Published in final edited form as:

J Org Chem. 2012 September 7; 77(17): 7330–7343. doi:10.1021/jo301050q.

Studies on the Selectivity Between Nickel-Catalyzed 1,2-*Cis*-2-Amino Glycosylation of Hydroxyl Groups of Thioglycoside Acceptors with C(2)-Substituted Benzylidene *N*-Phenyl Trifluoroacetimidates and Intermolecular Aglycon Transfer of the Sulfide Group

Fei Yu and Hien M. Nguyen*

Department of Chemistry, University of Iowa, Iowa City, IA 52242

Abstract

The stereoselective synthesis of saccharide thioglycosides containing 1,2-*cis*-2-amino glycosidic linkages is challenging. In addition to the difficulties associated with achieving high α -selectivity in the formation of 1,2-*cis*-2-amino glycosidic bonds, the glycosylation reaction is hampered by undesired transfer of the anomeric sulfide group from the glycosyl acceptor to the glycosyl donor. Overcoming these obstacles will pave the way for the preparation of oligosaccharides and glycoconjugates bearing the 1,2-*cis*-2-amino glycosidic linkages because the saccharide thioglycosides obtained can serve as donors for another coupling iteration. This approach streamlines selective deprotection and anomeric derivatization steps prior to the subsequent coupling event. We have developed an efficient approach for the synthesis of highly yielding and α -selective saccharide thioglycosides containing 1,2-*cis*-2-amino glycosidic bonds, via cationic nickel-catalyzed glycosylation of thioglycoside acceptors bearing the 2-trifluoromethylphenyl aglycon with *N*-phenyl trifluoroacetimidate donors. The 2-trifluoromethylphenyl group effectively blocks transfer of the anomeric sulfide group from the glycosyl acceptor to the C(2)-benzylidene donor and can be easily installed and activated. The current method also highlights the efficacy of the nickel catalyst selectively activating the C(2)-benzylidene imidate group in the presence of the anomeric sulfide group on the glycosyl acceptors.

INTRODUCTION

Alkyl and aryl thioglycosides have been widely utilized as both the acceptors and donors in the multi-step synthesis of oligosaccharides and glycoconjugates.¹ They are versatile in that their anomeric sulfide groups are easy to install and stable under many reaction conditions.² As a result, the sulfide groups not only serve as efficient protecting groups of anomeric centers but also act as glycosyl acceptors in combination with a variety of glycosyl donors such as trichloroacetimidates, halides and sulfoxides.³ The resulting saccharide thioglycosides can be subsequently activated for another coupling iteration to generate the corresponding oligosaccharides or glycoconjugates.^{3,4} Despite the widespread synthetic utility of thioglycosides, intermolecular aglycon transfer can be a serious side reaction. When an unreactive thioglycoside acceptor is employed in the coupling process, the anomeric sulfide group can be transferred from the glycosyl acceptor to the glycosyl donor

*hien-nguyen@uiowa.edu.

Supporting Information. Detailed experimental procedures and characterization data, including ¹H-NMR and ¹³C-NMR spectra for all new compounds, are provided. This material is available free of charge via the Internet at <http://pubs.acs.org>.

to give another thioglycoside.⁶ To prevent aglycon transfer, Li and Gildersleeve have recently reported the use of 2,6-dimethylphenyl (DMP) group as an efficient aglycon for thioglycoside acceptors.⁵ This bulky group effectively blocks intermolecular aglycon transfer⁶ of the anomeric sulfur atom in the glycosylation reaction.

We recently developed a novel strategy for the synthesis of 1,2-*cis*-2-aminosugars via nickel-catalyzed coupling with the C(2)-*N*-substituted benzylidene trichloroacetimidates (Scheme 1a).^{7,8} This method utilizes the nature of the nickel-ligand complex and metal-bound functional group at the C(2)-position of glycosyl donors to control the α -selectivity and provide high yielding oligosaccharides and glycoconjugates from a wide variety of glycosyl donors and acceptors.

