An oxidation–amidation approach for the synthesis of glycuronamides

Sicheng Lin,[+][a] Roger A. Ashmus,[+][a] and Todd L. Lowary*[a]

Abstract: A route for the synthesis of glycuronamides via the intermediacy of 6-*S*-tolyl-glycosides and uronic acid thioesters, is reported. The route, which is compatible with a variety of carbohydrate residues and protecting groups, was used to synthesize the repeating unit of the *E. coli* K54 capsular polysaccharide.

Introduction

Glycuronamides, amidated uronic acid derivatives, are commonly found in bacterial lipopolysaccharides (LPS) and capsular polysaccharides (CPS).[1–5] These structures frequently consist of glucuronic acid, galacturonic acid, mannuronic acid, or 2-acetamido-2-deoxy-D-galacturonic acid amidated with a range of different amines including ammonia,[1] ethanolamine,[6] L-alanine,[2] L-serine,[3] L-lysine,[7] L-threonine,[4] and serinol.[5] Examples include *Escherichia coli* K54 CPS, which has a repeating unit possessing a L-threonine-containing glucuronamide[9] and *Proteus mirabilis* O28 LPS, which contains two galacturonamide residues, one incorporating L-lysine and the other L-serine (Figure 1).[7] Polysaccharides containing glycuronamide residues play essential roles in the organisms that produce them. For instance, the L-threonine-containing galacturonamide in the *Colwellia psychrerythraea* 34H CPS has been suggested to be important for the survival of the organism in subfreezing marine environments.[4] Other studies have shown that CPS possessing uronic acids amidated with amino acids are important in the induction of protective immunity against abscess formation.[10] In addition, molecules containing these structures have often been targeted in the development of vaccines.[7,11–13] Consequently, the chemical synthesis of glycans possessing glycuronamides is of interest.

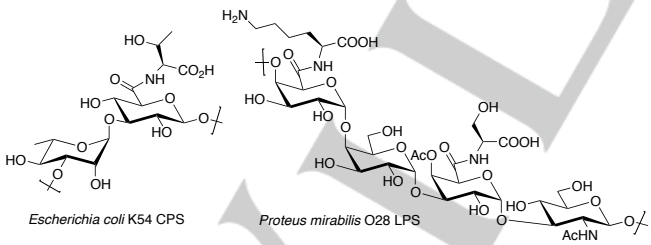
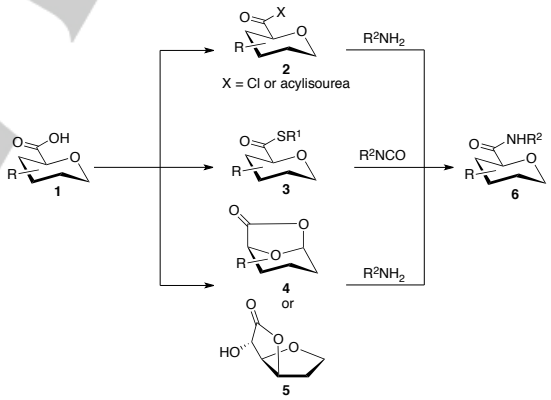


Figure 1. Examples of polysaccharide repeating units containing glycuronamide residues

The conventional approach for glycuronamide synthesis involves converting a uronic acid to a reactive intermediate (e.g., an activated ester or acyl halide) and then addition of an amine (Scheme 1, **1**→**2**→**6**).[14–20] Recently, Crich and Sasaki have developed an alternate method in which uronic acid thiocarboxylates made in situ react with isocyanates or isothiocyanates to produce glycuronamides (**1**→**3**→**6**).[21] In another alternate approach, treatment of 1,6- and 3,6-carbohydrate-based lactones with amines leads to the corresponding glucuronamides (**1**→**4/5**→**6**).[22–24] These alternative approaches, however have only been demonstrated on glucuronic acid residues. In addition, they are difficult to implement if the glycan of interest contains more than one glycuronamide (e.g., the repeating unit found in *P. mirabilis* O28 LPS, Figure 1).



Scheme 1. Approaches for glycuronamide synthesis.

In recent efforts to synthesize glycoconjugates containing glucuronamide residues using the conventional approach described above (**1**→**2**→**6**), we encountered an unexpected problem: The generation of a glucuronic acid derivative, either by hydrolysis of an ester or oxidation of a primary alcohol, led to decomposition of the molecule. Thus, we required a method for the formation of a glucuronamide that did not involve a carboxylic acid intermediate. Although methods for the direct conversion of primary alcohols to amides have been described,[25–36] in our hands these were unsuccessful.

We then turned our attention to a report by Yu and coworkers, which described the preparation of uronic acid esters from 6-*S*-phenyl-glycosides (Scheme 2a).[37,38] In this approach, the first step involves treatment of the sulfide precursor **7** with

[a] Department of Chemistry and Alberta Glycomics Centre,
The University of Alberta
Edmonton, Alberta T6G 2G2, Canada
E-mail: tlowary@ualberta.ca
[+] These authors contributed equally to this work.

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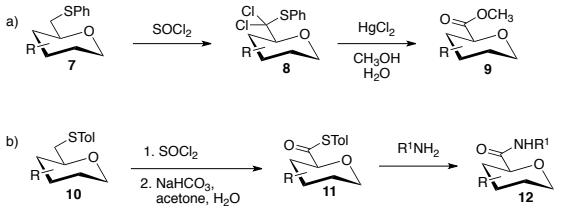
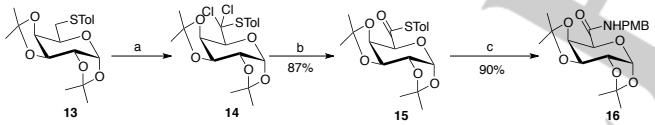
sulfuryl chloride to generate the corresponding α,α-dichlorosulfide (**8**), which in a second step can be converted to the uronic acid methyl ester (**9**). In other previous work, Fortes and coworkers showed that α,α-dichlorosulfides, when treated with water and acetone in the presence of Na_2CO_3, generate thioesters.[39,40] These investigations prompted us to explore the possibility of preparing glycuronamides from **10** via the formation of the uronic acid thioesters (e.g., **11**) and then treatment with amines (Scheme 2b).



Scheme 2. a) Synthesis of uronic acid methyl esters by Yu and coworkers.[37,38] b) proposed route to glycuronamides.

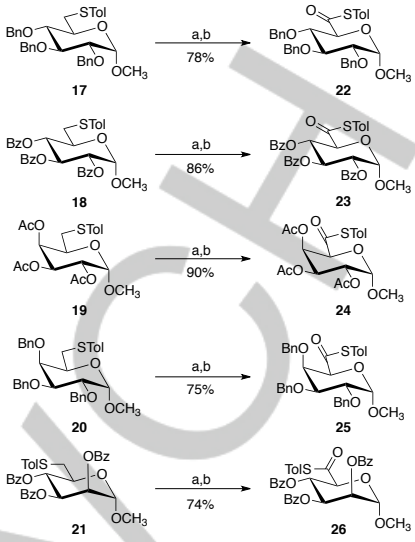
Results and Discussion

In a first series of experiments, we treated 6-*S*-tolyl-galactose derivative **13** with sulfuryl chloride to produce the dichlorosulfide intermediate **14** (Scheme 3). Without purification, this adduct was stirred with water in acetone in the presence of $NaHCO_3$, leading to the formation of thioester **15**, which could be isolated in 87% yield. Subsequent treatment of **15** with *p*-methoxybenzylamine in dichloromethane furnished the glucuronamide **16** in 90% isolated yield.



Scheme 3. Synthesis of galacturonamide **16** from thioether **13**. *Regents and conditions*: (a) pyridine, SO_2Cl_2, CCl_4, 0 °C, 5 h; (b) $NaHCO_3$, acetone–H_2O (3:2), rt, 18 h; (c) *p*-methoxybenzylamine, CH_2Cl_2, r.t., 10 h.

Having succeeded in applying this approach to **13**, we then examined the oxidation of various 6-*S*-tolyl-glycosides (**17**–**21**)[41] to the corresponding thioesters (**22**–**26**) as illustrated in Scheme 4. In each case, the two-step conversion afforded the desired product in good to excellent yield. Neither the electron-withdrawing nature of the protecting groups, nor the carbohydrate stereochemistry had a significant influence on the reaction yield or reaction time. In addition, the reaction could also be carried out both milligram and gram scale without difficulty. With the thioesters in hand, we explored their amidation with various amines (Table 1).



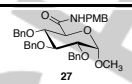
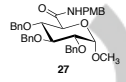
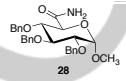
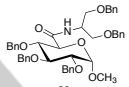
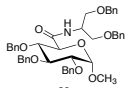
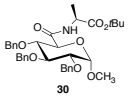
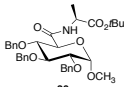
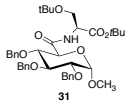
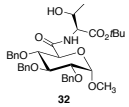
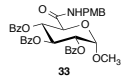
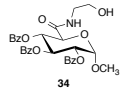
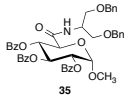
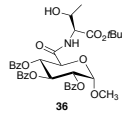
Scheme 4. Synthesis of uronic acid thioesters from 6-*S*-tolyl-glycosides. *Regents and conditions*: (a) pyridine, SO_2Cl_2, CCl_4, 0 °C, 5 h; (b) $NaHCO_3$, acetone–H_2O (3:2), r.t., 18 h.

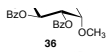
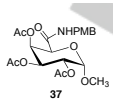
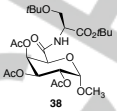
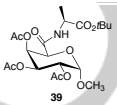
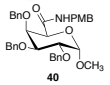
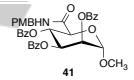
In exploring the scope of the amidation reaction (Table 1), we focused on the preparation of naturally occurring glycuronamides in their protected form. We found that varying the carbohydrate residue and their electronic properties (i.e., the electron withdrawing or donating ability of the protecting groups) did not affect the amidation yield or reaction rate.

When simple amines such as *p*-methoxybenzylamine (Entries 1, 10, 15, 18, 19) and ethanolamine (Entry 11) were used, the amidation proceeded in good yields (> 82%). Ammonia from concentrated ammonium hydroxide could also be used as the amine, albeit this afforded the glycuronamide **28** in somewhat lower (66%) yield and longer reactions times were required (Entry 3). The use of amines derived from L-alanine, L-serine, L-threonine as well as serinol, provided the corresponding glycuronamides in 63–73% yields.

The data in Table 1 also supports a general trend for the reaction rate: simple amines (e.g. *p*-methoxybenzylamine, ethanolamine) > moderately bulky amines (e.g. protected L-alanine derivatives) > more sterically demanding amines (the serinol analogue, L-threonine derivatives, L-serine derivatives). It was discovered that for L-threonine *t*-butyl ester changing the solvent from CH_2Cl_2 (Entry 13) to DMF (Entry 14) resulted in the reaction rate increasing nearly 2-fold and a significantly improved product yield. The same trend is observed with other amino acid-derived amines (Entries 8, 16). In attempts to increase the reaction rate, triethylamine was added (Entries 4, 5); however, no increase in the rate or improvement of the yield was observed. We also explored the use of 2,6-di-t-butyl-4-methyl-pyridine, but again no improvement in rate or product yield was seen. Indeed, for substrates possessing acyl protecting groups at O-4, the yield deceased (see next paragraph). It was also evident that the free amine (Entry 7) is a substantially better substrate than the corresponding hydrochloric salt, even in the presence of an excess of triethylamine (Entry 6). Not surprisingly, the data in

Table 1. Amidation of uronic acid thioesters with amines

Entry	Thioester	Amines[a]	Solvent	Time	Product	Yield[b]
1	**22**	PMB-NH_2	CH_2Cl_2	10 h	 **27**	85%
2	**22**	PMB-NH_2	DMF	10 h	 **27**	82%
3	**22**	NH_3OH (aq.)	DMF	40 h	 **28**	66%
4	**22**	1,3-Di-*O*-benzyl-serinol	CH_2Cl_2	72 h	 **29**	64%
5	**22**	1,3-Di-*O*-benzyl-serinol	CH_2Cl_2	72 h	 **29**	67%[c]
6	**22**	HCl·H_2N-L-Ala-*t*Bu	CH_2Cl_2	24 h	 **30**	33%[c]
7	**22**	H_2N-L-Ala-*t*Bu	CH_2Cl_2	24 h	 **30**	71%
8	**22**	H_2N-L-Ser(*t*Bu)-*t*Bu	CH_2Cl_2	72 h	 **31**	65%
9	**22**	H_2N-L-Thr-*t*Bu	CH_2Cl_2	72 h	 **32**	63%
10	**23**	PMB-NH_2	CH_2Cl_2	10 h	 **33**	86%
11	**23**	Ethanolamine	CH_2Cl_2	17 h	 **34**	86%
12	**23**	Serinol	CH_2Cl_2	40 h	 **35**	73%
13	**23**	H_2N-L-Thr-*t*Bu	CH_2Cl_2	87 h	 **36**	41%
14	**23**	H_2N-L-Thr-*t*Bu	DMF	38 h		71%

					 **36**	
15	**24**	PMB-NH_2	CH_2Cl_2	8 h	 **37**	91%
16	**24**	H_2N-L-Ser(*t*Bu)-*t*Bu	DMF	42 h	 **38**	64%
17	**24**	H_2N-L-Ala-*t*Bu	DMF	18 h	 **39**	63%
18	**25**	PMB-NH_2	CH_2Cl_2	10 h	 **40**	83%
19	**26**	PMB-NH_2	CH_2Cl_2	10 h	 **41**	98%

[a] 1.5 equiv. of amine except NH_4OH (aq.). [b] Yield of isolated product. [c] Triethylamine was added to the reaction.

entries 9, 11, and 13 demonstrate that amidation will occur over esterification when competing alcohol nucleophiles are present.

It is important to note that when O-4 in the carbohydrate is protected with an ester, significant elimination can occur in the presence of an excess amine nucleophile or when triethylamine is added to the reaction (Figure 2). Small amounts of the elimination adduct were also observed when a sterically demanding amine was used in the amidation step. However, changing the solvent from dichloromethane to DMF in the amidation of **23** with L-threonine *t*-butyl ester (Entries 13, 14), led to less elimination. In addition, by carefully controlling the amount of amine in the reaction and avoiding the addition of triethylamine, the formation of the elimination product with O-4 acylated substrates could be largely avoided (e.g., Table 1, Entry 10).

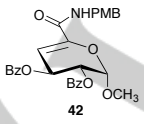
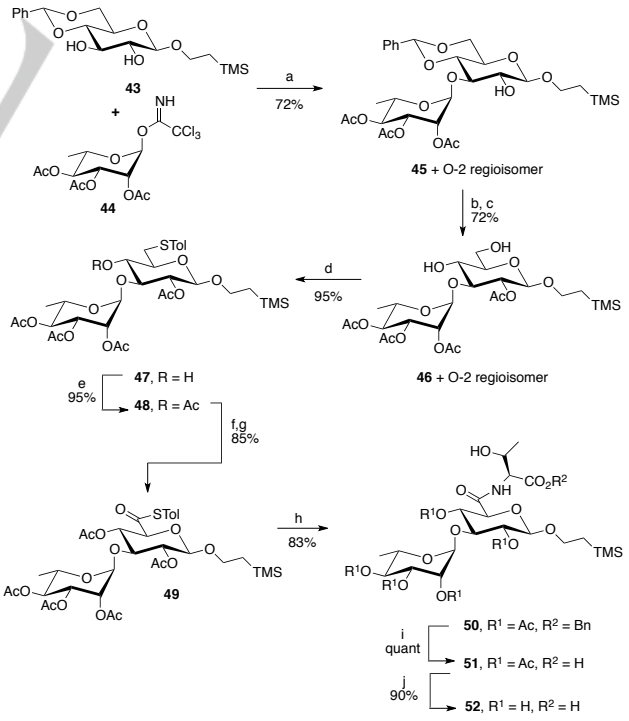

42

Figure 2. Example of the elimination product formed from O-4 acylated substrates (e.g., **23**) when an triethylamine is used in the amidation reaction.

