, 1H, J = 3.9 Hz), 4.30 (dd, 1H, J = 4.9, 9.8 Hz), 3.87 (dd, 1H, J = 4.9, 9.8 Hz), 3.75 (dd∼t, 1H, J = 9.8, 10.7 Hz), 3.66 (m, 1H), 3.58 (t, 1H, J = 9.8 Hz), 3.47 (s, 3H), 2.37 (t, 2H, J = 7.3 Hz), 2.24 (d, 1H, J = 11.7 Hz), 1.62 (m, 2H), 1.02–1.36 (m, 8H), 0.85 (t, 3H, J = 6.8); ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.9, 137.0, 129.0, 128.1, 126.1, 101.4, 100.1, 78.6, 72.0, 71.8, 68.9, 62.7, 55.5, 31.6, 28.9, 25.0, 22.5, 14.0. HRMS calcd for $C_{22}H_{33}O_7$ $[M+H]^+$ 409.2226, found 409.2209.

4.2.17. Methyl 4,6-*O*-benzylidene-2,3-di-*O*-decanoyl–α-D-glucopyranoside (10a)

Compound **10a** was isolated as a white powder in 21% yield. Mp 46.9–48.7 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40–7.45 (m, 2H), 7.30–7.36 (m, 3H), 5.61 (t, 1H, J = 9.9 Hz), 5.49 (s, 1H), 4.94 (d, 1H, J = 3.7 Hz), 4.91 (dd, 1H, J = 3.7 Hz, 9.9 Hz), 4.29 (dd, 1H, J = 4.8, 10.3 Hz), 3.92 (dt, 1H, J = 4.8, 9.9 Hz), 3.76 (t, 1H, J = 10.3 Hz), 3.64 (t, 1H, J = 9.5 Hz), 3.39 (s, 3H), 2.20–2.42 (m, 4H), 1.58 (m, 4H), 1.13–1.39 (m, 24H), 0.84–0.91 (m, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.1, 172.4, 136.8, 128.9, 128.0, 126.0, 101.4, 97.6, 79.2, 71.3, 68.7, 68.5, 62.2, 55.2, 34.2, 34.0, 31.8, 29.34, 29.28, 29.2 (br), 29.0, 28.9, 25.0, 24.8, 22.6, 14.0. HRMS calcd for $C_{34}H_{55}O_8$ $[M+H]^+$ 591.3897, found 591.3878.

4.2.18. Methyl 4,6-*O*-benzylidene-2-*O*-decanoyl–α-D-glucopyranoside (10b)

Compound **10b**[54] was isolated as a white powder in 59% yield. Mp 59.7–60.8 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46–7.52 (m, 2H), 7.33–7.39 (m, 3H), 5.50 (s, 1H), 4.94 (d, 1H, J = 3.7 Hz), 4.78 (dd, 1H, J = 3.7, 9.5 Hz), 4.28 (dd, 1H, J = 4.4, 9.9 Hz), 4.15 (t, 1H, J = 9.5 Hz), 3.82 (dt, 1H, J = 4.4, 9.9 Hz), 3.73 (t, 1H, J = 10.3 Hz), 3.53 (t, 1H, J = 9.5 Hz), 3.37 (s, 3H), 2.39 (t, 2H, J = 7.5 Hz), 1.62 (m, 2H), 1.19–1.36 (m, 12H), 0.88 (t, 3H, J = 6.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.5, 136.9, 129.2, 128.2, 126.2, 101.8, 97.5, 81.2, 73.3, 68.7, 68.5, 61.9, 55.3, 34.0, 31.8, 29.3, 29.2, 28.9, 24.8, 22.6, 14.0. HRMS calcd for $C_{24}H_{37}O_7$ $[M+H]^+$ 437.2539, found 437.2530.