In an effort to expand the capabilities of this method, we targeted the development of a variant proceeding via chemoselective coupling to the hydroxyl groups of thioglycosides, as depicted in Scheme 1b. A number of challenges have to be addressed in developing such a chemoselective glycosylation process. For instance, the nickel catalyst could fail to promote the coupling due to the displacement of metal-bound benzonitrile ligand by the anomeric sulfide group, producing an inactive nickel catalyst.⁹ Second, the trihaloacetimidate group could undergo [1,3]-rearrangement to provide the corresponding glycosyl trihaloacetamide.¹⁰ Third, intermolecular aglycon transfer of the anomeric sulfide group from the glycosyl acceptor to the glycosyl donor provides undesired thioglycoside.⁶ We report herein an efficient approach for the preparation of saccharides containing 1,2-*cis*-2-amino glycosidic linkages via nickel-catalyzed α -chemoselective glycosylation of the hydroxyl groups of thioglycoside acceptors with C(2)-benzylidene *N*-phenyl trifluoroacetimidates (Scheme 1b). This strategy overcomes the challenges associated with intermolecular aglycon transfer of the anomeric sulfide group from the acceptors to the C(2)-benzylidene imidate donors and retains the unique features of the nickel catalyst to control the α -selectivity at the newly-formed glycosidic bond.

RESULTS AND DISCUSSION

Optimization Studies

We initially explored the nickel-catalyzed glycosylation of *N*-Troc protected thioglycoside **3**^{5f,g} with the C(2)-*N*-*p*-trifluoromethyl-benzylidene trichloroacetimidate **1** (Scheme 1) to probe issues of both aglycon transfer and selectivity. Under previous nickel conditions (10 mol% Ni(4-F-PhCN)₄(OTf)₂ at 25 °C in CH₂Cl₂),⁷ disaccharide **4** (Scheme 2) was isolated in 40% along with aglycon transfer product **6** (26%) and [1,3]-rearrangement trichloroacetamide **8** (20%). Switching to C(2)-*N*-*o*-trifluoromethyl-benzylidene donor **2** improved both the yield and α -selectivity of disaccharide **5** (57%) and decreased the amount of transfer product **11** (12%) and trichloroacetamide **9** (10%). Formation of the rearrangement products **8** and **9** indicate the disadvantage of utilizing trichloroacetimidates as glycosyl donors.

To prevent [1,3]-rearrangement of the imidate group, the *N*-phenyl trifluoroacetimidate donor **10** (Table 1) was chosen due to its attenuated reactivity in comparison to trichloroacetimidates **1** and **2** (Scheme 2).¹¹ Accordingly, coupling of thioglycoside **3** (Table 1) with **10** was first examined at 25 °C, and the reaction was sluggish. Warming the reaction to 35 °C accelerated the coupling process and provided **5** (entry 1) in 58% yield as a single α -isomer. The undesired rearrangement acetamide (e.g. **9**) was not observed. In this experiment, both α - and β -isomers of donor **10** reacted, highlighting another advantage of using this glycosyl donor.¹² A significant amount of aglycon transfer product **7** (14%, entry 1), however, was still obtained in the reaction.

Thus, the key to the optimization is to minimize aglycon transfer. Unfortunately, we were unable to install the DMP group⁵ onto the anomeric center of *N*-Troc glucosamine. We then systematically examined the steric and electronic nature of the substituents on the phenyl ring of a number of thioglycosides **12–17** (Table 1) in the coupling with imidate **10**. While the electron-rich 4-methoxyphenyl aglycon **14** (entry 5) significantly increased the amount of transfer product **28**, the electron-poor groups **15–17** (entries 6–8) nearly blocked transfer. The most efficient acceptor was 2-trifluoromethylphenyl thioglycoside **17** (entry 8), which completely prevented transfer and provided disaccharide **24** (entry 8) in 61% yield and exclusively as the α -isomer. Even with two equivalents of donor **10**, no aglycon transfer product **31** (entry 9) was observed in the reaction. Overall, the 2-trifluoromethylphenyl group is an excellent alternative aglycon for thioglycoside acceptor. In addition, the nickel catalyst not only selectively activates the C(2)-benzylidene imidate **10** in the presence of the anomeric sulfide group on the glycosyl acceptor **17** but also effectively controls the α -anomeric selectivity in the synthesis of disaccharide thioglycoside **24** containing 1,2-*cis*-2-amino glycosidic bond.