To demonstrate the applicability of the approach to glycan synthesis, we used it to prepare the repeating unit of the *E. coli* K54 CPS, a disaccharide possessing a glucuronamide residue linked to L-threonine (**52**, Scheme 5).[9] The synthesis started with a TBSOTf-catalyzed glycosylation of glucosyl acceptor **43**[42] with rhamnosyl donor **44**,[43] which led to a 2:1 inseparable mixture of **45** and its O-2 regioisomer in favor of the desired adduct. Subsequent acetylation with acetic anhydride in pyridine and



Scheme 5. *Regents and conditions*: (a) 4 Å MS, TBSOTf, CH_2Cl_2, –78 °C, 20 min (inseparable, **46**:**46a** = 2:1); (b) Ac_2O, pyridine, DMAP, 3 h; (c) 80% CH_3COOH–H_2O, 80 °C, 2 h (separable, **47**:**47a** = 2:1); (d) $(TolS)_2$, Me_3P in THF,

pyridine, r.t., overnight; (e) Ac_2O, pyridine, DMAP, 3 h; (f) pyridine, SO_2Cl_2, CCl_4, 0 °C, 5 h; (g) $NaHCO_3$, acetone:H_2O (3:2), r.t., 18 h; (h) L-threonine benzyl ester, CH_2Cl_2, r.t., 44 h; (i) 5% Pd/C, CH_3OH, rt, overnight; (j) 50 mM $NaOCH_3$–CH_3OH, r.t., 4 h.

removal of the benzylidene acetal afforded disaccharide **46** and its regioisomer **46a** in 34% and 17% yield, respectively, over three steps. Treatment of **46** with tolyl disulfide and trimethylphosphine in pyridine selectively afforded the 6-*S*-tolyl sulfide **47** in 95% yield. Subsequent acetylation of **47** with acetic anhydride in pyridine afforded an 85% yield of **48**. Oxidation of **48** into thioester **49** proceeded in 85% yield upon treatment with sulfuryl chloride in carbon tetrachloride and then with water in the presence of $NaHCO_3$. The amidation of thioester **49** with L-threonine benzyl ester afforded glycuronamide **50** in 83% yield. With the disaccharide prepared, it was deprotected by first hydrogenolysis of the benzyl ester over 5% Pd/C, which afforded the free acid **51**. Subsequent treatment of **51** with sodium methoxide in methanol produced the disaccharide **52** in 90% yield.

Conclusions

In conclusion, an effective strategy for the preparation of glycuronamides from 6-*S*-tolyl-glycosides was developed. The method was compatible with a range of carbohydrate residues and amines and the approach could be easily applied to the synthesis of the *E. coli* K54 CPS repeating unit. To the best of our knowledge, the route described here is the first of its kind to completely avoid a carboxylic acid intermediate in the synthesis of complex glycans containing glycuronamides. Moreover, staged introductions of 6-*S*-tolyl-moieties into oligosaccharides should allow the preparation of molecules containing more than one uronic acid derivatives amidated to different amines.

Experimental Section

General Experimental Methods: All reagents were purchased from commercial sources and were used without further purification unless noted. Reaction solvents were purified by successive passage through columns of alumina and copper under argon. Unless stated otherwise, all reactions were carried out at room temperature and under a positive pressure of argon and were monitored by TLC on Silica Gel G-25 F254 (0.25 mm). Visualization of the reaction components was achieved using UV fluorescence (254 nm) and/or by charring with acidified anisaldehyde solution in ethanol, acetic acid and sulfuric acid. Organic solvents were evaporated under reduced pressure, and the products were purified by column chromatography on silica gel (230−400 mesh). Optical rotations were measured in a microcell (1 cm, 1 mL) at 21 °C and are in units of degree·mL/(g·dm). ^{1}H NMR spectra were recorded at 400 MHz or 500 MHz and chemical shifts are referenced to residual $CHCl_3$ (7.26 ppm, CDCl3) or CHD_2OD (3.30 ppm, CD_3OD). ^{13}C NMR spectra were recorded at 125 MHz, and chemical shifts are referenced to $CDCl_3$ (77.0 ppm) or CD_3OD (49.3 ppm). Reported splitting patterns are abbreviated as s = singlet, d = doublet, t = triplet, m = multiplet, br = broad, app = apparent. Assignments of NMR spectra were based on two-dimensional experiments (^{1}H−^{1}H COSY, HSQC and HMBC. High-resolution ESI-MS spectra (time-of-flight analyzer) were recorded on samples suspended in THF or CH_3OH and with added NaCl.

General Method 1: Preparation of 6-*S*-tolyl glycosides[37]

To a stirred solution of the 6-hydroxy glycopyranoside (1.0 mmol) in dry pyridine (5.0 mL) under argon were added $(TolS)_2$ (2.0 mmol) and PMe_3 (2.0 mmol, 1.0 M in THF). The reaction mixture was stirred overnight at room temperature. Then, the reaction mixture was concentrated, diluted with EtOAc (30 mL) and washed with brine. The organic layer was dried over $MgSO_4$, filtered and concentrated.

General Method 2: Preparation of uronic acid thioesters[39,40]

To a solution of the thioether (1.0 mmol) in dry CCl_4 (15 mL) at 0 °C under argon were added anhydrous pyridine (2.0 mmol) and then SO_2Cl_2 (2.0 mmol). The reaction mixture was stirred for 5 h at 0 °C, then diluted with CH_2Cl_2 and the mixture was washed with brine. The organic layer dried over $MgSO_4$, filtered and concentrated. The crude residue was dissolved in 3:2 acetone–H_2O (20 mL), and solid $NaHCO_3$ (4.0 mmol) was added. The reaction mixture was stirred for 18 h at room temperature, diluted with brine, and then extracted with EtOAc (3 × 30 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated.

General Method 3: Preparation of uronamides.

To a solution of the thioester (0.1 mmol) in CH_2Cl_2 (or DMF) (1 mL) was added the amine (0.15 mmol). The reaction mixture was monitored by TLC until the consumption of starting material and then diluted with CH_2Cl_2 (5 mL), washed with sat. NH_4Cl (aq.) and brine. The organic layer dried over $MgSO_4$, filtered and concentrated.

1,2:3,4-Di-*O*-isopropylidene-6-thio-6-S-*p*-tolyl-α-D-galactopyranose (13): Scale 1.0 mmol. Prepared as described in general method 1. The crude residue was purified by flash chromatography (5:1→4:1 hexane–EtOAc) to afford **13** (330 mg, 90%) as a clear viscous oil. R_f 0.39 (4:1 hexane–EtOAc); $[\alpha]_D$ –84.3 (0.4 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): δ 7.33–7.31 (m, 2H, Ar), 7.11–7.09 (m, 2H, Ar), 5.53 (d, 1H, *J* = 5.0 Hz, H-1), 4.61 (dd, 1H, *J* = 7.9, 2.4 Hz, H-3), 4.39 (dd, 1H, *J* = 7.9, 1.8 Hz, H-4), 4.29 (dd, 1H, *J* = 5.0, 2.4 Hz, H-2), 3.83 (td, 1H, *J* = 7.0, 1.7 Hz, H-5), 3.14 (d, 2H, *J* = 7.0 Hz, H-6), 2.31 (s, 3H, ArC$\underline{H}_3$), 1.47 (s, 3H, C(C$\underline{H}_3$)$_2$), 1.36 (s, 3H, C(C$\underline{H}_3$)$_2$), 1.30 (s, 3H, C(C$\underline{H}_3$)$_2$), 1.26 (s, 3H, C(C$\underline{H}_3$)$_2$); ^{13}C NMR (125 MHz; $CDCl_3$): δ 136.4 (Ar), 131.9 (Ar), 130.4 (Ar), 129.7 (Ar), 109.3 (C(CH$_3$)$_2$), 108.6 (C(CH$_3$)$_2$), 96.7 (C-1), 71.3 (C-4), 70.9 (C-3), 70.6 (C-2), 66.2 (C-5), 34.0 (C-6), 26.0 (C(CH$_3$)$_2$), 25.6 (C(CH$_3$)$_2$), 25.0 (C(CH$_3$)$_2$), 24.5 (C(CH$_3$)$_2$), 21.0 (ArCH$_3$); HRMS (ESI) Calc. for (M + Na) $C_{19}H_{26}NaO_5S$: 389.1393; Found 389.1397.

***S*-*p*-Tolyl thio(1,2:3,4-Di-*O*-isopropylidene-α-D-galactopyranose)-uronate (15):** Scale: 1.0 mmol. Prepared as described in general method 2. The crude residue was purified by flash chromatography (4:1 hexane–EtOAc) to afford **15** (331 mg, 87%) as a white amorphous solid. R_f 0.29 (4:1 hexane–EtOAc); $[\alpha]_D$ –179.5 (0.7 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): δ 7.35–7.32 (m, 2H, Ar), 7.24–7.22 (m, 2H, Ar), 5.75 (d, 1H, *J* = 4.9 Hz, H-1), 4.69 (dd, 1H, *J* = 7.7, 2.6 Hz, H-3), 4.65 (dd, 1H, *J* = 7.7, 2.2 Hz, H-4), 4.49 (d, 1H, *J* = 1.9 Hz, H-5), 4.43 (dd, 1H, *J* = 4.9, 2.5 Hz, H-2), 2.39 (s, 3H, ArC$\underline{H}_3$), 1.56 (s, 3H, C(C$\underline{H}_3$)$_2$), 1.55 (s, 3H, C(C$\underline{H}_3$)$_2$), 1.38 (s, 3H, C(C$\underline{H}_3$)$_2$), 1.36 (s, 3H, C(C$\underline{H}_3$)$_2$); ^{13}C NMR (125 MHz; $CDCl_3$): δ 197.9 (C-6), 139.5 (Ar), 134.7 (Ar), 130.0 (Ar), 123.6 (Ar), 110.1 (C(CH$_3$)$_2$), 109.3 (C(CH$_3$)$_2$), 96.7 (C-1), 74.2 (C-5), 72.3 (C-4), 70.8 (C-3), 70.7 (C-2), 26.1 (C(CH$_3$)$_2$), 26.0 (C(CH$_3$)$_2$), 24.8 (C(CH$_3$)$_2$), 24.6 (C(CH$_3$)$_2$), 21.4 (ArCH$_3$); HRMS (ESI) Calc. for (M + Na) $C_{19}H_{24}NaO_6S$: 403.1186; Found 403.1186.

***N*-(4-Methoxybenzyl) 1,2:3,4-Di-*O*-isopropylidene-α-D-galactopyranosiduronamide (16):** Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (2:1 hexane–EtOAc) to afford **16** (35 mg, 90%) as a white solid. R_f 0.18 (2:1 hexane–EtOAc); $[\alpha]_D$ –78.2 (0.5 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): δ 7.24–7.21 (m, 2H, Ar), 6.85–6.82 (m, 2H, Ar), 6.78 (app t, 1H, *J* = 5.5, 5.5 Hz, CONHCH$_2$), 5.54 (d, 1H, *J* = 4.9 Hz, H-1), 4.72 (dd, 1H, *J* = 7.9, 2.1 Hz, H-3), 4.68–4.64 (m, 2H, H-4, NHC$\underline{H}_2$Ar), 4.34 (m, 2H,

H-2, H-5), 4.23 (dd, 1H, *J* = 14.8, 4.7 Hz, NHC$\underline{H}_2$Ar), 3.78 (s, 3H, ArOC$\underline{H}_3$), 1.51 (s, 3H, C(C$\underline{H}_3$)$_2$), 1.39 (s, 3H, C(C$\underline{H}_3$)$_2$), 1.35 (s, 3H, C(C$\underline{H}_3$)$_2$), 1.32 (s, 3H, C(C$\underline{H}_3$)$_2$); ^{13}C NMR (175 MHz; $CDCl_3$): *δ* 168.2 (C-6), 158.9 (Ar), 130.0 (Ar), 128.9 Ar), 113.9 (Ar), 109.4 (C(CH$_3$)$_2$), 109.2 (C(CH$_3$)$_2$), 96.2 (C-1), 71.6 (C-3), 70.7 (C-2), 70.4 (C-4), 68.8 (C-5), 55.3 (ArOCH$_3$), 42.2 (NHCH$_2$Ar), 26.0 (C(CH$_3$)$_2$), 25.9 (C(CH$_3$)$_2$), 24.8 (C(CH$_3$)$_2$), 24.2 (C(CH$_3$)$_2$); HRMS (ESI) Calc. for (M + Na) $C_{20}H_{27}NNaO_7$: 416.1680; Found 416.1678.

Methyl 2,3,4-tri-*O*-benzyl-6-thio-6-*S*-*p*-tolyl-α-D-glucopyranoside (17): Scale 1.0 mmol. Prepared from methyl 2,3,4-tri-*O*-benzyl-α-D-glucopyranoside[44] as described in general method 1. The crude residue was purified by flash chromatography (5:1→4:1 hexane–EtOAc) to afford **17** (542 mg, 95%) as a clear viscous oil. The ^{1}H NMR data for the product was consistent with that reported in the literature.[45]

Methyl 2,3,4-tri-*O*-benzoyl-6-thio-6-*S*-*p*-tolyl-α-D-glucopyranoside (18): Scale 1.0 mmol. Prepared from methyl 2,3,4-tri-*O*-benzoyl-α-D-glucopyranoside[46]as described in general method 1. The crude residue was purified by flash chromatography (5:1→4:1 hexane–EtOAc) to afford **18** (576 mg, 94%) as a clear viscous oil. R_f 0.44 (4:1 hexane–EtOAc); $[\alpha]_D$ +40.8 (1.0 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): *δ* 8.00–7.98 (m, 2H, Ar), 7.96–7.94 (m, 2H, Ar), 7.88–7.86 (m, 2H, Ar), 7.57–7.51 (m, 2H, Ar), 7.46–7.38 (m, 5H, Ar), 7.32–7.26 (m, 4H, Ar), 7.06 (d, 2H, *J* = 7.9 Hz, Ar), 6.11 (app t, 1H, *J* = 9.8 Hz, H-3), 5.49 (app t, 1H, *J* = 9.7 Hz, H-4), 5.29 (dd, 1H, *J* = 10.2, 3.7 Hz, H-2), 5.24 (d, 1H, *J* = 3.7 Hz, H-1), 4.24 (ddd, 1H, *J* = 9.5, 9.4, 2.5 Hz, H-5), 3.50 (s, 3H, OC$\underline{H}_3$), 3.23 (dd, 1H, *J* = 14.0, 2.5 Hz, H-6a), 3.13 (dd, 1H, *J* = 14.0, 9.1 Hz, H-6b), 2.33 (s, 3H, ArC$\underline{H}_3$); ^{13}C NMR (125 MHz; $CDCl_3$): *δ* 165.8 (2 × C=O), 165.5 (C=O), 136.6 (Ar), 133.5 (Ar), 133.4 (Ar), 133.1 (Ar), 132.3 (Ar), 130.2 (Ar), 130.0 (Ar), 129.9 (Ar), 129.8 (Ar), 129.7 (Ar), 129.3 (Ar), 129.1 (Ar), 128.0 (Ar), 128.4 (2 × Ar), 128.3 (Ar), 96.8 (C-1), 72.3 (C-4), 72.2 (C-2), 70.4 (C-3), 68.9 (C-5), 55.5 (O$\underline{C}$H$_3$), 36.6 (C-6), 21.0 (Ar$\underline{C}$H$_3$); HRMS (ESI) Calc. for (M + Na) $C_{25}H_{32}NaO_8S$: 635.1710; Found 635.1707.

Methyl 2,3,4-tri-*O*-acetyl-6-thio-6-*S*-*p*-tolyl-α-D-galactopyranoside (19): Scale 1.0 mmol. Prepared from methyl 2,3,4-tri-*O*-acetyl-α-D-galactopyranoside [47] as described in general method 1. The crude residue was purified by flash chromatography (3:2→2:1 hexane–EtOAc) to afford **19** (363 mg, 85%) as a clear viscous oil. R_f 0.44 (2:1 hexane–EtOAc); $[\alpha]_D$ +82.7 (1.0 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): *δ* 7.29 (d, 2H, *J* = 8.1 Hz, Ar), 7.13 (d, 2H, *J* = 7.9 Hz, Ar), 5.49 (dd, 1H, *J* = 3.4, 1.2 Hz, H-4), 5.33 (dd, 1H, *J* = 10.9, 3.4 Hz, H-3), 5.15 (dd, 1H, *J* = 10.9, 3.6 Hz, H-2), 5.00 (d, 1H, *J* = 3.6 Hz, H-1), 4.05 (ddd, 1H, *J* = 7.8, 5.5, 1.0 Hz, H-5), 3.39 (s, 3H, OC$\underline{H}_3$), 3.07 (dd, 1H, *J* = 13.8, 8.0 Hz, H-6a), 2.90 (dd, 1H, *J* = 13.8, 5.4 Hz, H-6b), 2.35 (s, 3H, ArC$\underline{H}_3$), 2.15 (s, 3H, COC$\underline{H}_3$), 2.09 (s, 3H, COC$\underline{H}_3$), 2.00 (s, 3H, COC$\underline{H}_3$); ^{13}C NMR (125 MHz; $CDCl_3$): *δ* 170.4 (C=O), 170.3 (C=O), 169.9 (C=O), 137.0 (Ar), 131.6 (Ar), 130.6 (Ar), 129.9 (Ar), 97.2 (C-1), 69.6 (C-3), 68.2 (C-2), 67.8 (C-4), 67.5 (C-5), 55.4 (O$\underline{C}$H$_3$), 35.2 (C-6), 21.0 (CO$\underline{C}$H$_3$), 20.8 (CO$\underline{C}$H$_3$), 20.7 (CO$\underline{C}$H$_3$); HRMS (ESI) Calc. for (M + NH_4) $C_{20}H_{30}NO_8S$: 444.1687; Found 444.1679.