4.2.19. Methyl 4,6-*O*-benzylidene-2-*O*-decanoyl–α-D-glucopyranoside (10c)

Compound **10c** was isolated as a white powder in 11% yield. Mp 117.1–118.2 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41–7.47 (m, 2H), 7.31–7.37 (m, 3H), 5.49 (s, 1H), 5.34 (t, 1H, J = 9.7 Hz), 4.80 (d, 1H, J = 3.7 Hz), 4.30 (dd, 1H, J = 4.8, 9.9 Hz), 3.86 (td, 1H, J = 4.7, 9.8 Hz), 3.74 (t, 1H, J = 10.3 Hz), 3.66 (dd, 1H, J = 3.7, 9.5 Hz), 3.58 (t, 1H, J = 9.5 Hz), 3.44 (s, 3H), 2.37 (t, 2H, J = 7.3 Hz), 1.62 (m, 2H), 1.12–1.39 (m, 12H), 0.87 (t, 3H, J = 7.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 173.8, 136.9, 128.9, 128.0, 126.0, 101.3, 100.0, 78.6, 71.9, 71.6, 68.8, 62.6, 55.4, 34.3, 31.7, 29.3, 29.2, 28.8, 25.0, 22.6, 14.0. HRMS calcd for $C_{24}H_{37}O_7$ $[M+H]^+$ 437.2539, found 437.2527.

4.2.20. Methyl 4,6-*O*-benzylidene-2,3-di-*O*-(2′-methylacrolyl)–α-D-glucopyranoside (11a)

Methacrylic acid was used as the starting material, in 1.2 equiv relative to compound **4**. Compound **11a**[55] was isolated as needle-like crystals in 2% yield. Mp 106.6–107.4 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41–7.47 (m, 2H), 7.31–7.37 (m, 3H), 6.14 (s, 1H), 6.04 (s, 1H), 5.75 (t, 1H, J = 9.8 Hz), 5.60 (s, 1H), 5.53 (s, 2H), 5.03 (d, 1H, J = 3.9 Hz), 4.97 (dd, 1H, J = 3.9, 9.8 Hz), 4.32 (dd, 1H, J = 4.9, 9.8 Hz), 3.97 (dt, 1H, J = 4.9, 9.8 Hz), 3.80 (dd∼t, 1H, J = 9.8, 10.7 Hz), 3.75 (t, 1H, J = 9.8 Hz), 3.40 (s, 3H), 1.90 (br s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.8, 166.1, 136.8, 135.7, 135.1, 128.9, 128.0, 127.1, 126.0, 125.7, 101.4, 97.6, 79.1, 72.1, 69.1, 68.7, 62.3, 55.2, 18.2, 18.0. HRMS calcd for $C_{22}H_{27}O_8$ $[M+H]^+$ 419.1706, found 419.1702.

4.2.21. Methyl 4,6-*O*-benzylidene-2-*O*-(2′-methylacrolyl)–α-D-glucopyranoside (11b)

Compound **11b**[55] was isolated as viscous oil in 67% yield. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.47–7.53 (m, 2H), 7.34–7.41 (m, 3H), 6.21 (s, 1H), 5.63 (s, 1H), 5.53 (s, 1H), 4.97 (d, 1H, J = 3.9 Hz), 4.82 (dd, 1H, J = 3.9, 9.8 Hz), 4.28 (dd, 1H, J = 4.9, 10.7 Hz), 4.20 (dd∼t, 1H, J = 8.8, 9.8 Hz), 3.84 (dt, 1H, J = 4.9, 9.8 Hz), 3.74 (dd∼t, 1H, J = 9.8, 10.7 Hz), 3.53 (dd∼t, 1H, J = 8.8, 9.8 Hz), 3.37 (s, 3H), 2.77 (br s, 1H), 1.97 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.9, 136.9, 135.5, 129.2, 128.2, 126.7, 126.2, 101.9, 97.5, 81.3, 73.8, 68.7, 68.5, 61.9, 55.3, 18.1. HRMS calcd for $C_{18}H_{23}O_7$ $[M+H]^+$ 351.1444, found 351.1436.