To evaluate the unique features of the nickel catalyst as the effective activating agent to promote the glycosylation reaction, a number of catalysts (Table 2) were screened in the coupling of 2-trifluoromethylphenyl thioglycoside **3** with imidate donor **10**. Using TMSOTf (entry 1) resulted in 13% of disaccharide **5** with α : β = 10:1 and 40% of transfer product **7**. Similar results were obtained with a milder Lewis acid, Cu(OTf)₂ (entry 2). Use of both Rh(COD)₂OTf and Ir(COD)₂OTf catalysts (entries 3 and 4) provided **5** in lower yield (43 – 45%) and α -selectivity (α : β = 6:1 – 8:1) in comparison to the nickel catalyst whereas **7** was obtained in 58% yield and as a single α -isomer (Table 1, entry 1). In addition, employing iridium as the activating agent significantly increased the amount of transfer product **7** (14% → 26%). The palladium catalyst (entry 5), Pd(4-F-PhCN)₂OTf₂, decreased the yield of disaccharide **5** (40%) but increased the yield of transfer product **7** (14% → 24%). Gold catalyst, Ph₃PAuOTf (entry 6), provided exclusive α -disaccharide **5** in 43% yield, but a significant amount of sulfide transfer **7** (24%) was still obtained in the reaction. Although less than 1% of transfer product **7** was observed in the reaction using Fe(OTf)₂ as the catalyst (entry 7), the desired disaccharide **5** was only isolated in 11% yield.

Substrate Scope

We next examined the scope of the glycosylation of a variety of thioglycosides with armed and disarmed imidates **10**, **32**, and **33** (Table 3). In contrast to disarmed donor **10** (Table 1, entry 1), coupling of armed donor **33** (Table 3, entry 1) with phenyl thioglycoside **3** resulted in no transfer product **47**; disaccharide **39** (entry 1) was isolated in 70% yield, albeit in lower α -selectivity (α : β = 6:1). Similarly, coupling of phenyl *D*-galactosyl thioglycoside **34** with both donors **10** and **32** (entries 2 and 3) provided a large quantity of sulfide transfer products **7** and **49**, respectively. The armed donor **32** provided less aglycon transfer than the disarmed donor **10** (9% vs. 24%). The 2-trifluoromethylphenyl aglycon was then incorporated into *D*-galactosyl thioglycoside **35** (entry 4).⁶ No trace amount of transfer product **31** (entry 4) was observed, and exclusive α -disaccharide **42** was isolated in 71% yield. The efficacy of the nickel method was further evaluated with *L*-rhamnose acceptors **36** and **37** (entries 5 and 8). As anticipated, although glycosylation of the phenyl thioglycoside acceptor **36** with both disarmed donor **10** (entry 5) and armed donor **32** (entry 6) provided disaccharides **43** and **44**, respectively, in good yields (72 – 81%) and with complete α -selectivity, a significant amount of transfer products **7** (15%) and **49** (9%) was still observed in the coupling process. On the other hand, the electron deficient 2-trifluoromethylphenyl thioglycoside **37** completely blocked sulfide transfer (entries 7 and 8), providing disaccharides **45** and **46** in high yield (78 – 98%) and as single α -isomers. To further compare, the DMP group was incorporated into *L*-rhamnose thioglycoside **38** (entry 9). In agreement with previous

studies,⁵ no transfer product **51** was obtained in the reaction. The modified disaccharide **47** (entry 9), however, was obtained in lower yield than disaccharide **45** (entry 5) bearing the 2-trifluoromethylphenyl aglycon. Overall, the results clearly illustrate that the electron-withdrawing 2-trifluoromethylphenyl aglycon completely prevents transfer of the anomeric sulfide group from thioglycoside acceptors to both disarmed and armed *N*-phenyl trifluoroacetimidate donors.