Methyl 2,3,4-tri-*O*-benzyl-6-thio-6-*S*-*p*-tolyl-α-D-galactopyranoside (20): Scale 1.0 mmol. Prepared from methyl 2,3,4-tri-*O*-benzyl-α-D-galactopyranoside[48] as described in general method 1. The crude residue was purified by flash chromatography (6:1→4:1 hexane–EtOAc) to afford **20** (479 mg, 82%) as a clear viscous oil. R_f 0.44 (4:1 hexane–EtOAc); $[\alpha]_D$ –13.0 (0.3 *c*, $CHCl_3$); ^{1}H NMR (400 MHz; $CDCl_3$): *δ* 7.40–7.26 (m, 15H, Ar), 7.18–7.16 (m, 2H, Ar), 7.07 (d, 2H, *J* = 8.3 Hz, Ar), 5.00 (d, 1H, *J* = 11.4 Hz, PhC$\underline{H}_2$O), 4.87 (d, 1H, *J* = 11.7 Hz, PhC$\underline{H}_2$O), 4.82 (d, 1H, *J* = 12.1 Hz, PhC$\underline{H}_2$O), 4.75 (d, 1H, *J* = 11.7 Hz, PhC$\underline{H}_2$O), 4.69–4.65 (m, 2H, PhC$\underline{H}_2$O, H-1), 4.55 (d, 1H, *J* = 11.4 Hz, PhC$\underline{H}_2$O), 4.02 (dd, 1H, *J* = 10.0, 3.6 Hz, H-2), 3.97 (d, 1H, *J* = 2.5 Hz, H-4), 3.89 (dd, 1H, *J* = 10.0, 2.5 Hz, H-3), 3.77–3.73 (m, 1H, H-5), 3.32 (s, 3H, OC$\underline{H}_3$), 3.07 (dd, 1H *J* = 13.4, 6.5 Hz, H-6a), 2.89 (dd, 1H, *J* = 13.4, 7.1 Hz, H-6b), 2.31 (s, 3H, ArC$\underline{H}_3$); ^{13}C NMR (125 MHz; $CDCl_3$): *δ* 138.8 (Ar), 138.5 (2 × Ar), 136.2 (Ar), 132.4 (Ar), 129.8 (Ar), 129.6 (Ar), 128.4 (3 × Ar), 128.3 (Ar), 128.1 (Ar), 127.7 (2 × Ar) 127.6 (Ar), 127.5 (Ar), 98.9 (C-1), 79.4 (C-3), 76.3 (C-2), 75.7 (C-4), 74.9 (PhC$\underline{H}_2$O), 73.5 (2 × PhC$\underline{H}_2$O), 69.4 (C-5), 55.3 (O$\underline{C}$H$_3$), 34.7 (C-6), 21.0 (Ar$\underline{C}$H$_3$); HRMS (ESI) Calc. for (M + NH_4) $C_{35}H_{42}NO_5S$: 588.2778; Found 588.2764.

Methyl 2,3,4-tri-*O*-benzoyl-6-thio-6-*S*-*p*-tolyl-α-D-mannopyranoside (21): Scale: 1.0 mmol. Prepared from methyl 2,3,4-tri-*O*-benzoyl-α-D-mannopyranoside[9] as described in general method 1. The crude residue was purified by flash chromatography (6:1→2:1 hexane–EtOAc) to afford **21** (594 mg, 97%) as a white amorphous solid. R_f 0.42 (4:1 hexane–EtOAc); $[\alpha]_D$ –112.0 (1.0 *c*, $CHCl_3$); ^{1}H NMR (400 MHz; $CDCl_3$): *δ* 8.13–8.11 (m, 2H, Ar), 7.96–7.94 (m, 2H, Ar), 7.84–7.82 (m, 2H, Ar), 7.64–7.38 (m, 7H, Ar), 7.28–7.24 (m, 4H, Ar), 7.05 (d, 2H, *J* = 8.0 Hz, Ar), 5.87–5.80 (m, 2H, H3, H4), 5.67 (app t, 1H, *J* = 1.7 Hz, H-2), 4.99 (d, 1H, *J* = 1.7 Hz, H-1), 4.27–4.22 (m, 1H, H-5), 3.53 (s, 3H, OC$\underline{H}_3$), 3.29 (dd, 1H, *J* = 13.8, 2.5 Hz, H-6a), 3.20 (dd, 1H, *J* = 13.8, 8.7 Hz, H-6b), 2.31 (s, 3H, ArC$\underline{H}_3$); ^{13}C NMR (125 MHz; $CDCl_3$): *δ* 165.7 (C=O), 165.6 (C=O), 165.4 (C=O), 136.5 (Ar), 133.5 (2 × Ar), 133.1 (Ar), 132.3 (Ar), 130.2 (Ar), 130.0 (Ar), 129.9 (2x, Ar), 129.8 (Ar), 129.4 (Ar), 129.2 (Ar), 129.0 (Ar), 128.6 (Ar), 128.5 (Ar), 128.2 (Ar), 98.5 (C-1), 70.6 (C-2), 70.0 (2 × C3 & C4), 69.7 (C5), 55.4 (O$\underline{C}$H$_3$), 36.8 (C-6), 21.0 (Ar$\underline{C}$H$_3$); HRMS (ESI) Calc. for (M + Na) $C_{35}H_{32}NaO_8S$: 635.1710; Found 635.1706.

***S*-*p*-Tolyl thio(methyl 2,3,4-tri-*O*-benzyl-α-D-glucopyranosid)uronate (22):** Scale 1.0 mmol. Prepared as described in general method 2. The crude residue was purified by flash chromatography (6:1→4:1 hexane–EtOAc) to afford **22** (456 mg, 78%) as a colorless oil. R_f 0.40 (4:1 hexane–EtOAc); $[\alpha]_D$ +15.5 (1.0 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): *δ* 7.38–7.25 (m, 19H, Ar), 4.97 (d, 1H, *J* = 10.9 Hz, PhC$\underline{H}_2$O), 4.86 (d, 1H, *J* = 10.9 Hz, PhC$\underline{H}_2$O), 4.85 (d, 1H, *J* = 12.4 Hz, PhC$\underline{H}_2$O), 4.78 (d, 1H, *J* = 10.4 Hz, PhC$\underline{H}_2$O), 4.73 (d, 1H, *J* = 3.5 Hz, H-1), 4.69 (d, 1H, *J* = 12.4, PhC$\underline{H}_2$O), 4.68 (d, 1H, *J* = 10.4, PhC$\underline{H}_2$O), 4.37 (d, 1H, *J* = 9.7 Hz, H-5), 4.05 (app t, 1H, *J* = 9.3 Hz, H-3), 3.82 (dd, 1H, *J* = 9.7, 9.3 Hz, H-4), 3.62 (dd, 1H, *J* = 9.3, 3.5 Hz, H-2), 3.49 (s, 3H, OC$\underline{H}_3$), 2.40 (s, 3H, ArC$\underline{H}_3$); ^{13}C NMR (125 MHz; $CDCl_3$): *δ* 195.4 (C-6), 140.0 (Ar), 138.6 (Ar), 138.0 (2 × Ar), 134.5 (Ar), 130.2 (Ar), 128.6 (Ar), 128.4 (2 × Ar), 128.2 (Ar), 128.1 (2 × Ar), 128.0 (Ar), 127.8 (Ar), 127.7 (Ar), 123.1 (Ar), 98.8 (C-1), 81.5 (C-3), 79.9 (C-4), 79.3 (C-2), 76.0 (PhC$\underline{H}_2$O), 75.5 (C5), 75.3 (PhC$\underline{H}_2$O), 73.7 (PhC$\underline{H}_2$O), 55.9 (O$\underline{C}$H$_3$), 21.4 (Ar$\underline{C}$H$_3$); HRMS (ESI) Calc. for (M + NH_4) $C_{35}H_{40}O_6S$: 602.2571; Found 602.2572.

***S*-*p*-Tolyl thio(methyl 2,3,4-tri-*O*-benzoyl-α-D-glucopyranosid)uronate (23):** Scale 1.0 mmol. Prepared as described in general method 2. The crude residue was purified by flash chromatography (dry loading) (4:1→3:1 hexane–EtOAc) to afford **23** (539 mg, 86%) as a white amorphous solid. R_f 0.31 (4:1 hexane–EtOAc); $[\alpha]_D$ +52.9 (1.0 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): *δ* 8.03–8.01 (m, 2H, Ar), 7.97–7.95 (m, 2H, Ar), 7.93–7.90 (m, 2H, Ar), 7.57–7.30 (m, 11H, Ar), 7.22 (dd, 2H, *J* = 8.5, 0.6 Hz, Ar), 6.21 (app t, 1H, *J* = 9.8 Hz, H-3), 5.85 (app t, 1H, *J* = 9.7 Hz, H-4), 5.44 (d, 1H, *J* = 3.6 Hz, H-1), 5.38 (dd, *J* = 10.1, 3.6 Hz, H-2), 4.71 (d, 1H, *J* = 9.7 Hz, H-5), 3.59 (s, 3H, OC$\underline{H}_3$), 2.37 (s, 3H, ArC$\underline{H}_3$); ^{13}C NMR (125 MHz; $CDCl_3$): *δ* 194.7 (C-6), 165.8 (C=O), 165.6 (C=O), 165.1 (C=O), 140.0 (Ar), 134.8 (Ar), 133.5 (Ar), 133.3 (Ar), 133.2 (Ar), 130.2 (Ar), 130.0 (Ar), 129.9 (Ar), 129.7 (Ar), 129.1 (Ar), 129.0 (Ar), 128.9 (Ar), 128.5 (Ar), 128.3 (2 × Ar), 122.6 (Ar), 97.6 (C-1), 74.0 (C-5), 71.6 (C-2), 70.1 (C-4), 69.9 (C-3), 56.4 (O$\underline{C}$H$_3$), 21.4 (Ar$\underline{C}$H$_3$); HRMS (ESI) Calc. for (M + Na) $C_{35}H_{30}NaO_9S$: 649.1503; Found 649.1497.

***S*-*p*-Tolyl thio(methyl 2,3,4-tri-*O*-acetyl-α-D-galactopyranosid)uronate (24):** Scale 1.0 mmol. Prepared as described in general method 2. The crude residue was purified by flash chromatography (2:1 hexane–EtOAc) to afford **24** (396 mg, 90%) as a clear viscous oil. R_f 0.36 (2:1 hexane–EtOAc); $[\alpha]_D$ +72.8 (1.0 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): *δ* 7.27–7.23 (m, 4H, Ar), 5.82 (dd, 1H, *J* = 3.3, 1.6 Hz, H-4), 5.43–5.39 (m, 1H, H-3), 5.27–5.24 (m, 2H, H-1, H-2), 4.66 (d, 1H, *J* = 1.6 Hz, H-5), 3.55 (s, 3H, OC$\underline{H}_3$), 2.39 (s, 3H, ArC$\underline{H}_3$), 2.12 (s, 6H, COC$\underline{H}_3$, COC$\underline{H}_3$), 2.00 (s, 3H, COC$\underline{H}_3$); ^{13}C NMR (125 MHz; $CDCl_3$): *δ* 195.0 (C-6), 170.3 (C=O), 169.8

(C=O), 169.5 (C=O), 140.1 (Ar), 134.5 (Ar), 130.2 (Ar), 122.6 (Ar), 97.8 (C-1), 74.2 (C-5), 68.8 (C-4), 67.9 (C-2), 67.2 (C-3), 56.3 (O<u>C</u>H$_3$), 21.4 (CO<u>C</u>H$_3$), 20.8 (CO<u>C</u>H$_3$), 20.6 (CO<u>C</u>H$_3$), 20.5 (Ar<u>C</u>H$_3$); HRMS (ESI) Calc. for (M + NH$_4$) $C_{20}H_{28}NO_9S$: 458.1479; Found 458.1472.

***S*-*p*-Tolyl thio(methyl 2,3,4-tri-*O*-benzyl-α-D-galactopyranosid)uronate (25):** Scale 1.0 mmol. Prepared as described in general method 2. The crude residue was purified by flash chromatography (4:1 hexane–EtOAc) to afford **25** (439 mg, 75%) as a clear viscous oil. R_f 0.42 (4:1 hexane–EtOAc); [α]$_D$ –41.0 (0.2 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): *δ* 7.40–7.29 (m, 15H, Ar), 7.23–7.21 (m, 4H, Ar), 4.92 (d, 1H, *J* = 11.1 Hz, PhC<u>H</u>$_2$O), 4.91 (d, 1H, *J* =3.6 Hz, H-1), 4.88 (d, 1H, *J* = 12.0 Hz, PhC<u>H</u>$_2$O), 4.84 (d, 1H, *J* = 11.7 Hz, PhC<u>H</u>$_2$O), 4.75 (d, 1H, *J* = 11.7 Hz, PhC<u>H</u>$_2$O), 4.71 (d, 1H, *J* = 12.0 Hz, PhC<u>H</u>$_2$O), 4.56 (d, 1H, *J* = 11.1 Hz, PhC<u>H</u>$_2$O), 4.43 (d, 1H, *J* = 1.4 Hz, H-5), 4.39 (dd, 1H, *J* = 2.8, 1.4 Hz, H-4), 4.16 (dd, 1H, *J* = 10.1, 3.6 Hz, H-2), 3.97 (dd, 1H, *J* = 10.1, 2.8 Hz, H-3), 3.49 (s, 3H, OC<u>H</u>$_3$), 2.40 (s, 3H, ArC<u>H</u>$_3$); ^{13}C NMR (125 MHz, $CDCl_3$): *δ* 198.2 (C-6), 139.8 (Ar), 138.5 (Ar), 138.4 (2 × Ar), 134.8 (Ar), 130.1 (Ar), 128.4 (Ar), 128.1 (2 × Ar), 127.8 (Ar), 127.6 (Ar), 127.5 (2 x Ar), 123.4 (Ar), 99.4 (C-1), 78.3 (C-3), 76.4 (C-4), 76.1 (2 ×C-5, C-2), 75.6 (Ph<u>C</u>H$_2$O), 73.9 (Ph<u>C</u>H$_2$O), 73.2 (Ph<u>C</u>H$_2$O), 56.1 (O<u>C</u>H$_3$), 21.4 (Ar<u>C</u>H$_3$); HRMS (ESI) Calc. for (M + NH$_4$) $C_{35}H_{40}NO_6S$: 602.2571; Found 602.2557.

***S*-*p*-Tolyl thio(methyl 2,3,4-tri-*O*-benzoyl-α-D-mannopyranosid)uronate (26):** Scale 1.0 mmol. Prepared as described in general method 2. The crude residue was purified by flash chromatography (4:1→3:1 hexane–EtOAc) to afford **26** (464 mg, 74%) as a white amorphous solid. R_f 0.31 (4:1 hexane–EtOAc); [α]$_D$ –100.5 (1.0 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): *δ* 8.21–8.19 (m, 2H, Ar), 8.01–7.99 (m, 2H, Ar), 7.90–7.88 (m, 2H, Ar), 7.66–7.45 (m, 5H, Ar), 7.40–7.28 (m, 6H, Ar), 7.24 (d, 2H, *J* = 8.0 Hz, Ar), 6.20 (app t, 1H, *J* = 9.7 Hz, H-4), 5.96 (dd, 1H, *J* = 9.7, 3.2 Hz, H-3), 5.77 (dd, 1H, *J* = 3.2, 2.2 Hz, H-2), 5.21 (d, 1H, *J* = 2.2 Hz, H-1), 4.76 (d, 1H, *J* = 9.7 Hz, H-5), 3.65 (s, 3H, OC<u>H</u>$_3$), 2.38 (s, 3H, ArC<u>H</u>$_3$); ^{13}C NMR (125 MHz; $CDCl_3$): *δ* 194.9 (C-6), 165.50 (C=O), 165.35 (C=O), 165.29 (C=O), 140.0 (Ar), 134.8 (Ar), 133.7 (Ar), 133.3 (2 × Ar), 130.2 (Ar), 130.1 (Ar), 129.9 (Ar), 129.8 (Ar), 129.2 (2 × Ar), 129.0 (Ar), 128.7 (Ar), 128.4 (Ar), 122.7 (Ar), 99.1 (C-1), 75.4 (C-5), 69.9 (C-2), 69.4 (C-3), 67.8 (C-4), 56.3 (O<u>C</u>H$_3$), 21.4 (Ar<u>C</u>H$_3$); HRMS (ESI) Calc. for (M + NH$_4$) $C_{35}H_{34}NO_9S$: 644.1949; Found 644.1935.