4.2.22. Methyl 4,6-*O*-benzylidene-3-*O*-(2′-methylacrolyl)–α-D-glucopyranoside (11c)

Compound **11c**[55] was isolated as off-white crystals in 10% yield. Mp 185.0–186.0 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41–7.48 (m, 2H), 7.32–7.39 (m, 3H), 6.17 (s, 1H), 5.59 (s, 1H), 5.51 (s, 1H), 5.40 (t, 1H, J = 9.8 Hz), 4.82 (d, 1H, J = 3.9 Hz), 4.32 (dd, 1H, J = 4.9, 10.7 Hz), 3.89 (m, 1H), 3.77 (dd∼t, 1H, J = 9.8, 10.7 Hz), 3.72 (m, 1H), 3.66 (t, 1H, J = 9.8 Hz), 3.47 (s, 3H), 2.44 (d, 1H, J = 11.7 Hz), 1.96 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.4, 137.0, 135.9, 129.0, 128.1, 126.3, 126.1, 101.3, 100.1, 78.7, 72.6, 71.9, 68.8, 62.6, 55.5, 18.3. HRMS calcd for $C_{18}H_{23}O_7$ $[M+H]^+$ 351.1444, found 351.1451.

4.2.23. Methyl 4,6-*O*-benzylidene-2,3-di-*O*-benzoyl–α-D-glucopyranoside (12a)

Compound **12a**[56,57] was isolated as a white solid in 6% yield. Mp 152.4–153.0 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95–8.07 (m, 4H), 7.28–7.56 (m, 11H), 6.08 (t, 1H, J = 9.9 Hz), 5.58 (s, 1H), 5.27 (dd,

1H, J = 3.7, 9.9 Hz), 5.20 (d, 1H, J = 3.7 Hz), 4.39 (dd, 1H, J = 4.8, 10.3 Hz), 4.10 (dt, 1H, J = 4.8, 9.9 Hz), 3.92 (t, 1H, J = 9.5 Hz), 3.88 (t, 1H, J = 10.3 Hz), 3.44 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.0, 165.6, 136.8, 133.3, 133.0, 130.0, 129.7, 129.0, 128.4, 128.2, 128.1, 126.1, 101.6, 97.8, 79.3, 72.5, 69.5, 68.9, 62.5, 55.5.

4.2.24. Methyl 4,6-*O*-benzylidene-2-*O*-benzoyl–α-D-glucopyranoside (12b)

Compound **12b**[58] was isolated as a crystalline solid in 42% yield. Mp 170.3–170.9 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.08–8.12 (m, 2H), 7.56–7.61 (m, 1H), 7.50–7.54 (m, 2H), 7.43–7.48 (m, 2H), 7.37–7.41 (m, 3H), 5.57 (s, 1H), 5.08 (d, 1H, J = 3.7 Hz), 5.04 (dd, 1H, J = 3.7, 9.2 Hz), 4.36 (dd∼t, 1H, J = 9.2, 9.5 Hz), 4.34 (d, 1H, J = 4.8, 10.3 Hz), 3.92 (dt, 1H, J = 4.8, 10.3 Hz), 3.80 (t, 1H, J = 10.3 Hz), 3.63 (dd∼t, 1H, J = 9.2, 9.5 Hz), 3.40 (s, 3H), 2.74 (br s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.2, 137.0, 133.3, 129.9, 129.4, 129.2, 128.4, 128.3, 126.3, 102.0, 97.8, 81.4, 74.0, 68.9, 68.8, 62.0, 55.5.