The utility of the current method was further explored with galactosamine donors **52** and **53** (Table 4). Coupling of phenyl thioglycoside **3** with both disarmed and armed galactosamine donors **52** and **53** (entries 1 and 2) provided disaccharides **54** and **55**, respectively, in moderate yield (56 – 67%) and with excellent α -selectivity ($\alpha:\beta = 14:1 - >20:1$). As expected, a significant amount of transfer products **60** and **61** (6 – 16%) was also isolated in the reaction. On the other hand, employing 2-trifluoromethylphenyl thioglycoside **17** (entry 3) as a glycosyl acceptor completely blocked formation of transfer product **62** and provided α -disaccharide **56** (entry 3) in 73% yield. Derivative of disaccharides **5456** (entries 1–3), GalNAc- α -(1 $\rightarrow$ 3)-GlcNAc, is a part of the *O*-polysaccharide present in the outer membrane of Gram-negative bacteria such as *Salmonella enterica*¹³ and *Providencia rustigianii*.¹⁴ *S. enterica* is a major pathogen of humans and animals.¹¹ *P. rustigianii* invades human intestinal mucosa and causes stomach infection particularly in children.¹² Next, phenyl thioglycoside **34** (entries 4 and 5) was investigated with both glycosyl donors **52** and **53**, and a significant amount of transfer products **60** and **61** were obtained in the glycosylation reaction. Under nickel conditions, the higher amount of transfer product **61** (40%, entry 5) was obtained with partially armed donor **53** than that of transfer product **60** (24%, entry 4) with disarmed donor **52**. Thioglycoside **35** (entry 6) bearing the 2-trifluoromethylphenyl aglycon was then explored with this problematic reaction. As expected, the modified disaccharide **59** (entry 6) was isolated in 67% yield and with exclusively α -selectivity. Again, transfer product **62** was not observed with this 2-trifluoromethylphenyl acceptor **35**. Disaccharides **57–59** (entries 4–5), derivatives of GalNAc- α -(1 $\rightarrow$ 3)-Gal, are vital disaccharide units of human blood group A antigens.¹⁵

One of the key concerns in reducing the reactivity of the sulfide aglycon to prevent intermolecular transfer is that the modified arylthiol group cannot be efficiently activated. To illustrate that the 2-trifluoromethylphenyl aglycon can be sufficiently activated with thiophilic reagents (Scheme 3), disaccharide thioglycoside donor **45** was treated with the reagent combination of NIS and AgOTf.¹⁶¹⁷ Subsequent addition of a galactosyl acceptor **63** provided trisaccharide **64** in 84% yield, validating the ability of the 2-trifluoromethylphenyl group as an excellent alternative aglycon for thioglycosides. Encouraged by this result, we further explored the glycosylation of glycosyl acceptor **63** with less reactive disaccharide thioglycoside donor **24** (Scheme 3b) under similar nickel conditions. Gratifyingly, the coupling process proceeded smoothly to provide the desired trisaccharide **65** in 81% yield and with exclusive β -selectivity. The results obtained in Scheme 3 also illustrate the ability of the C(2)-*N*-substituted benzylidene functionality to act as the efficient protecting group. Next, it is essential to determine that these benzylidene groups could be converted to the corresponding *N*-acetyl or other functional groups. Accordingly, treatment of **65** with HCl, acetone/CH₂Cl₂ at 25°C for less than 5 min provided the corresponding amine salt along with the concomitant removal of the benzylidene protecting group. To ease the purification process, the resulting amine salt intermediate was acetylated to afford the fully protected trisaccharide **66** (Scheme 3b) in 99% yield over two steps.