***N*-(4-Methoxybenzyl) (methyl 2,3,4-tri-*O*-benzyl-α-D-glucopyranosid)uronamide (27):** Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (2:1 hexane–EtOAc) to afford **27** (51 mg, 85%) as a white solid. R_f 0.18 (2:1 hexane–EtOAc); [α]$_D$ –6.1 (1.0 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): *δ* 7.38–7.25 (m, 15H, Ar), 7.15 (d, 2H, *J* = 8.6 Hz, Ar), 6.82 (d, 2H, *J* = 8.6 Hz, Ar), 6.33 (app t, 1H, *J* = 5.5 Hz, CON<u>H</u>CH$_2$), 4.97 (d, 1H, *J* = 10.9 Hz, PhC<u>H</u>$_2$O), 4.85 (d, 1H, *J* = 10.9 Hz, PhC<u>H</u>$_2$O), 4.82 (d, 1H, *J* = 12.0 Hz, PhC<u>H</u>$_2$O), 4.78 (d, 1H, *J* = 10.5 Hz, PhC<u>H</u>$_2$O), 4.67 (d, 1H, *J* = 12.0 Hz, PhC<u>H</u>$_2$O), 4.64–4.61 (m, 2H, H-1, PhC<u>H</u>$_2$O), 4.43 (dd, 1H, *J* = 14.4, 5.5 Hz, NHC<u>H</u>$_2$Ar), 4.34 (dd, 1H, *J* = 14.4, 5.5 Hz, NHC<u>H</u>$_2$Ar), 4.10 (d, 1H, *J* = 9.9 Hz, H-5), 4.02 (app t, 1H, *J* = 9.3 Hz, H-3), 3.79 (s, 3H, ArOC<u>H</u>$_3$), 3.63 (dd, 1H, *J* = 9.9, 9.3 Hz, H-4), 3.57 (dd, 1H, *J* = 9.3, 3.5 Hz, H-2), 3.40 (s, 3H, OC<u>H</u>$_3$); ^{13}C NMR (125 MHz; $CDCl_3$): *δ* 168.6 (C-6), 159.1 (Ar), 138.6 (Ar), 138.0 (Ar), 137.9 (Ar), 129.8 (Ar), 129.3 (Ar), 128.5 (Ar), 128.4 (3 × Ar), 128.2 (Ar), 128.1 (2 × Ar), 128.0 (Ar), 127.8 (Ar), 127.7 (Ar), 114.1 (Ar), 98.5 (C-1), 81.5 (C-3), 80.3 (C-4), 79.2 (C-2), 75.9 (Ph<u>C</u>H$_2$O), 75.2 (Ph<u>C</u>H$_2$O), 73.6 (Ph<u>C</u>H$_2$O), 70.8 (C-5), 55.8 (O<u>C</u>H$_3$), 55.3 (ArO<u>C</u>H$_3$), 43.0 (NH<u>C</u>H$_2$Ar); HRMS (ESI) Calc. for (M + H) $C_{36}H_{40}NO_7$: 598.2799; Found 598.2790.

Methyl 2,3,4-tri-*O*-benzyl-α-D-glucopyranosiduronamide (28): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (1:2 hexane–EtOAc) to afford **28** (32 mg, 66%) as a white solid. R_f 0.24 (1:2 hexane–EtOAc); [α]$_D$ –8.2 (1.0 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): *δ* 7.39–7.28 (m, 15H), 6.12 (br s, 1H, CON<u>H</u>$_a$), 5.79 (br s, 1 H, CON<u>H</u>$_b$), 4.98 (d, 1H, *J* = 10.9 Hz, PhC<u>H</u>$_2$O), 4.87–4.81 (m, 3H, PhC<u>H</u>$_2$O), 4.71–4.65 (m, 3H, PhC<u>H</u>$_2$O, H-1), 4.12 (d, 1H, *J* = 9.7 Hz, H-5), 4.02 (app t, 1H, *J* = 9.5 Hz, H-3), 3.61 (dd, 1H, *J* = 9.7, 9.5 Hz, H-4), 3.57 (dd, 1H, *J* = 9.5, 3.5 Hz, H-2), 3.41 (s, 3H, OC<u>H</u>$_3$); ^{13}C NMR (125 MHz; $CDCl_3$): *δ* 171.4 (C-6), 138.5 (Ar), 138.0 (Ar), 137.7 (Ar), 128.6 (Ar), 128.5 (2 × Ar), 128.4 (2 × Ar), 128.3 (Ar), 128.2 (3 x Ar), 128.1 (Ar), 128.0 (Ar), 127.9 (Ar), 127.7 (Ar), 98.4 (C-1), 81.6 (C-3), 80.2 (C-4), 79.2 (C-2), 75.9 (Ph<u>C</u>H$_2$O), 75.4 (Ph<u>C</u>H$_2$O), 73.6 (Ph<u>C</u>H$_2$O), 70.0 (C-5), 55.8 (O<u>C</u>H$_3$); HRMS (ESI) Calc. for (M + H) $C_{28}H_{32}NO_6$: 478.2224; Found 478.2217.

2-*N*-(Methyl 2,3,4-tri-*O*-benzyl-α-D-glucopyranosiduronoyl)-1,3-di-*O*-benzyl-2-deoxy-glycerol (29): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (4:1→2:1 hexane–EtOAc) to afford **29** (47 mg, 64%) as a white solid. R_f 0.24 (2:1 hexane–EtOAc); [α]$_D$ –6.3 (1.0 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): *δ* 7.40–7.26 (m, 25H, Ar), 6.49 (d, 1H, *J* = 8.4 Hz, CON<u>H</u>CH), 4.96 (d, 1H, *J* = 10.9 Hz, PhC<u>H</u>$_2$O), 4.85–4.82 (m, 2H, PhC<u>H</u>$_2$O), 4.74 (d, 1H, *J* = 10.6 Hz, PhC<u>H</u>$_2$O), 4.69–4.64 (m, 3H, PhC<u>H</u>$_2$O, H-1), 4.52–4.44 (m, 4H, PhC<u>H</u>$_2$O), 4.37–4.33 (m, 1H, NHC<u>H</u>), 4.07 (d, 1H, *J* = 9.9 Hz, H-5), 4.01 (app t, 1H, *J* = 9.3 Hz, H-3), 3.65–3.56 (m, 4H, CHC<u>H</u>$_2$OBn, H-2, H-4), 3.53 (dd, 1H, *J* = 9.3, 5.9 Hz, CHC<u>H</u>$_2$OBn), 3.46 (dd, 1H, *J* = 9.3, 5.9 Hz, CHC<u>H</u>$_2$OBn), 3.40 (s, 3H, OC<u>H</u>$_3$); ^{13}C NMR (125 MHz; $CDCl_3$): *δ* 168.7 (C-6), 138.7 (Ar), 138.1 (2 × Ar), 138.0 (2 × Ar), 128.5 (Ar), 128.4 (2 × Ar), 128.3 (Ar), 128.2 (Ar), 128.0 (3 × Ar), 127.7 (4 × Ar), 127.6(Ar), 98.5 (C-1), 81.5 (C-3), 80.4 (C-4), 79.2 (C-2), 75.9 (Ph<u>C</u>H$_2$O), 75.1 (Ph<u>C</u>H$_2$O), 73.6 (Ph<u>C</u>H$_2$O), 73.1 (2 × Ph<u>C</u>H$_2$O), 70.9 (C-5), 68.3 (CH<u>C</u>H$_2$OBn), 68.2 (CH<u>C</u>H$_2$OBn), 55.8 (O<u>C</u>H$_3$), 48.4 (NH<u>C</u>H); HRMS (ESI) Calc. for (M + H) $C_{45}H_{50}NO_8$: 732.3531; Found 732.3516.

***N*-(Methyl 2,3,4-tri-*O*-benzyl-α-D-glucopyranosiduronoyl)-L-alanine *tert*-butyl ester (30):** Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (2:1 hexane–EtOAc) to afford **30** (43 mg, 71%) as a viscous oil. R_f 0.27 (2:1 hexane–EtOAc); [α]$_D$ –4.64 (1.0 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): *δ* 7.39–7.27 (m, 15H, Ar), 6.83 (d, 1H, *J* = 7.0 Hz, CON<u>H</u>CH), 4.96 (d, 1H, *J* = 10.9 Hz, PhC<u>H</u>$_2$O), 4.85 (d, 1H, *J* = 11.8 Hz, PhC<u>H</u>$_2$O), 4.83 (d, 1H, *J* = 12.7 Hz, PhC<u>H</u>$_2$O), 4.76 (d, 1H, *J* = 10.3 Hz, PhC<u>H</u>$_2$O), 4.73 (d, 1H, *J* = 10.4 Hz, PhC<u>H</u>$_2$O), 4.67 (d, 1H, *J* = 12.1 Hz, PhC<u>H</u>$_2$O), 4.66 (d, 1H, *J* = 3.5 Hz, H-1) 4.46 (dt, 1H, *J* = 14.2, 7.2 Hz, NHC<u>H</u>CO$_2$C(CH$_3$)$_3$), 4.11 (d, 1H, *J* = 9.9 Hz, H-5), 4.02 (app t, 1H, *J* = 9.3 Hz, H-3), 3.61 (dd, 1H, *J* = 9.9, 8.9 Hz, H-4), 3.56 (dd, 1H, *J* = 9.7, 3.5 Hz, H-2), 3.41 (s, 3H, OC<u>H</u>$_3$), 1.48 (s, 9H, NHCHCO$_2$C(C<u>H</u>$_3$)$_3$), 1.36 (d, 3H, *J* = 7.1 Hz, CHC<u>H</u>$_3$); ^{13}C NMR (125 MHz; $CDCl_3$): *δ* 172.0 (C=O), 168.5 (C=O), 138.7 (Ar), 138.0 (Ar), 138.0 (Ar), 128.5 (Ar), 128.4 (Ar), 128.3 (Ar), 128.3 (Ar), 128.2 (Ar), 128.0 (Ar), 127.9 (Ar), 127.7 (Ar), 127.6 (Ar), 98.4 (C-1), 82.2 (NHCHCO$_2$<u>C</u>(CH$_3$)$_3$), 81.5 (C-3), 80.4 (C-4), 79.2 (C-2), 75.9 (Ph<u>C</u>H$_2$O), 75.2 (Ph<u>C</u>H$_2$O), 73.6 (Ph<u>C</u>H$_2$O), 70.7 (C-5), 55.8 (O<u>C</u>H$_3$), 48.5 (NH<u>C</u>HCO$_2$C(CH$_3$)$_3$), 28.0 (NHCHCO$_2$C(<u>C</u>H$_3$)$_3$), 18.6 (CH<u>C</u>H$_3$); HRMS (ESI) Calc. for (M + Na) $C_{35}H_{43}NNaO_8$: 628.2881; Found 628.2876.

***N*-(Methyl 2,3,4-tri-*O*-benzyl-α-D-glucopyranosiduronoyl)-*O*-*tert*-butyl-L-serine *tert*-butyl ester (31):** Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (4:1→2:1 hexane–EtOAc) to afford **31** (42 mg, 70%) as a clear viscous oil. R_f 0.47 (2:1 hexane–EtOAc); [α]$_D$ +11.3 (1.0 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): *δ* 7.39–7.25 (m, 15H, Ar), 7.02 (d, 1H, *J* = 7.8 Hz, CON<u>H</u>CH), 4.94 (d, 1H, *J* = 10.8 Hz, PhC<u>H</u>$_2$O), 4.83 (d, 1H, *J* = 10.8 Hz, PhC<u>H</u>$_2$O), 4.83 (d, 1H, *J* = 12.3 Hz, PhC<u>H</u>$_2$O), 4.78 (d, 1H, *J* = 10.2 Hz, PhC<u>H</u>$_2$O), 4.73 (d, 1H, *J* = 10.3 Hz, PhC<u>H</u>$_2$O), 4.68 (d, 1H, *J* = 3.5 Hz, H-1), 4.68 (d, 1H, *J* = 12.3 Hz, PhC<u>H</u>$_2$O), 4.65–4.62 (m, 1H, NHC<u>H</u>CH$_2$), 4.15 (d, 1H, *J* = 9.9 Hz, H-5), 4.02 (app t, 1H, *J* = 9.3 Hz, H-3), 3.77 (dd, 1H, *J* = 8.8, 2.9 Hz, CHC<u>H</u>$_2$O), 3.63 (app t, 1H, *J* = 9.4 Hz, H-4), 3.59–3.57 (m, 2H, H-2, CHC<u>H</u>$_2$O), 3.42 (s, 3H, OC<u>H</u>$_3$), 1.48 (s, 9H, C(C<u>H</u>$_3$)$_3$), 1.11 (s, 9H, C(C<u>H</u>$_3$)$_3$); ^{13}C NMR (125 MHz; $CDCl_3$): *δ* 169.2 (C=O), 168.7 (C=O), 138.7 (Ar), 138.1 (2 × Ar), 128.5 (Ar), 128.4 (Ar), 128.3(2 × Ar), 128.2 (Ar), 128.0 (2 × Ar), 127.6 (Ar), 98.4 (C-1), 82.0 (<u>C</u>(CH$_3$)$_3$), 81.5 (C-3), 80.6 (C-3), 79.3

(C-2), 76.0 (PhCH$_2$O), 75.1 (PhCH$_2$O), 73.6 (PhCH$_2$O), 73.0 (C(CH$_3$)$_3$), 70.9 (C-5), 62.1 (CHCH$_2$O), 55.7 (OCH$_3$), 53.1 (NHCH), 28.1 (C(CH$_3$)$_3$), 27.4 (C(CH$_3$)$_3$); HRMS (ESI) Calc. for (M + H) $C_{39}H_{52}NO_9$: 678.3637; Found 678.3631.

***N*-(Methyl 2,3,4-tri-*O*-benzyl-α-D-glucopyranosiduronoyl)-L-threonine *tert*-butyl ester (32):** Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (2:1 hexane–EtOAc) to afford **32** (40 mg, 63%) as a oil. R_f 0.22 (2:1 hexane–EtOAc); [α]$_D$ –14.6 (1.0 *c*, CHCl$_3$); ^{1}H NMR (500 MHz; CDCl$_3$): *δ* 7.39–7.25 (m, 15H, Ar), 6.97 (d, 1H, *J* = 8.6 Hz, CONHCH), 4.96 (d, 1H, *J* = 10.8 Hz, PhCH$_2$O), 4.84 (d, 1H, *J* = 10.8 Hz, PhCH$_2$O), 4.83 (d, 1H, *J* = 12.4 Hz, PhCH$_2$O), 4.78–4.74 (m, 2H, PhCH$_2$O), 4.68 (d, 1H, *J* = 12.4 Hz, PhCH$_2$O), 4.68 (d, 1H, *J* = 3.5 Hz, H-1), 4.54 (dd, 1H, *J* = 8.6, 2.9 Hz, NHCHCH), 4.30–4.29 (m, 1H, CHCHOH), 4.20 (d, 1H, *J* = 10.0 Hz, H-5), 4.04 (app t, 1H, *J* = 9.2 Hz, H-3), 3.65 (dd, 1H, *J* = 9.8, 9.0 Hz, H-4), 3.58 (dd, 1H, *J* = 9.7, 3.5 Hz, H-2), 3.41 (s, 3H, OCH$_3$), 2.05 (s, 1H, CHOH), 1.49 (s, 9H, C(CH$_3$)$_3$), 1.21 (d, 3H, *J* = 6.4 Hz, CHCH$_3$); ^{13}C NMR (125 MHz; CDCl$_3$): *δ* 169.8 (C=O), 169.7 (C=O), 138.6 (Ar), 138.0 (2 × Ar), 128.6 (Ar), 128.4 (Ar), 128.3 (Ar), 128.2 (2 × Ar), 128.1 (Ar), 127.9 (Ar), 127.7 (Ar), 127.6 (Ar), 98.4 (C-1), 82.7 (C(CH$_3$)$_3$), 81.5 (C-3), 80.6 (C-4), 79.2 (C-2), 76.0 (PhCH$_2$O), 75.2 (PhCH$_2$O), 73.6 (PhCH$_2$O), 70.6 (C-5), 68.4 (CHCHOH), 57.5 (NHCH), 55.8 (OCH$_3$), 28.0 (C(CH$_3$)$_3$), 20.0 (CHCH$_3$); HRMS (ESI) Calc. for (M + H) $C_{36}H_{46}NO_9$: 636.3167; Found 636.3161.

***N*-(4-Methoxybenzyl) (methyl 2,3,4-tri-*O*-benzoyl-α-D-glucopyranosid)uronamide (33):** Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (3:2→1:1 hexane–EtOAc) to afford **33** (55 mg, 86%) as a clear viscous oil. R_f 0.43 (1:1 hexane–EtOAc); [α]$_D$ +99.7 (1.0 *c*, CHCl$_3$); ^{1}H NMR (500 MHz; CDCl$_3$): *δ* 8.04–7.99 (m, 4H, Ar), 7.91–7.89 (m, 2H, Ar), 7.56–7.50 (m, 2H, Ar), 7.48–7.38 (m, 5H, Ar), 7.34–7.30 (m, 2H, Ar), 7.29–7.26 (m, 2H, Ar), 6.93–6.91 (m, 2H, Ar), 6.71 (app t, 1H, *J* = 5.6 Hz, CONHCH$_2$), 6.20 (app t, 1H, *J* = 9.9 Hz, H-3), 5.68 (app t, 1H, *J* = 9.9 Hz, H-4), 5.30 (d, 1H, *J* = 3.6 Hz, H-1), 5.24 (dd, 1H, *J* = 10.2, 3.6 Hz, H-2), 4.56 (d, 1H, *J* = 10.2 Hz, H-5), 4.49 (dd, 1H, *J* = 14.5, 6.0 Hz, NHCH$_2$Ar), 4.35 (dd, 1H, *J* = 14.5, 5.4 Hz, NHCH$_2$Ar), 3.84 (s, 3H, ArOCH$_3$), 3.50 (s, 3H, OCH$_3$); ^{13}C NMR (125 MHz; CDCl$_3$): *δ* 166.9 (C=O), 165.9 (C=O), 165.6 (C=O), 165.5 (C=O), 159.2 (Ar), 133.5 (Ar), 133.2 (Ar), 133.1 (Ar), 130.0 (2 × Ar), 129.8 (Ar), 129.7 (Ar), 129.4 (Ar), 129.3 (Ar), 129.2 (Ar), 128.9 (Ar), 128.5 (Ar), 128.3 (2 × Ar), 114.2 (Ar), 97.2 (C-1), 71.9 (C-2), 70.4 (C-4), 69.8 (C-3), 68.7 (C-5), 56.2 (OCH$_3$), 55.3 (ArOCH$_3$), 42.7 (NHCH$_2$Ar); HRMS (ESI) Calc. for (M + H) $C_{36}H_{34}NO_{10}$: 640.2168; Found 640.2177.