4.2.25. Methyl 4,6-*O*-benzylidene-3-*O*-benzoyl–α-D-glucopyranoside (12c)

Compound **12c**[56] was isolated as white needle-like crystals in 10% yield. Mp 216.6–217.0 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.08 (d, 2H, J = 7.7 Hz), 7.55 (t, 1H, J = 7.3 Hz), 7.39–7.46 (m, 4H), 7.28–7.34 (m, 3H), 5.60 (t, 1H, J = 9.5 Hz), 5.54 (s, 1H), 4.86 (d, 1H, J = 3.7 Hz), 4.35 (dd, 1H, J = 4.8, 10.3 Hz), 3.96 (dt, 1H, J = 4.8, 9.9 Hz), 3.84 (dd, 1H, J = 3.7, 9.5 Hz), 3.81 (dd∼t, 1H, J = 9.9, 10.3 Hz), 3.77 (t, 1H, J = 9.5 Hz), 3.49 (s, 3H), 2.47 (br s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.6, 136.9, 133.0, 129.8, 128.9, 128.2, 128.1, 126.1, 101.4, 100.1, 78.8, 72.9, 71.9, 68.9, 62.7, 55.6.

4.2.26. Methyl 4,6-*O*-benzylidene-2,3-di-*O*-napthoyl–α-D-glucopyranoside (13a)

Compound **13a** was isolated as white crystalline solid in a 13% yield. Mp 131.6–132.1 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.94 (d, 1H, J = 8.8 Hz), 8.66 (d, 1H, J = 8.8 Hz), 8.32 (d, 1H, J = 7.8 Hz), 7.97–8.02 (m, 2H), 7.92 (d, 1H, J = 7.8 Hz), 7.85 (d, 1H, J = 7.8 Hz), 7.80 (d, 1H, J = 8.8 Hz), 7.31–7.58 (m, 11H), 6.25 (t, 1H, J = 9.8 Hz), 5.64 (s, 1H), 5.45 (dd, 1H, J = 3.9, 9.8 Hz), 5.29 (d, 1H, J = 3.9 Hz), 4.43 (dd, 1H, J = 4.9, 9.8 Hz), 4.17 (dt, 1H, J = 4.9, 9.8 Hz), 3.99 (dd∼t, 1H, J = 8.8, 9.8 Hz), 3.91 (t, 1H, J = 9.8, 10.7 Hz), 3.51 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.7, 166.6, 136.9, 134.1, 133.7, 133.5, 132.9, 131.3, 130.9, 129.2, 129.0, 128.5, 128.3, 128.2, 127.9, 127.5, 127.4, 126.1, 125.5, 125.3, 124.6, 124.4, 101.5, 98.0, 79.5, 72.2, 69.6, 68.9, 62.6, 55.5. HRMS calcd for $C_{36}H_{31}O_8$ $[M+H]^+$ 591.2019, found 591.2040.

4.2.27. Methyl 4,6-*O*-benzylidene-2-*O*-napthoyl–α-D-glucopyranoside (13b)

Compound **13b** was isolated as white crystals in 83% yield. Mp 174.6–175.0 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.92 (d, 1H, J = 8.8 Hz), 8.27 (d, 1H, J = 7.8 Hz), 8.04 (d, 1H, J = 7.8 Hz), 7.89 (d, 1H, J = 8.8 Hz), 7.63 (m, 1H), 7.48–7.58 (m, 4H), 7.35–7.43 (m, 3H), 5.59 (s, 1H), 5.21 (d, 1H, J = 3.9 Hz), 5.14 (dd, 1H, J = 3.9, 9.8 Hz), 4.39 (dd∼t, 1H, J = 8.8, 9.8 Hz), 4.35 (dd, 1H, J = 4.9, 9.8 Hz), 3.95 (dt, 1H, J = 3.9, 9.8 Hz), 3.82 (dd∼t, 1H, J = 9.8, 10.7 Hz), 3.67 (dd∼t, 1H, J = 8.8, 9.8 Hz), 3.45 (s, 3H), 2.63 (br s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.2, 136.9, 133.8, 131.3, 130.8, 129.3, 128.5, 128.4, 127.9, 126.5, 126.3, 125.7, 124.5, 102.0, 97.7, 81.4, 74.2, 68.9, 68.8, 62.0, 55.5. HRMS calcd for $C_{25}H_{25}O_7$ $[M+H]^+$ 437.1600, found 437.1589.

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Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.carres.2008.12.006.

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