Currently, the most common method for the synthesis of 1,2-*cis*-2-aminosugars employs glycosyl donors bearing the C(2)-azido functionality.¹⁸ To compare the ability of the nickel catalyst to efficiently activate the C(2)-azido donor, a series of glycosylations were performed with glycosyl *N*-phenyl trifluoroacetimidate **67** (Scheme 4).^{9,19} Accordingly,

coupling of phenyl thioglycoside acceptor **3** with imidate **67** in the presence of 10 mol% $\text{Ni}(\text{4-F-PhCN})_4(\text{OTf})_2$ provided sulfide transfer product **69** (40%) as the major product (Scheme 4a). The desired disaccharide **68** was obtained in 18% yield, albeit with excellent α -selectivity. Although transfer product was not detected in the reaction with the 2-trifluoromethyl-phenyl thioglycoside acceptor **17**, only 13% of the desired disaccharide **67** was isolated (Scheme 4b).²⁰ When *L*-rhamnoside **36** was employed as the glycosyl donors in the reaction with C(2)-azido donor **67** (Scheme 4c), higher amount of transfer product **69** (28% vs. 15%) and lower yield of the desired disaccharide **71** (49% vs. 81%) were obtained than those with C(2)-benzylidene donor **10** (Table 3, entry 5). Overall, these results suggest that the nickel catalyst, $\text{Ni}(\text{4-F-PhCN})_4(\text{OTf})_2$, is the more efficient activating reagent for C(2)-*N*-substituted benzylideneamino donors than that for C(2)-azido donors.

CONCLUSION

In summary, we have developed an efficient strategy to chemoselective glycosylation for the preparation of various saccharide thioglycoside building blocks in moderate to good yields and with excellent levels of α -selectivity. This approach employs a method of nickel-catalyzed 1,2-*cis*-2-amino glycosylation of thioglycoside acceptors bearing the 2-trifluoromethylphenyl aglycon with armed and disarmed C(2)-substituted *N*-phenyl trifluoroacetimidate donors. The resulting saccharide thioglycosides serve as glycosyl donors for another coupling iteration to generate oligosaccharides. Overall, the 2-trifluoromethylphenyl functionality is a more efficient aglycon than its phenyl counterpart to completely prevent transfer of the sulfide group from the glycosyl acceptor to the C(2)-benzylidene *N*-phenyl trifluoroacetimidate donors. In addition, it can be easily introduced onto the glycosyl acceptor and subsequently activated. This approach to the stereoselective synthesis of saccharide thioglycosides also highlights the ability of the C(2)-*N*-substituted benzylidene functionality as the efficient protecting group. Efforts are underway in our group to adapt this strategy for the preparation of biologically active oligosaccharides and glycoconjugates.

EXPERIMENTAL SECTION

General Procedure for the Preparation of Glycosyl Donors: 3,4,6-Tri-*O*-Acetyl-2-Deoxy-2-*o*-Trifluoromethylbenzylideneamino- β -Glucopyranosyl *N*-Phenyl Trifluoroacetimidate **10**