***N*-(2-Hydroxyethyl) (methyl 2,3,4-tri-*O*-benzoyl-α-D-glucopyranosid)uronamide (34):** Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (20:1 CH_2Cl_2–CH_3OH) to afford **34** (48 mg, 86%) as a clear viscous oil. R_f 0.31 (1:1 CH_2Cl_2–CH_3OH); [α]$_D$ +75.0 (1.0 *c*, CHCl$_3$); ^{1}H NMR (600 MHz; CDCl$_3$): *δ* 8.01–7.99 (m, 4H, Ar), 7.90–7.88 (m, 2H, Ar), 7.56–7.50 (m, 2H, Ar), 7.46–7.38 (m, 5H, Ar), 7.32–7.29 (m, 2H, Ar), 6.89 (app t, 1H, *J* = 5.8 Hz, CONHCH$_2$), 6.22 (app t, 1H, *J* = 9.9 Hz, H-3), 5.62 (app t, 1H, *J* = 9.9 Hz, H-4), 5.34 (d, 1H, *J* = 3.6 Hz, H-1), 5.29 (dd, 1H, *J* = 10.1, 3.6 Hz, H-2), 4.50 (d, 1H, *J* = 10.2 Hz, H-5), 3.84–3.81 (m, 1H, CH$_2$CH$_2$OH), 3.71–3.69 (m, 1H, CH$_2$CH$_2$O), 3.60 (dddd, 1H, *J* = 14.2, 5.8, 5.8, 3.2 Hz, NHCH$_2$CH$_2$), 3.50 (s, 3H, OCH$_3$), 3.30 (dddd, 1H, *J* = 13.9, 8.1, 5.6, 3.4 Hz, NHCH$_2$CH$_2$), 2.76 (s, 1H, CH$_2$OH); ^{13}C NMR (125 MHz; CDCl$_3$): *δ* 168.2 (C=O), 166.1 (C=O), 165.9 (C=O), 165.6 (C=O), 133.6 (Ar), 133.4 (Ar), 133.2 (Ar), 130.0 (2 × Ar) 129.7 (Ar), 129.1 (Ar), 128.9 (Ar), 128.8 (Ar), 128.5 (Ar), 128.4 (Ar), 128.3 (Ar), 97.3 (C-1), 71.9 (C-2), 71.0 (C-4), 69.5 (C-3), 69.1 (C-5), 61.2 (CH$_2$CH$_2$O), 56.2 (OCH$_3$), 42.2 (NHCH$_2$CH$_2$); HRMS (ESI) Calc. for (M + H) $C_{30}H_{30}NO_{10}$: 564.1864; Found 564.1859.

2-*N*-(Methyl 2,3,4-tri-*O*-benzoyl-α-D-glucopyranosiduronoyl)-1,3-di-*O*-benzyl-2-deoxy-glycerol (35): Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (2:1 hexane–EtOAc) to afford **35** (56 mg, 73%) as a clear viscous oil. R_f 0.23 (2:1 hexane–EtOAc); [α]$_D$ +70.6 (1.0 *c*, CHCl$_3$); ^{1}H NMR (500 MHz; CDCl$_3$): *δ* 8.03–7.99 (m, 4H, Ar), 7.92–7.90 (m, 2H, Ar), 7.57–7.30 (m, 19H, Ar), 6.88 (d, 1H, *J* = 8.5 Hz, CONHCH), 6.20 (app t, 1H, *J* = 9.9 Hz, H-3), 5.63 (app t, 1H, *J* = 9.9 Hz, H-4), 5.34 (d, 1H, *J* = 3.6 Hz, H-1), 5.29 (dd, 1H, *J* = 10.2, 3.6 Hz, H-2), 4.62 (d, 1H, *J* = 12.0 Hz, PhCH$_2$O), 4.59 (d, 1H, *J* = 12.0 Hz, PhCH$_2$O), 4.54 (d, 1H, *J* = 12.0 Hz, PhCH$_2$O), 4.51 (d, 1H, *J* = 12.0 Hz, PhCH$_2$O), 4.50 (d, 1H, *J* = 10.1 Hz, H-5), 4.31–4.28 (m, 1H, NHCH), 3.73 (dd, 1H, *J* = 9.3, 3.9 Hz, CHCH$_2$OBn), 3.69 (dd, 1H, *J* = 9.4, 4.3 Hz, CHCH$_2$OBn), 3.65 (dd, 1H, *J* = 9.3, 6.2 Hz, CHCH$_2$OBn), 3.56 (dd, 1H, *J* = 9.4, 5.9 Hz, CHCH$_2$OBn), 3.50 (s, 3H, OCH$_3$); ^{13}C NMR (125 MHz; CDCl$_3$): *δ* 166.9 (C=O), 165.9 (C=O), 165.6 (C=O), 165.4 (C=O), 138.2 (Ar), 138.1 (Ar), 133.5 (Ar), 133.2 (Ar), 133.1 (Ar), 130.0 (2 × Ar), 129.7 (Ar), 129.3 (Ar), 129.2 (Ar), 128.9 (Ar), 128.5 (Ar), 128.4 (2 × Ar), 128.3 (2 × Ar), 127.8 (Ar), 127.7 (2 × Ar), 127.6 (Ar), 97.2 (C-1), 73.2 (PhCH$_2$O), 73.1 (PhCH$_2$O), 71.9 (C-2), 70.4 (C-4), 69.9 (C-3), 68.8 (C-5), 68.2 (CHCH$_2$OBn), 68.1 (CHCH$_2$OBn), 56.2 (OCH$_3$), 48.2 (NHCH); HRMS (ESI) Calc. for (M + H) $C_{45}H_{44}NO_{11}$: 774.2909; Found 774.2893.

***N*-(Methyl 2,3,4-tri-*O*-benzoyl-α-D-glucopyranosiduronoyl)-L-threonine *tert*-butyl ester (36):** Scale 0.1 mmol. Following the general method 3, the crude residue was purified by flash chromatography (3:2→1:1 hexane–EtOAc) to afford **36** (28 mg, 41%) as a clear viscous oil. R_f 0.52 (1:1 hexane–EtOAc); [α]$_D$ +67.1 (1.0 *c*, CHCl$_3$); ^{1}H NMR (600 MHz; CDCl$_3$): *δ* 8.02–7.97 (m, 4H, Ar), 7.90–7.88 (m, 2H, Ar), 7.56–7.36 (m, 7H, Ar), 7.32–7.29 (m, 2H, Ar), 7.23 (d, 1H, *J* = 8.7 Hz, CONHCH), 6.21 (app t, 1H, *J* = 9.9 Hz, H-3), 5.68 (app t, 1H, *J* = 9.9 Hz, H-4), 5.37 (d, 1H, *J* = 3.6 Hz, H-1), 5.31 (dd, 1H, *J* = 10.2, 3.6 Hz, H-2), 4.56 (d, 1H, *J* = 10.2 Hz, H-5), 4.47 (dd, 1H, *J* = 8.7, 3.2 Hz, NHCH), 4.31–4.30 (m, 1H, CHCHOH), 3.52 (s, 3H, OCH$_3$), 2.27 (s, 1H, CHOH), 1.50 (s, 9H, C(CH$_3$)$_3$), 1.31 (d, 3H, *J* = 6.5 Hz, CHCH$_3$); ^{13}C NMR (125 MHz; CDCl$_3$): *δ* 169.6 (C=O), 167.7 (C=O), 165.8 (C=O), 165.7 (C=O), 165.6 (C=O), 133.5 (Ar), 133.2 (2 × Ar) 130.0 (Ar), 129.7 (Ar), 129.1 (2 × Ar), 128.9 (Ar), 128.5 (Ar), 128.4 (Ar), 128.3 (2 × Ar), 97.3 (C-1), 82.8 (C(CH$_3$)$_3$), 71.8 (C-2), 70.7 (C-4), 69.8 (C-3), 68.9 (2 × C-5, CHCHOH), 57.5 (NHCH), 56.3 (OCH$_3$), 28.0 (C(CH$_3$)$_3$), 20.1 (CHCH$_3$); HRMS (ESI) Calc. for (M + H) $C_{36}H_{40}NO_{12}$: 678.2545; Found 678.2531.

***N*-(4-Methoxybenzyl) (methyl 2,3,4-tri-*O*-acetyl-α-D-galactopyranoside)uronamide (37):** Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (3:2 EtOAc–hexane) to afford **37** (41 mg, 91%) as a clear viscous oil. R_f 0.25 (3:2 EtOAc–hexane); [α]$_D$ +116.5 (1.0 *c*, CHCl$_3$); ^{1}H NMR (500 MHz; CDCl$_3$): *δ* 7.24–7.21 (m, 2H, Ar), 6.90–6.87 (m, 2H, Ar), 6.81 (app t, 1H, *J* = 5.8 Hz, CONHCH$_2$), 5.88 (dd, 1H, *J* = 3.4, 1.7 Hz, H-4), 5.44 (dd, 1H, *J* = 10.5, 3.4 Hz, H-3), 5.12–5.08 (m, 2H, H-1, H-2), 4.62 (dd, 1H, *J* = 14.6, 7.0 Hz, NHCH$_2$Ar), 4.51 (d, 1H, *J* = 1.6 Hz, H-5), 4.22 (dd, 1H, *J* = 14.6, 5.0 Hz, NHCH$_2$), 3.82 (s, 3H, ArOCH$_3$), 3.43 (s, 3H, OCH$_3$), 2.10 (s, 3H, COCH$_3$), 1.99 (s, 3H, COCH$_3$), 1.95 (s, 3H, COCH$_3$); ^{13}C NMR (125 MHz; CDCl$_3$): *δ* 170.5 (C=O), 169.7 (C=O), 169.3 (C=O), 166.3 (C=O), 159.2 (Ar), 130.1 (Ar), 129.2 (Ar), 114.1 (Ar), 97.5 (C-1), 69.5 (C-5), 69.0 (C-4), 68.0 (C-2), 67.1 (C-3), 56.1 (OCH$_3$), 55.3 (ArOCH$_3$), 42.5 (NHCH$_2$), 20.8 (COCH$_3$), 20.6 (COCH$_3$), 20.4 (COCH$_3$); HRMS (ESI) Calc. for (M + Na) $C_{21}H_{27}NNaO_{10}$: 476.1527; Found 476.1516.

***N*-(Methyl 2,3,4-tri-*O*-acetyl-α-D-galactopyranosiduronoyl)-*O*-*tert*-butyl-L-serine *tert*-butyl ester (38):** Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (3:2 →1:1 hexane–EtOAc) to afford **38** (34 mg, 64%) as a clear viscous oil. R_f 0.48 (1:1 hexane–EtOAc); [α]$_D$ +101.8 (1.0 *c*, CHCl$_3$); ^{1}H NMR (500 MHz; CDCl$_3$): *δ* 7.29 (d, 1H, *J* = 8.1 Hz, CONHCH), 5.87 (dd, 1H, *J* = 3.4, 1.6 Hz, H-4), 5.44 (dd, 1H, *J* = 10.7, 3.4 Hz, H-3), 5.18 (dd, 1H, *J* = 10.7, 3.6 Hz, H-2), 5.15 (d, 1H, *J* = 3.6 Hz, H-1), 4.63 (app dt, 1H, *J* = 8.6, 3.0 Hz, NHCHCH$_2$), 4.51 (d, 1H, *J* = 1.5 Hz, H-5), 3.82 (dd, 1H, *J* = 8.8, 3.1 Hz, CHCH$_2$O), 3.48 (dd, 1H, *J* = 8.8, 3.0 Hz, CHCH$_2$O), 3.47 (s,

3H, OCH_3), 2.12 (s, 3H, COCH_3), 2.08 (s, 3H, COCH_3), 2.00 (s, 3H, COCH_3), 1.49 (s, 9H, C(CH_3)$_3$), 1.19 (s, 9H, C(CH_3)$_3$); ^{13}C NMR (125 MHz; $CDCl_3$): δ 170.5 (C=O), 169.7 (C=O), 169.3 (C=O), 169.0 (C=O), 166.2 (C=O), 97.4 (C-1), 82.0 (OC(CH$_3$)$_3$), 73.2 (OC(CH$_3$)$_3$), 69.3 (C-5), 68.9 (C-4), 68.0 (C-2), 67.3 (C-3), 62.5 (CHCH$_2$O), 56.1 (OCH$_3$), 52.9 (NHCHCH$_2$), 28.0 (C(CH$_3$)$_3$), 27.4 (C(CH$_3$)$_3$), 20.8 (COCH$_3$), 20.7 (COCH$_3$), 20.6 (COCH$_3$); HRMS (ESI) Calc. for (M + H) $C_{24}H_{40}NO_{12}$: 534.2545; Found 534.2538.

***N*-(Methyl 2,3,4-tri-*O*-acetyl-α-D-galactopyranosiduronoyl)-L-alanine *tert*-butyl ester (39):** Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (3:2→1:1 hexane–EtOAc) to afford **39** (29 mg, 63%) as a clear viscous oil. R_f 0.20 (3:2 hexane–EtOAc); $[\alpha]_D$ +92.7 (1.0 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): δ 7.15 (d, 1H, *J* = 7.6 Hz, CONHCH), 5.84 (dd, 1H, *J* = 3.4, 1.7 Hz, H-4), 5.44 (dd, 1H, *J* = 10.1, 3.4 Hz, H-3), 5.16–5.12 (m, 2H, H-1, H-2), 4.52–4.46 (m, 2H, H-5, NHCHCH$_3$), 3.45 (s, 3H, OCH_3), 2.11 (s, 3H, COCH_3), 2.07 (s, 3H, COCH_3), 1.99 (s, 3H, COCH_3), 1.49 (s, 9H, C(CH_3)$_3$), 1.38 (d, 3H, *J* = 7.1 Hz, CHCH_3); ^{13}C NMR (125 MHz; $CDCl_3$): δ 171.7 (C=O), 170.5 (C=O), 169.7 (C=O), 169.2 (C=O), 165.9 (C=O), 97.5 (C-1), 82.3 (C(CH$_3$)$_3$), 69.4 (C-5), 69.0 (C-4), 68.0 (C-2), 67.1 (C-3), 56.1 (OCH$_3$), 48.3 (NHCHCH$_3$), 28.0 (C(CH$_3$)$_3$), 20.8 (COCH$_3$), 20.6 (COCH$_3$), 20.4 (COCH$_3$), 18.7 (CHCH$_3$); HRMS (ESI) Calc. for (M + Na) $C_{20}H_{31}NNaO_{11}$: 484.1789 Found 484.1779.

***N*-(4-Methoxybenzyl) (2,3,4-tri-*O*-benzyl-α-D-galactopyranosid)uronamide (40):** Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (2:1 hexane–EtOAc) to afford **40** (50 mg, 83%) as a clear viscous oil. R_f 0.20 (2:1 hexane–EtOAc); $[\alpha]_D$ +60.1 (1.0 *c*, $CHCl_3$); ^{1}H NMR (400 MHz; $CDCl_3$): δ 7.39–7.26 (m, 15H, Ar), 7.11 (d, 2H, *J* = 8.5 Hz, Ar), 6.79 (app t, 1H, *J* = 5.6 Hz, CONHCH$_2$), 6.73 (d, 2H, *J* = 8.6 Hz, Ar), 4.92 (d, 1H, *J* = 10.9 Hz, PhCH_2O), 4.85 (d, 1H, *J* = 12.1 Hz, PhCH_2O), 4.81 (d, 1H, *J* = 11.8 Hz, PhCH_2O), 4.76 (d, 1H, *J* = 11.8 Hz, PhCH_2O), 4.70–4.67 (m, 2H, PhCH_2O, H-1), 4.58 (d, 1H, *J* = 10.9 Hz, PhCH_2O), 4.48–4.42 (m, 2H, H-3, NHCH_2Ar), 4.35–4.29 (m, 2H, NHCH_2Ar, H-5), 4.05–3.98 (m, 2H, H-2, H-4), 3.76 (s, 3H, ArOCH_3), 3.36 (s, 3H, OCH_3); ^{13}C NMR (125 MHz; $CDCl_3$): δ 168.6 (C-6), 159.0 (Ar), 138.7 (Ar), 138.5 (2 × Ar), 129.7 (Ar), 129.1 (Ar), 128.4 (2 × Ar), 128.2 (Ar), 128.1 (Ar), 128.0 (Ar), 127.8 (Ar), 127.6 (Ar), 127.5 (2 × Ar) , 114.0 (Ar), 99.2 (C-1), 78.4 (C-4), 76.6 (C-3), 75.7 (C-2), 75.4 (PhCH$_2$O), 73.7 (PhCH$_2$O), 73.0 (PhCH$_2$O), 71.3 (C-5), 55.9 (OCH$_3$), 55.3 (ArOCH$_3$), 42.6 (NHCH$_2$Ar); HRMS (ESI) Calc. for (M + H) $C_{36}H_{40}NO_7$: 598.2799; Found 598.2790.

***N*-(4-Methoxybenzyl) (2,3,4-tri-*O*-benzoyl-α-D-mannopyranosid)uronamide (41):** Scale 0.1 mmol. Prepared as described in general method 3. The crude residue was purified by flash chromatography (3:2→1:1 hexane–EtOAc) to afford **41** (63 mg, 98%) as a clear viscous oil. R_f 0.43 (1:1 hexane–EtOAc); $[\alpha]_D$ –19.0 (1.0 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): δ 8.07–8.05 (m, 4H, Ar), 7.87 (d, 2H, *J* = 7.4 Hz, Ar), 7.64–7.39 (m, 7H, Ar), 7.31–7.26 (m, 4H, Ar), 6.89 (d, 2H, *J* = 8.5 Hz, Ar), 6.80 (app t, 1H, *J* = 5.5 Hz, CONHCH$_2$), 6.04 (dd, 1H, *J* = 10.0, 10.0 Hz, H-4), 5.93 (dd, 1H, *J* = 10.1, 3.2 Hz, H-3), 5.69 (dd, 1H, *J* = 2.9, 1.9 Hz, H-2), 5.04 (d, 1H, *J* = 1.3 Hz, H-1), 4.58 (d, 1H, *J* = 10.0 Hz, H-5), 4.50 (dd, 1H, *J* = 14.5, 6.0 Hz, NHCH_2Ar), 4.38 (dd, 1H, *J* = 14.6, 5.4 Hz, NHCH_2Ar), 3.82 (s, 3H, ArOCH_3), 3.55 (s, 3H, OCH_3); ^{13}C NMR (125 MHz; $CDCl_3$): δ 167.3 (C=O), 165.7 (C=O), 165.41 (C=O), 165.37 (C=O), 159.1 (Ar), 133.6 (Ar), 133.3 (Ar), 133.1 (Ar), 130.0 (Ar), 129.9 (2 × Ar), 129.8 (Ar), 129.5 (Ar), 129.2 (2 × Ar), 129.1 (Ar), 128.7 (Ar), 128.4 (Ar), 128.3 (Ar), 114.2 (Ar), 98.8 (C-1), 70.2 (C-2), 69.7 (C-5), 69.5 (C-3), 67.8 (C-4), 56.1 (OCH$_3$), 55.3 (ArOCH$_3$), 42.6 (NHCH$_2$Ar); HRMS (ESI) Calc. for (M + H) $C_{36}H_{34}NO_{10}$: 640.2177 Found 640.2163.

***N*-(4-Methoxybenzyl) (methyl 2,3-di-*O*-benzoyl-4-deoxy-β-L-*threo*-hex-4-enopyranosid)uronamide (42):** To a solution of **23** (63 mg, 0.1 mmol) in CH_2Cl_2 (1 mL) was added *p*-methoxybenzylamine (19 μL, 0.15 mmol), followed by triethylamine (62 μL, 0.45 mmol). The reaction mixture was stirred for 10 h at room temperature, then diluted with CH_2Cl_2 (10 mL), washed with sat. NH_4Cl (aq.), brine, dried over $MgSO_4$ and concentrated. The crude reside was purified by flash chromatography (2:1→3:2 hexane–EtOAc) to afford **42** (39 mg, 75%) as a clear viscous oil. R_f 0.19 (2:1 hexane–EtOAc); $[\alpha]_D$ +75.3 (1.2 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): δ 8.06–8.01 (m, 4H, Ar), 7.59–7.54 (m, 2H, Ar), 7.46–7.41 (m, 4H, Ar), 7.29–7.26 (m, 2H, Ar), 6.93–6.90 (m, 2H, Ar), 6.80 (app t, 1H, *J* = 5.8 Hz, CONHCH$_2$), 6.30 (d, 1H, *J* = 3.0 Hz, H-4), 6.13 (dd, 1H, *J* = 8.0, 3.0 Hz, H-3), 5.54 (dd, 1H, *J* = 8.0, 2.5 Hz, H-2), 5.35 (d, 1H, *J* = 2.6 Hz, H-1), 4.57 (dd, 1H, *J* = 14.6, 6.1 Hz, NHCH_2Ar), 4.46 (dd, 1H, *J* = 14.6, 5.5 Hz, NHCH_2Ar), 3.83 (s, 3H, ArOCH_3), 3.54 (s, 3H, OCH_3); ^{13}C NMR (125 MHz; $CDCl_3$): δ 165.8 (C=O), 165.6 (C=O), 160.5 (C=O), 159.2 (Ar), 143.7 (C-5), 133.6 (Ar), 133.3 (Ar), 130.0 (Ar), 129.8 (Ar), 129.8 (Ar), 129.5 (Ar), 129.3 (Ar), 129.0 (Ar), 128.5 (Ar), 128.4 (Ar), 114.2 (Ar), 104.9 (C-4), 98.9 (C-1), 69.9 (C-2), 66.8 (C-3), 57.1 (OCH$_3$), 55.3 (ArOCH$_3$), 43.0 (NHCH$_2$Ar); HRMS (ESI) Calc. for (M + Na) $C_{29}H_{27}NNaO_8$: 540.1629; Found 540.1633.

2-(Trimethylsilyl)ethyl 2,3,4-tri-*O*-acetyl-α-L-rhamnopyranosyl-(1→3)-4,6-*O*-benzylidene-β-D-glucopyranoside and 2-(Trimethylsilyl)ethyl 2,3,4-tri-*O*-acetyl-α-L-rhamnopyranosyl-(1→2)-4,6-*O*-benzylidene-β-D-glucopyranoside (45/45a): A mixture of trichloroacetimidate **44**[43] (854 mg, 1.96 mmol), alcohol **43**[42] (869 mg, 2.36 mmol), and 4 Å molecular sieves (4 g) in CH_2Cl_2 (80 mL) was stirred for 30 min at room temperature under an argon atmosphere. The mixture was cooled to –78 °C, then TBSOTf (46 μL, 0.2 mmol) was added. The reaction mixture was stirred for 20 min at –78 °C, then the TBSOTf was quenched by the addition of Et_3N (28 μL). The mixture was filtered through Celite and concentrated. The crude residue was purified by flash chromatography (2:1 hexane–EtOAc) to afford **45/45a** (904mg, 72%, **45**:**45a** = 2:1) as a white solid, which was an inseparable mixture. R_f 0.27 (2:1 hexane–EtOAc); ^{1}H NMR (400 MHz; $CDCl_3$): δ 7.49–7.45 (m, 6H), 7.39–7.36 (m, 3H), 7.34–7.31 (m, 6H), 5.55 (s, 2H), 5.51 (s, 1H), 5.35–5.27 (m, 9H), 5.20 (d, 2H, *J* = 1.5 Hz, H-1' of **45**), 5.07 (t, 1H, *J* = 10.0 Hz), 4.97 (t, 2H, *J* = 10.0 Hz), 4.49 (d, 1H, *J* = 7.7 Hz, H-1 of **45a**), 4.40–4.32 (m, 7H), 4.20 (dq, 2H, *J* = 9.9, 6.3 Hz), 4.03–3.74 (m, 9H), 3.66–3.54 (m, 9H), 3.51–3.38 (m, 4H), 2.71 (d, 1H, *J* = 2.8 Hz), 2.41 (d, 1H, *J* = 2.7 Hz), 2.14 (s, 3H), 2.13 (s, 6H), 2.03 (s, 3H), 1.99 (s, 6H), 1.97 (s, 3H), 1.95 (s, 6H), 1.20 (d, 3H, *J* = 6.3 Hz), 1.06–0.92 (m, 6H), 0.85 (d, 6H, *J* = 6.2 Hz), 0.04 (s, 9H), 0.03 (s, 18H); ^{13}C NMR (125 MHz; $CDCl_3$): δ 170.2, 170.2, 170.2, 170.0, 169.9, 137.2, 137.0, 129.3, 129.0, 128.4, 128.0, 126.3, 126.2, 103.0 (C-1 of **45**), 101.8, 101.7 (C-1 of **45a**), 101.6, 97.7 (C-1' of **45**), 97.6 (C-1' of **45a**), 80.7, 79.0, 77.1, 76.4, 75.7, 74.9, 71.3, 71.17, 69.7, 69.7, 69.3, 69.3, 68.8, 68.7, 68.2, 68.0, 66.8, 66.4, 66.0, 65.9, 21.0, 21.0, 20.8, 20.8, 18.5, 18.3, 17.3, 16.8, –1.4, –1.5; HRMS (ESI) Calc. for (M + Na) $C_{30}H_{44}NaO_{13}Si$: 663.2443; Found 663.2440.

2-(Trimethylsilyl)ethyl 2,3,4-tri-*O*-acetyl-α-L-rhamnopyranosyl-(1→3)-2-*O*-acetyl-4,6-*O*-benzylidene-β-D-glucopyranoside (S1) and 2-(Trimethylsilyl)ethyl 2,3,4-tri-*O*-acetyl-α-L-rhamnopyranosyl-(1→2)-3-*O*-acetyl-4,6-*O*-benzylidene-β-D-glucopyranoside (S1a): To a solution of **45/45a** (904mg, 1.41 mmol) in pyridine (14 mL) and Ac_2O (7 mL) was added DMAP (17 mg, 0.14 mmol). The reaction mixture was stirred for 3 h at room temperature, then the Ac_2O was quenched by addition of CH_3OH (7 mL). Then, the mixture was co-concentrated with toluene (3 ×). The crude residue was purified by flash chromatography (1:1 hexane–EtOAc) to afford **S1/S1a** (934 mg, 97%, **S1**:**S1a** = 2:1) as a white solid, which was an inseparable mixture. R_f 0.56 (1:1 hexane–EtOAc); ^{1}H NMR (500 MHz; $CDCl_3$): δ 7.50–7.48 (m, 5H), 7.45–7.43 (m, 2H), 7.38–7.33 (m, 11H), 5.57 (s, 2H), 5.48 (s, 1H), 5.40 (t, 1H, *J* = 9.4 Hz), 5.34–5.29 (m, 4H), 5.11–5.05 (m, 5H), 5.04 (d, 1H, *J* = 1.9 Hz, H-1' of **S1a**), 4.99 (dd, 2H, *J* = 3.4, 1.8 Hz), 4.95 (t, 2H, *J* = 9.9 Hz), 4.91 (d, 2H, *J* = 1.7 Hz, H-1' of **S1**), 4.57 (d, 1H, *J* = 7.6 Hz, H-1 of **S1a**), 4.49 (d, 2H, *J* = 8.0 Hz, H-1 of **S1**), 4.41–4.37 (m, 3H), 4.32 (dq, 1H, *J* = 10.2, 6.3 Hz), 4.10 (dq, 2H, *J* = 10.0, 6.2 Hz), 4.04–3.88 (m, 5H), 3.87–3.75 (m, 3H), 3.75–3.62 (m, 4H), 3.62–3.44 (m, 6H), 2.15 (s, 3H), 2.14 (s, 6H), 2.14 (s, 3H), 2.12 (s, 6H), 2.05 (s, 3H), 2.02 (s, 3H), 2.00 (s, 6H), 1.98 (s, 6H), 1.21 (d, 3H, *J* = 6.2 Hz), 1.05-0.89 (m, 6H), 0.68 (d, 6H, *J* = 6.2 Hz), 0.06 (s, 9H), 0.03 (s, 18H); ^{13}C NMR (125

MHz; $CDCl_3$): δ 170.0 , 170.0, 169.8, 169.4, 137.1, 136.9, 129.2, 129.0, 128.2, 128.1, 126.4, 126.1, 102.0, 101.7 (C-1 of **S1a**), 101.4, 101.0 (C-1 of **S1**), 97.7 (C-1' of **S1a**), 97.6 (C-1' of **S1**), 79.1, 78.7, 73.9, 73.5, 71.4, 71.4, 70.6, 70.3, 68.8, 68.7, 68.6, 68.4, 68.1, 67.6, 66.6, 66.6, 66.3, 66.2, 25.0, 20.9, 20.9, 20.8, 20.8, 20.8, 18.4, 18.1, 17.3, 16.5, –1.42, –1.49; HRMS (ESI) Calc. for (M + Na) $C_{32}H_{46}NaO_{14}Si$: 705.2549; Found 705.2541.

2-(Trimethylsilyl)ethyl 2,3,4-tri-*O*-acetyl-α-L-rhamnopyranosyl-(1→3)-2-*O*-acetyl-β-D-glucopyranoside (46) and 2-(Trimethylsilyl)ethyl 2,3,4-tri-*O*-acetyl-α-L-rhamnopyranosyl-(1→3)-3-*O*-acetyl-β-D-glucopyranoside (46a): To a solution of **S1/S1a** (767 mg, 1.12 mmol) in 80% CH_3COOH–H_2O (10 mL) was heated at 80 °C for 2 h and then cooled to room temperature. The mixture was concentrated and then co-evaporated with toluene (3 ×). The crude residue was purified by flash chromatography (1:1→1:2 hexane–EtOAc) to afford **46** (326 mg, 49%) as a white amorphous solid and **46a** (166 mg, 25%) as a white amorphous solid. Data for **46**: R_f 0.45 (1:2 hexane–EtOAc); $[\alpha]_D$ –17.7 (1.5 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): δ 5.22 (dd, 1H *J* = 10.1, 3.3 Hz, H-3'), 5.15 (dd, 1H, *J* = 3.3, 2.1 Hz, H-2'), 5.11 (app t, 1H, *J* = 9.9 Hz, H-4'), 4.96 (dd, 1H, *J* = 9.5, 8.1 Hz, H-2), 4.90 (d, 1H, *J* = 2.0 Hz, H-1'), 4.47 (d, 1H, *J* = 8.1 Hz, H-1), 4.15 (dq, 1H, *J* = 9.8, 6.5 Hz, H-5'), 4.00–3.93 (m, 2H, H-6a, $OCH_2CH_2Si(CH_3)_3$), 3.84 (ddd, 1H, *J* = 11.7, 7.4, 4.8 Hz, H-6b), 3.65 (app td, 1H, *J* = 9.0, 2.4 Hz, H-4), 3.61–3.54 (m, 3H, H-3, $OCH_2CH_2Si(CH_3)_3$, 4-OH), 3.38 (ddd, 1H, *J* = 8.2, 4.6, 3.4 Hz, H-5'), 2.16 (s, 3H, $COCH_3$), 2.16 (s, 3H, $COCH_3$), 2.09 (t, 1H, *J* = 7.2 Hz, 6-OH), 2.06 (s, 3H, $COCH_3$), 2.00 (s, 3H, $COCH_3$), 1.26 (d, 3H, *J* = 6.3 Hz, H-6'), 0.98 (ddd, 1H, *J* = 14.1, 10.6, 6.7 Hz, $OCH_2CH_2Si(CH_3)_3$), 0.91 (ddd, 1H, *J* = 14.0, 10.2, 5.6 Hz, $OCH_2CH_2Si(CH_3)_3$), 0.03 (s, 9H, $OCH_2CH_2Si(CH_3)_3$); ^{13}C NMR (125 MHz; $CDCl_3$): δ 170.1 (C=O), 169.9 (C=O), 169.6 (C=O), 169.4 (C=O), 100.3 (C-1), 99.1 (C-1'), 85.9 (C-3), 75.1 (C-5), 71.3 (C-2), 70.6 (C-4'), 70.2 (C-4), 69.8 (C-2'), 68.6 (C-3'), 67.9 (C-5'), 67.4 ($OCH_2CH_2Si(CH_3)_3$), 62.4 (C-6), 20.9 ($COCH_3$), 20.8 ($COCH_3$), 20.7 ($COCH_3$), 20.7 ($COCH_3$), 18.0 ($OCH_2CH_2Si(CH_3)_3$), 17.5 (C-6'), –1.4 ($OCH_2CH_2Si(CH_3)_3$); HRMS (ESI) Calc. for (M + Na) $C_{25}H_{42}NaO_{14}Si$: 617.2236 Found 617.2228. Data for **46a**: R_f 0.42 (1:2 hexane–EtOAc); $[\alpha]_D$ –28.0 (3.2 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): δ 5.27 (dd, 1H, *J* = 10.1, 3.4 Hz, H-3'), 5.08 (app t, 1H, *J* = 10.1 Hz, H-4'), 5.06 (dd, 1H, *J* = 3.7, 1.8 Hz, H-2'), 5.02 (app t, 1H, *J* = 9.4 Hz, H-3), 5.00 (d, 1H, *J* = 1.8 Hz, H-1') 4.48 (d, 1H, *J* = 7.8 Hz, H-1), 4.33 (dq, 1H, *J* = 10.1, 6.2 Hz, H-5'), 3.98 (td, 1H, *J* = 9.8, 8.1 Hz, $OCH_2CH_2Si(CH_3)_3$), 3.93 (dd, 1H, *J* = 11.9, 3.5 Hz, H-6a), 3.83 (dd, 1H, *J* = 11.9, 4.7 Hz, H-6b), 3.65–3.60 (m, 3H, H-2, H-4, $OCH_2CH_2Si(CH_3)_3$), 3.41 (ddd, 1H, *J* = 9.5, 4.6, 3.7 Hz, H-5), 3.16 (br s, 1H, 4-OH) 2.18–2.14 (m, 7H, 2× $COCH_3$, 6-OH), 2.04 (s, 3H, $COCH_3$), 2.01 (s, 3H, $COCH_3$), 1.19 (d, 3H, *J* = 6.2 Hz, H-6'), 1.04–0.98 (m, 2H, $OCH_2CH_2Si(CH_3)_3$), 0.04 (s, 9H, $OCH_2CH_2Si(CH_3)_3$); ^{13}C NMR (125 MHz; $CDCl_3$): δ 172.7 (C=O), 170.1 (C=O), 170.0 (C=O), 169.9 (C=O), 101.0 (C-1), 97.6 (C-1'), 78.8(C-3), 76.1 (C-2), 75.6 (C-5), 71.3 (C-4'), 70.2 (C-2'), 70.2 (C-4), 68.7 (C-3'), 67.9 ($OCH_2CH_2Si(CH_3)_3$), 66.5 (C-5'), 62.3 (C-6), 20.9 ($COCH_3$), 20.9 ($COCH_3$), 20.8 ($COCH_3$), 20.7 ($COCH_3$), 18.4 ($OCH_2CH_2Si(CH_3)_3$), 17.3 (C-6'), –1.5 ($OCH_2CH_2Si(CH_3)_3$); HRMS (ESI) Calc. for (M + Na) $C_{25}H_{42}NaO_{14}Si$: 617.2236; Found 617.2230.

2-(Trimethylsilyl)ethyl 2,3,4-tri-*O*-acetyl-α-L-rhamnopyranosyl-(1→3)-2-*O*-acetyl-6-thio-6-*S*-*p*-tolyl-β-D-glucopyranoside (47): To a stirred solution of **46** (128 mg, 0.216 mmol) in dry pyridine (1.1 mL) were added $(TolS)_2$ (108 mg, 0.44 mmol) and $P(CH_3)_3$ (0.44 mL, 0.44 mmol, 1.0 M in THF) under argon. The reaction mixture was stirred overnight at room temperature. Then, the reaction mixture was concentrated, diluted with EtOAc (30 mL) and washed with brine. The organic layer was dried over $MgSO_4$, filtered and concentrated. The crude residue was purified by flash chromatography (2:1 hexane–EtOAc) to afford **47** (144 mg, 95%) as a viscous oil. R_f 0.18 (2:1 hexane–EtOAc); $[\alpha]_D$ +1.7 (0.3 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): δ 7.34–7.32 (m, 2H, Ar), 7.12–7.09 (m, 2H, Ar), 5.22 (dd, 1H, *J* = 10.0, 3.3 Hz, H-3'), 5.14 (dd, 1H, *J* = 3.2, 2.1 Hz, H-2'), 5.10 (app t, 1H, *J* = 9.9 Hz, H-4'), 4.98 (dd, 1H, *J* = 9.1, 8.4 Hz, H-2), 4.87 (d, 1H, *J* = 2.1 Hz, H-1'), 4.39 (d, 1H, *J* = 8.1 Hz, H-1), 4.12 (dq, 1H, *J* = 9.8, 6.3 Hz, H-5'), 3.92 (td, 1H, *J* = 9.9, 5.7 Hz, $OCH_2CH_2Si(CH_3)_3$), 3.57–3.41 (m, 6H, $OCH_2CH_2Si(CH_3)_3$, H-3,H-4,H-5,H-6a, 4-OH), 3.09 (dd, 1H, *J* = 13.7, 7.7 Hz, H-6b), 2.33 (s, 3H, Ar-CH_3), 2.16 (s, 3H, $COCH_3$), 2.15 (s, 3H, $COCH_3$), 2.07 (s, 3H, $COCH_3$), 2.00 (s, 3H, $COCH_3$), 1.25 (d, 3H, *J* = 6.3 Hz, H-6'), 0.96 (ddd, 1H, *J* = 14.0, 10.3, 6.8 Hz, $OCH_2CH_2Si(CH_3)_3$), 0.90 (ddd, 1H, *J* = 13.7, 9.9, 5.6 Hz, $OCH_2CH_2Si(CH_3)_3$), 0.02 (s, 9H, $OCH_2CH_2Si(CH_3)_3$); ^{13}C NMR (125 MHz; $CDCl_3$): δ 170.0 (C=O), 169.9 (C=O), 169.5 (C=O), 169.4 (C=O), 136.1 (Ar), 132.9 (Ar), 129.8 (Ar), 129.7 (Ar), 100.0 (C-1), 99.2 (C-1'), 86.3 (C-3), 74.7 (C-5), 72.7 (C-4), 71.4 (C-2), 70.6 (C-4'), 69.8 (C-2'), 68.6 (C-3'), 67.9 (C-5'), 67.0 ($OCH_2CH_2Si(CH_3)_3$), 36.2 (C-6), 21.0 (Ar-CH_3), 20.9 ($COCH_3$), 20.8 ($COCH_3$), 20.7 ($COCH_3$), 20.7 ($COCH_3$), 17.9 ($OCH_2CH_2Si(CH_3)_3$), 17.5 (C-6'), –1.4 ($OCH_2CH_2Si(CH_3)_3$); HRMS (ESI) Calc. for (M + Na) $C_{32}H_{48}NaO_{13}SSi$: 723.2477; Found 723.2472.

2-(Trimethylsilyl)ethyl 2,3,4-tri-*O*-acetyl-α-L-rhamnopyranosyl-(1→3)-2,4-di-*O*-acetyl-6-thio-6-*S*-*p*-tolyl-β-D-glucopyranoside (48): To a solution of **47** (143.6 mg, 0.205 mmol) in pyridine (2 mL) and Ac_2O (1 mL) was added DMAP (2.6 mg, 0.021 mmol). The reaction mixture was stirred for 3 h at room temperature, then the Ac_2O was quenched by addition of CH_3OH (1 mL). Then the mixture was co-concentrated with toluene (3 ×). The crude reside was purified by flash chromatography (2:1 hexane–EtOAc) to afford **48** (145 mg, 95%) as a white amorphous solid. R_f 0.19 (2:1 hexane–EtOAc); $[\alpha]_D$ –10.7 (0.3 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): δ 7.28–7.26 (m, 2H, Ar), 7.12–7.10 (m, 2H, Ar), 5.12–5.09 (m, 2H, H-3', H-2'), 5.03 (dd, 1H, *J* = 9.7, 8.1 Hz, H-2), 5.02 (app t, 1H, *J* = 9.8 Hz, H-4'), 4.98 (app t, 1H, *J* = 9.4 Hz, H-4), 4.80 (d, 1H, *J* =1.2 Hz, H-1'), 4.38 (d, 1H, *J* = 8.0 Hz, H-1), 3.93-3.86 (m, 2H, H-5', $OCH_2CH_2Si(CH_3)_3$), 3.75 (app t, 1H, *J* = 9.3 Hz, H-3), 3.55 (td, 1H, *J* = 9.9, 6.6 Hz, $OCH_2CH_2Si(CH_3)_3$), 3.46 (ddd, 1H, *J* = 9.7, 8.3, 3.4 Hz, H-5), 3.05 (dd, 1H, *J* = 14.0, 8.2 Hz, H-6a), 2.99 (dd, 1H, *J* = 13.9, 3.4 Hz, H-6b), 2.33 (s, 3H, Ar-CH_3), 2.16 (s, 3H, $COCH_3$), 2.15 (s, 3H, $COCH_3$), 2.11 (s, 3H, $COCH_3$), 2.05 (s, 3H, $COCH_3$), 1.96 (s, 3H, $COCH_3$), 1.16 (d, 3H, *J* = 6.2 Hz, H-6'), 0.96 (ddd, 1H, *J* = 13.9, 10.3, 6.8 Hz, $OCH_2CH_2Si(CH_3)_3$), 0.90 (ddd, 1H, *J* = 14.0, 10.0, 5.8 Hz, $OCH_2CH_2Si(CH_3)_3$), 0.02 (s, 9H, $OCH_2CH_2Si(CH_3)_3$); ^{13}C NMR (125 MHz; $CDCl_3$): δ 170.2 (C=O), 170.1(C=O), 169.8 (C=O), 169.5 (C=O), 169.4 (C=O), 136.5 (Ar), 132.5 (Ar), 130.1 (Ar), 129.7 (Ar), 100.1 (C-1), 99.5 (C-1'), 81.9 (C-3), 73.5 (C-5), 73.2 (C-4), 71.9 (C-4'), 70.6 (C-2), 69.9 (C-2'), 68.9 (C-3'), 67.5 (C-5'), 67.1 ($OCH_2CH_2Si(CH_3)_3$), 36.5 (C-6), 21.3 ($COCH_3$), 21.0 (Ar-CH_3), 20.9 ($COCH_3$), 20.8 ($COCH_3$), 20.8 ($COCH_3$), 20.6 ($COCH_3$), 17.9 ($OCH_2CH_2Si(CH_3)_3$), 17.2 (C-6'), –1.4 ($OCH_2CH_2Si(CH_3)_3$); HRMS (ESI) Calc. for (M + Na) $C_{34}H_{50}NaO_{14}SSi$: 765.2583; Found 765.2580.

2-(Trimethylsilyl)ethyl 2,3,4-tri-*O*-acetyl-α-L-rhamnopyranosyl-(1→3)-*S*-*p*-tolyl thio(2,4-di-*O*-acetyl-β-D-glucopyranosid)uronate (49): To a solution of **48** (136 mg, 0.18 mmol) in dry CCl_4 (2.7 mL) at 0 °C were added anhydrous pyridine (29 μL, 0.36 mmol) followed by the addition of SO_2Cl_2 (29 μL, 0.36 mmol) under argon. The reaction mixture was stirred for 5 h at 0 °C and then diluted with CH_2Cl_2 and was washed with brine. The organic layer was dried over $MgSO_4$, filtered and concentrated. The crude residue was dissolved in 3:2 acetone–H_2O (3.6 mL), and solid $NaHCO_3$ (60.5 mg, 0.72 mmol) was added. The reaction mixture was stirred overnight at room temperature, diluted with brine and then extracted with EtOAc (3 × 5 mL). The organic layer was dried over $MgSO_4$, filtered and concentrated. The crude residue was purified by flash chromatography (2:1 hexane–EtOAc) to afford **49** (116 mg, 85%) as a white amorphous solid. R_f 0.45 (1:1 hexane–EtOAc); $[\alpha]_D$ –66.8 (0.6 *c*, $CHCl_3$); ^{1}H NMR (500 MHz; $CDCl_3$): δ 7.31–7.29 (m, 2H, Ar), 7.25–7.23 (m, 2H, Ar), 5.32 (dd, 1H, *J* = 9.7, 9.3 Hz, H-4), 5.16 (dd, 1H, *J* = 9.3, 7.9 Hz, H-2), 5.13–5.11 (m, 2H, H-2', H-3'), 5.04 (app t, 1H, *J* = 9.8 Hz, H-4'), 4.86 (d, 1H, *J* = 1.5 Hz, H-1'), 4.56 (d, 1H, *J* = 7.9 Hz, H-1), 4.08 (td, 1H, *J* = 9.6, 6.7 Hz, $OCH_2CH_2Si(CH_3)_3$), 3.99 (d, 1H, *J* = 9.9 Hz, H-5), 3.92 (dq, 1H, *J* = 9.7, 6.1 Hz, H-5'), 3.86 (app t, 1H, *J* = 9.2 Hz, H-3), 3.68 (td, 1H, *J* = 9.5, 6.8 Hz, $OCH_2CH_2Si(CH_3)_3$), 2.39 (s, 3H, Ar-CH_3), 2.19 (s, 3H, $COCH_3$), 2.15 (s, 3H, $COCH_3$), 2.06 (s, 3H, $COCH_3$), 2.05 (s, 3H, $COCH_3$), 1.98 (s, 3H, $COCH_3$), 1.16 (d, 3H, *J* = 6.2 Hz, H-6'), 1.03 (ddd, 1H, *J* = 14.0, 9.4, 6.8 Hz, $OCH_2CH_2Si(CH_3)_3$), 0.99 (ddd, 1H, *J* = 14.0, 9.4, 6.8 Hz,

$OCH_2CH_2Si(CH_3)_3$), 0.06 (s, 9H, $OCH_2CH_2Si(CH_3)_3$); ^{13}C NMR (125 MHz; $CDCl_3$): δ 195.5 (C-6), 170.2 (C=O), 170.1 (C=O), 169.5 (C=O), 169.4 (C=O), 169.3 (C=O), 139.9 (Ar), 134.8 (Ar), 130.2 (Ar), 122.8 (Ar), 100.2 (C-1), 99.4 (C-1'), 81.1 (C-3), 77.7 (C-5), 71.4 (C-2), 70.8 (C-4), 70.6 (C-4'), 69.9 (C-2'), 68.8 (C-3'), 67.5 ($OCH_2CH_2Si(CH_3)_3$), 67.5 (C-5'), 21.4 (Ar-CH_3), 21.0 ($COCH_3$), 21.0 ($COCH_3$), 20.8 ($COCH_3$), 20.8 ($COCH_3$), 20.7 ($COCH_3$), 18.0 ($OCH_2CH_2Si(CH_3)_3$), 17.3 (C-6'), –1.3 ($OCH_2CH_2Si(CH_3)_3$); HRMS (ESI) Calc. for (M + NH_4) $C_{34}H_{52}NO_{15}SSi$: 774.2807 Found 774.2821.

***N*-{2-(Trimethylsilyl)ethyl 2,3,4-tri-*O*-acetyl-α-L-rhamnopyranosyl-(1→3)-(2,4-di-*O*-acetyl-β-D-glucopyranosiduronoyl)}-L-threonine benzyl ester (50):** To a solution of **49** (79.8 mg, 0.105 mmol) in CH_2Cl_2 (2.1 mL) was added L-threonine benzyl ester (33.1 mg, 0.158 mmol). The reaction mixture was stirred for 44 h at room temperature, then diluted with CH_2Cl_2 (10 mL), washed with sat. NH_4Cl (aq.) and brine. The organic layer was dried over $MgSO_4$, filtered and concentrated. The crude residue was purified by flash chromatography (2:1→1:1 hexane–EtOAc) to afford **50** (73.5 mg, 83%) as a white amorphous solid. R_f 0.29 (1:1 hexane–EtOAc); $[\alpha]_D$ –23.1 (0.6 *c*, $CHCl_3$); ^1H NMR (400 MHz; $CDCl_3$): δ 7.38–7.31 (m, 5H, Ar), 7.19 (d, 1H, *J* = 8.8 Hz, $NHCHCO_2Bn$), 5.22 (d, 1H, *J* = 12.3 Hz, CH_2Ph), 5.17 (d, 1H, *J* = 12.3 Hz, CH_2Ph), 5.14 (app t, 1H, *J* = 9.4 Hz, H-4), 5.11–5.06 (m, 3H, H-2, H-2', H-3'), 5.01 (app t, 1H, *J* = 9.7 Hz, H-4'), 4.86 (d, 1H, *J* = 1.2 Hz, H-1'), 4.55 (dd, 1H, *J* = 8.7, 3.3 Hz, $NHCHCO_2Bn$), 4.50 (d, 1H, *J* = 8.0 Hz, H-1), 4.29 (ddq, 1H, *J* = 6.3, 5.5, 3.7 Hz, $HOCHCH_3$), 3.97 (td, 1H, *J* = 9.7, 6.4 Hz, $OCH_2CH_2Si(CH_3)_3$), 3.91–3.84 (m, 3H, H-5', H-3, H-5), 3.58 (td, 1H, *J* = 9.6, 6.8 Hz, $OCH_2CH_2Si(CH_3)_3$), 2.16 (s, 3H, $COCH_3$), 2.13 (s, 3H, $COCH_3$), 2.10 (s, 3H, $COCH_3$), 2.06 (d, 1H, *J* = 5.5 Hz, $HOCHCH_3$), 2.02 (s, 3H, $COCH_3$), 1.95 (s, 3H, $COCH_3$), 1.24 (d, 3H, *J* = 6.4 Hz, $HOCHCH_3$), 1.14 (d, 3H, *J* = 6.2 Hz, H-6'), 0.97 (ddd, *J* = 14.2, 9.7, 6.7 Hz, $OCH_2CH_2Si(CH_3)_3$), 0.92 (ddd, *J* = 14.4, 10.0, 6.6 Hz, $OCH_2CH_2Si(CH_3)_3$), 0.02 (s, 9H, $OCH_2CH_2Si(CH_3)_3$); ^{13}C NMR (125 MHz; $CDCl_3$): δ 170.1 (C=O), 170.1 (C=O), 170.0 (C=O), 169.9 (C=O), 169.6 (C=O), 169.4 (C=O), 167.6 (C-6), 135.2 (Ar), 128.65 (Ar), 128.50 (Ar), 128.2 (Ar), 100.2 (C-1), 99.1 (C-1'), 80.4 (C-3), 72.8 (C-5), 71.7 (C-2), 71.1 (C-4), 70.6 (C-4'), 69.9 (C-2'), 68.8 ($HOCHCH_3$), 68.5 (C-3'), 68.0 ($OCH_2CH_2Si(CH_3)_3$), 67.4 (C-5'), 67.3 (CH_2Ph), 57.2 ($NHCHCO_2Bn$), 21.0 ($COCH_3$), 20.9 ($COCH_3$), 20.8 ($COCH_3$), 20.8 ($COCH_3$), 20.7 ($COCH_3$), 19.9 ($HOCHCH_3$), 18.0 ($OCH_2CH_2Si(CH_3)_3$), 17.3 (C-6'), –1.4 ($OCH_2CH_2Si(CH_3)_3$); HRMS (ESI) Calc. for (M + Na) $C_{38}H_{55}NNaO_{18}Si$: 864.3081; Found 864.3076.

***N*-{2-(Trimethylsilyl)ethyl 2,3,4-tri-*O*-acetyl-α-L-rhamnopyranosyl-(1→3)-(2,4-di-*O*-acetyl-β-D-glucopyranosiduronoyl)}-L-threonine (51):** To a solution of **50** (67.4 mg, 0.08 mmol) in CH_3OH was added palladium on charcoal (5%, 10 mg). The flask was flushed with H_2 gas, and then the reaction mixture was stirred at room temperature overnight under a H_2 atmosphere. The mixture was filtered through Celite, and the filtrate was concentrated to afford **51** (60.2 mg, quant.) as a white solid. R_f 0.30 (5:1 CH_2Cl_2–CH_3OH); $[\alpha]_D$ –30.2 (1.6 *c*, $CHCl_3$); ^1H NMR (500 MHz; CD_3OD): δ 5.14 (app t, 1H, *J* = 9.6 Hz, H-4), 5.08 (dd, 1H, *J* = 3.3, 2.0 Hz, H-2'), 5.04 (dd, 1H, *J* = 10.1, 3.3 Hz, H-3'), 5.00 (dd, 1H, *J* = 9.6, 8.1 Hz, H-2), 4.96 (app t, 1H, *J* = 9.6 Hz, H-4) 4.92 (d, 1H, *J* = 1.9 Hz, H-1'), 4.68 (d, 1H, *J* = 8.1 Hz, H-1), 4.31–4.28 (m, 2H, $NHCHCO_2H$, $HOCHCH_3$), 4.07 (app t, 1H, *J* = 9.5 Hz, H-3), 4.04 (td, 1H, *J* = 9.8, 5.9 Hz, $OCH_2CH_2Si(CH_3)_3$), 4.02 (d, 1H, *J* = 9.9 Hz, H-5), 3.85 (dq, 1H, *J* = 9.7, 6.2 Hz, H-5'), 3.64 (td, 1H, *J* = 9.6, 6.7 Hz, $OCH_2CH_2Si(CH_3)_3$), 2.12 (s, 3H, $COCH_3$), 2.12 (s, 3H, $COCH_3$), 2.06 (s, 3H, s, 3H, $COCH_3$), 2.02 (s, 3H, s, 3H, $COCH_3$), 1.93 (s, 3H, s, 3H, $COCH_3$), 1.19 (d, 3H, *J* = 6.3 Hz, $HOCHCH_3$), 1.12 (d, 3H, *J* = 6.2 Hz, H-6'), 0.97 (ddd, 1H, *J* = 14.0, 9.9, 6.7 Hz, $OCH_2CH_2Si(CH_3)_3$), 0.89 (ddd, 1H, *J* = 14.0, 9.6, 5.8 Hz, $OCH_2CH_2Si(CH_3)_3$), 0.02 (s, 9H, $OCH_2CH_2Si(CH_3)_3$); ^{13}C NMR (125 MHz; CD_3OD): δ 174.5 (C=O), 171.7 (C=O), 171.7 (C=O), 171.4 (C=O), 171.4 (C=O), 171.3 (C=O), 169.6 (C-6), 101.3 (C-1), 100.6 (C-1'), 81.9 (C-3), 73.7 (C-5), 73.4 (C-2), 72.5 (C-4), 71.9 (C-4'), 71.1 (C-2'), 70.3 (C-3'), 68.7 ($HOCHCH_3$), 68.6 ($OCH_2CH_2Si(CH_3)_3$), 58.9 ($NHCHCO_2H$), 21.4 ($COCH_3$), 21.1 ($COCH_3$), 20.7 ($COCH_3$), 20.6 ($COCH_3$), 20.6 ($COCH_3$), 20.3 ($HOCHCH_3$), 18.9 ($OCH_2CH_2Si(CH_3)_3$), 17.7 (C-6'), –1.3 ($OCH_2CH_2Si(CH_3)_3$); HRMS (ESI) Calc. for (M + Na) $C_{31}H_{49}NNaO_{18}Si$: 774.2611; Found 774.2600.

***N*-{2-(Trimethylsilyl)ethyl α-L-rhamnopyranosyl-(1→3)-(β-D-glucopyranosiduronoyl)}-L-threonine (52):** To a solution of **51** (60.2 mg, 0.08 mmol) in CH_3OH (1 mL) was added a solution of $NaOCH_3$ in CH_3OH (1 mL, 0.1 M). The reaction mixture was stirred for 4 h at room temperature and then neutralized by addition of Amberlite® IR-120 (H^+) cation exchange resin. The mixture was filtered and the filtrate was concentrated. The residue was dissolved in water and then lyophilized to afford **52** (39.0 mg, 90%) as a white solid. R_f 0.24 (1:2:4 H_2O–2-propanol–EtOAc); $[\alpha]_D$ –53.2 (0.3 *c*, CH_3OH); ^1H NMR (500 MHz; CD_3OD): δ 5.18 (d, 1H, *J* = 1.6 Hz, H-1'), 4.45 (br s, 1H, $NHCHCO_2H$), 4.39 (d, 1H, *J* = 7.9 Hz, H-1), 4.36 (br s, 1H, $HOCHCH_3$), 4.07 (dq, 1H, *J* = 9.6, 6.2 Hz, H-5'), 4.00 (ddd, 1H, *J* = 11.0, 9.7, 6.0 Hz, $OCH_2CH_2Si(CH_3)_3$), 3.92 (dd, 1H, *J* = 3.3, 1.7 Hz, H-2'), 3.87 (d, 1H, *J* = 9.3 Hz, H-5), 3.71–3.65 (m, 2H, H-3', $OCH_2CH_2Si(CH_3)_3$), 3.59 (app t, 1H, *J* = 8.7 Hz, H-3), 3.54 (app t, 1H, *J* = 9.0 Hz, H-4), 3.37 (app t, 1H, *J* = 9.7 Hz, H-4'), 3.34 (dd, 1H, *J* = 8.5 Hz, H-2), 1.23 (d, 3H, *J* = 6.2 Hz, H-6'), 1.19 (d, 3H, *J* = 6.3 Hz, $HOCHCH_3$), 1.05 (ddd, 1H, *J* = 13.8, 11.0, 5.8 Hz, $OCH_2CH_2Si(CH_3)_3$), 0.99 (ddd, 1H, *J* = 13.8, 11.0, 6.0 Hz, $OCH_2CH_2Si(CH_3)_3$), 0.03 (s, 9H, $OCH_2CH_2Si(CH_3)_3$); ^{13}C NMR (125 MHz; CD_3OD): δ 173.4 (C=O), 172.2 (C-6), 103.8 (C-1), 102.5 (C-1'), 83.0 (C-3), 76.0 (C-5), 75.5 (C-2), 74.1 (C-4'), 72.4 (C-4), 72.4 (C-2'), 72.3 (C-3'), 69.9 (C-5'), 68.6 ($OCH_2CH_2Si(CH_3)_3$), 68.4 ($HOCHCH_3$), 58.6 ($NHCHCO_2H$), 20.6 ($HOCHCH_3$), 19.2 ($OCH_2CH_2Si(CH_3)_3$), 17.9 (C-6'), –1.4 ($OCH_2CH_2Si(CH_3)_3$); HRMS (ESI) Calc. for (M - H) $C_{21}H_{38}NO_{13}Si$: 540.2118; Found 540.2113

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[1] E. Vinogradov, W. J. Conlan, J. S. Gunn, M. B. Perry, *Carbohydr. Res.* **2004**, *339*, 649–654.

[2] E. V. Vinogradov, D. Krajewska-Pietrasik, W. Kaca, A. S. Shashkov, Y. A. Knirel, N. K. Kochetkov, *Eur. J. Biochem.* **1989**, *185*, 645–650.

[3] M. Siwińska, E. A. Levina, O. G. Ovchinnikova, D. Drzewiecka, A. S. Shashkov, A. Różalski and Y. A. Knirel, *Carbohydr Res.* **2015**, *407*, 131–136.

[4] S. Carillo, A. Casillo, G. Pieretti, E. Parrilli, F. Sannino, M. Bayer-Giraldi, S. Cosconati, E. Novellino, M. Ewert, J. W. Deming, R. Lanzetta, G. Marino, M. Parrilli, A. Randazzo, M. L. Tutino, M. M. Corsaro, *J. Am. Chem. Soc.* **2015**, *137*, 179–189.

[5] G. O. Aspinall, S. Fujimoto, A. G. McDonald, H. Pang, L. A. Kurjanczyk, J. L. Penner, *Infect. Immun.* **1994**, *62*, 2122–2125.

[6] Y. A. Knirel, E. V. Vinogradov, A. S. Shashkov, Z. Sidorczyk, A. Rozalski, J. Radziejewska-Lebrecht, W. Kaca, *J. Carbohydr. Chem.* **1993**, *12*, 379–414.

[7] J. Radziejewska-Lebrecht, A. S. Shashkov, E. V. Vinogradov, H. Grosskurth, B. Bartodziejska, A. Rozalska, W. Kaca, L. O. Kononov, A. Y. Chernyak, H. Mayer, Y. A. Knirel, N. K. Kochetkov, *Eur. J. Biochem.* **1995**, *230*, 705–712.

[8] F. S. Michael, C. M. Szymanski, J. Li, K. H. Chan, N. H. Khieu, S. Larocque, W. W. Wakarchuk, J.-R. Brisson, M. A. Monteiro, *Eur. J. Biochem.* **2002**, *269*, 5119–5136.

[9] P. Hofmann, B. Jann, K. Jann, *Carbohydr. Res.* **1985**, *139*, 261–271.

[10] A. O. Tzianabos, A. B. Onderdonk, D. F. Zaleznik, R. S. Smith, D. L. Kasper, *Infect. Immun.* **1994**, *62*, 4881–4886.
[11] W. Gromska, H. Mayer. *Eur. J. Biochem.* **1976**, *62*, 391–399.
[12] W. Kaca, Y.A. Knirel, E. V. Vinogradov, K. Kotelko, *Arch. Immunol. Ther. Exp. (Warsz).* **1987**, *35*, 431–437.
[13] Z. Sidorczyk, A. Swierzko, Y. A. Knirel, E. V. Vinogradov, A. Y. Chernyak, L. O. Kononov, M. Cedzynski, A. Rozalski, W. Kaca, A. S. Shashkov, N. K. Kochetkov, *Eur. J. Biochem.* **1995**, *230*, 713–721
[14] A. Y. Chernyak, L. O. Kononov, N. K. Kochetkov, *Carbohydr. Res.* **1991**, *216*, 381–398.
[15] N. Röckendrof, T. K. Lindhorst, *J. Org. Chem.* **2004**, *69*, 4441–4445.
[16] M. Tosin, P. V. Murphy, *Org. Lett.* **2002**, *4*, 3675–3678.
[17] J. Wang, B. Elchert, Y. Hui, J. Y. Takemoto, M. Bensaci, J. Wennergren, H. Chang, R. Rai, C.-W. T. Chang, *Bioorg. Med. Chem.* **2004**, *12*, 6397–6413.
[18] J. G. Taylor, X. Li, M. Oberthür, W. Zhu, D. E. Kahne, *J. Am. Chem. Soc.* **2006**, *128*, 15084–15085.
[19] D. Doyle, P. V. Murphy, *Carbohydr. Res.* **2008**, *343*, 2535–2544.
[20] R. Leyden, T. Velasco-Torrijos, S. André, S. Gouin, H.-J. Gabius, P. V. Murphy, *J. Org. Chem.* **2009**, *74*, 9010–9026.
[21] D. Crich, K. Sasaki, *Org. Lett.* **2009**, *11*, 3514–3517.
[22] M. Bosco, S. Rat, J. Kovensky, A. Wadouachi, *Tetrahedron Lett.* **2010**, *51*, 2553–2556.
[23] N. M. Xavier, S. Schwarz, P. D. Vaz, R. Csuk, A. P. Rauter, *Eur. J. Org. Chem.* **2014**, *2014*, 2770–2779.
[24] N. Xavier, S. Lucas, R. Jorda, S. Schwarz, A. Loesche, R. Csuk, M. C. Oliveira, *Synlett* **2015**, *26*, 2663–2672.
[25] C. Gunanathan, Y. Ben-David, D. Milstein, **Science** *2007*, *317*, 790–792.
[26] L. U. Nordstrøm, H. Vogt, R. Madsen, *J. Am. Chem. Soc.* **2008**, *130*, 17672–17673.
[27] J. H. Dam, G. Osztrovszky, L. U. Nordstrøm, R. Madsen, *Chem. Eur. J.* **2010**, *16*, 6820–6827.
[28] K. S. Goh, C.-H. Tan, *RSC Adv*. **2012**, *2*, 5536–5538.
[29] S. C. Ghosh, J. S. Y. Ngiam, C. L. L. Chai, A. M. Seayad, T. T. Dang, A. Chen, *Adv. Synth. Catal.* **2012**, *354*, 1407–1412.
[30] C. Chen, Y. Zhang, S. H. Hong, *J. Org. Chem.* **2011**, *76*, 10005–10010.
[31] S. Muthaiah, S. C. Ghosh, J.-E. Jee, C. Chen, J. Zhang, S. H. Hong, *J. Org. Chem.* **2010**, *75*, 3002–3006.
[32] A. J. A. Waston, A. C. Maxwell, J. M. J. Williams, *Org. Lett.* **2009**, *11*, 2667–2670.
[33] G. Wang, Q.-Y. Yu, J. Wang, S. Wang, S.-Y. Chen, X.-Q. Yu, *RSC Adv*. **2013**, *3*, 21306–21310
[34] H. Yao, Y. Tang, K. Yamamoto, *Tetrahedron Lett.* **2012**, *53*, 5094–5098.
[35] A. Schulze, A. Giannis, *Adv. Synth. Catal.* **2004**, *346*, 252–256.
[36] B. A. Granger, I. T. Jewett, J. D. Butler, B. Hua, C. E. Knezevic, E. I. Pakinson, P. J. Hergenrother, S. F. Martin, *J. Am. Chem. Soc.* **2013**, *135*, 12984–12986.
[37] B. Yu, X. Zhu, Y. Hui, *Org. Lett.* **2000**, *2*, 2539–2541.
[38] B. Yu, X. Zhu, Y. Hui, *Tetrahedron* **2001**, *57*, 9403–9413.
[39] C. C. Fortes, H. C. Fortes, D. C. R. G. Goncalves, *J. Chem. Soc. Chem. Commun.* **1982**, 857–858.
[40] C. C. Fortes, C. R. O. Souto, E. A. Okino, *Synth. Commun.* **1991**, *21*, 2045–2052.
[41] The synthesis of **17**–**21** was carried out from the corresponding alcohol by treatment with *p*-tolyl disulfide and trimethylphosphine.
[42] H. Tanaka, R. Takeuchi, M. Jimbo, N. Kuniya, T. Takahashi, *Chem. Eur. J.* **2013**, *19*, 3177–3187.
[43] C. G. Francisco, A. J. Herrera, A. R. Kennedy, A. Martín, D. Melián, I. Pérez-Martín, L. M. Quintanal, E. Suárez, *Chem. Eur. J.* **2008**, *14*, 10369–10381.
[44] M. Matwiejuk, J. Thiem, *Eur. J. Org. Chem.* **2011**, 5860–5878.
[45] K. Umemura, H. Matsuyama, M. Kobayashi, N. Kamigata, *Bull. Chem. Soc. Jpn.* **1989**, *62*, 3026–3028.
[46] E. I. Balmond, D. M. Coe, M. C. Galan, E. M. McGarrigle, *Angrew. Chem. Int. Ed.* **2012**, *51*, 9152–9155.
[47] R. Sundell, L. T. Kanerva, *Eur. J. Org. Chem.* **2013**, 4971–4978.
[48] A. Noel, B. Delpech, D. Crich, *Org. Lett.* **2012**, *14*, 4138–4141.
[49] A. M. Esmurziev, N. Simic, B. H. Hoff, E. Sundby, *J. Carbohydr. Chem.* **2010**, *29*, 348–367

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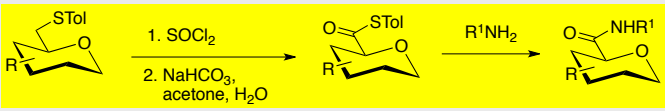

A route for the synthesis of glycuronamides via the intermediacy of 6-*S*-tolyl-glycosides and uronic acid thioesters, is reported. The route, which is compatible with a variety of carbohydrate residues and protecting groups, was used to synthesize the repeating unit of the *E. coli* K54 capsular polysaccharide.

Glycuronamide Synthesis

*Sicheng Lin, Roger A. Ashmus Todd L. Lowary**

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An oxidation–amidation approach for the synthesis of glycuronamides