A 100 mL RBF was charged with triacetyl β -glucosamine hemiacetal **10A** (4.9 g, 10.6 mmol, 1.0 equiv.),^{7b} 2,2,2-trifluoro-*N*-phenyl-ethanimidoyl chloride (6.66 g, 31.9 mmol, 3.0 equiv.), K_2CO_3 (2.93 g, 21.2 mmol, 2.0 equiv.) and acetone (30.0 mL). The solution was stirred at room temperature overnight. When the reaction was complete as monitored by TLC (hexane/ethyl acetate = 3/1), the reaction mixture was filtered, evaporated, and purified by flash chromatography on silica gel (hexane/ethyl acetate = 5/1 $\rightarrow$ 3/1 with 1% Et_3N) to afford **10** (5.26 g, 80%, α : β = 1:4) as a viscous oil. **10a**: ^1H NMR (CDCl_3 , 400 MHz): δ = 8.68 (s, 1 H), 8.22 (d, J = 7.6 Hz, 1 H), 7.73–7.52 (m, 3 H), 7.25–7.13 (m, 2 H), 7.12–6.98 (m, 1 H), 6.88–6.65 (m, 2 H), 6.44 (brs, 1 H), 6.65 (t, J = 10.0 Hz, 1 H), 5.23 (app t, J = 10.0 Hz, 1 H), 4.48–4.27 (m, 2 H), 4.22–4.08 (m, 1 H), 3.88–3.77 (m, 1 H), 2.10 (s, 3 H), 2.05 (s, 3 H), 1.89 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): δ = 170.4, 169.7, 169.5, 161.5, 143.2, 133.1, 132.1, 131.0, 129.4 (q, $J_{\text{C-F}}$ = 30.5 Hz), 128.64, 128.59, 125.6 (q, $J_{\text{C-F}}$ = 5.6 Hz), 124.3, 124.0 (d, $J_{\text{C-F}}$ = 272 Hz), 119.4, 94.7, 71.1, 70.5, 68.0, 61.7, 20.55, 20.50, 20.2; IR (film, cm^{-1}): ν = 2963, 1752, 1644, 1367, 1315, 1212; HRMS (ESI): calc. for $\text{C}_{28}\text{H}_{26}\text{F}_6\text{N}_2\text{O}_8\text{Na}$ ($\text{M}+\text{Na}$): 655.1491; found: 655.1497. **10b**: ^1H NMR (CDCl_3 , 400 MHz): δ = 8.68 (d, J = 2.4 Hz, 1 H), 8.11 (d, J = 7.6 Hz, 1 H), 7.71 (d, J = 7.2 Hz, 1 H), 7.68–7.51 (m, 2 H), 7.38–7.27 (m, 2 H), 7.19–7.07 (m, 1 H), 6.82 (d, J = 7.6 Hz, 2 H), 6.02 (brs, 1 H), 5.46 (t, J = 10.0 Hz, 1 H), 5.19 (app t, J = 10.0 Hz, 1 H), 4.34 (dd, J = 12.4, 4.8 Hz, 1 H),

4.17 (dd, $J = 12.4, 2.0$ Hz, 1 H), 3.93–3.76 (m, 1 H), 3.71 (t, $J = 8.8$ Hz, 1 H), 2.10 (s, 3 H), 2.04 (s, 3 H), 1.93 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.4, 169.5, 143.2, 133.3, 132.1, 130.9, 129.3$ (q, $J_{\text{C-F}} = 31.0$ Hz), 128.7, 128.6, 125.6 (q, $J_{\text{C-F}} = 5.5$ Hz), 124.4, 124.0 (d, $J_{\text{C-F}} = 272$ Hz), 119.2, 95.7, 73.3, 72.9, 72.7, 68.0, 61.7, 20.53, 20.47, 20.2; IR (film, cm^{-1}): $\nu = 2887, 1752, 1645, 1489, 1315, 1231$; HRMS (ESI): calc. for $\text{C}_{28}\text{H}_{26}\text{F}_6\text{N}_2\text{O}_8\text{Na}$ ($\text{M}+\text{Na}$): 655.1491; found: 655.1511.

3,4,6-Tri-*O*-Acetyl-2-Deoxy-2-*o*-Trifluoromethylbenzylideneamino-*o*-Galactopyranosyl *N*-Phenyl Trifluoroacetimidate 52

Viscous oil: 276 mg, 94%, $\alpha:\beta = 1:4$; **52a**: ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.70$ (s, 1 H), 8.22 (d, $J = 7.6$ Hz, 1 H), 7.70 (d, $J = 7.6$ Hz, 1 H), 7.65–7.52 (m, 2 H), 7.31–7.18 (m, 2 H), 7.10–7.02 (m, 1 H), 6.89–6.66 (m, 2 H), 6.50 (brs, 1 H), 5.68–5.56 (m, 1 H), 5.51 (dd, $J = 10.4, 2.8$ Hz, 1 H), 4.53 (app t, $J = 6.0$ Hz, 1 H), 4.34–4.11 (m, 2 H), 4.09–3.93 (m, 1 H), 2.20 (s, 3 H), 2.08 (s, 3 H), 1.90 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.3, 170.0, 169.7, 161.6, 143.3, 133.3, 132.1, 130.9, 129.2$ (q, $J_{\text{C-F}} = 31.0$ Hz), 128.7, 128.5, 125.6 (q, $J_{\text{C-F}} = 5.5$ Hz), 124.6, 124.1 (d, $J_{\text{C-F}} = 272$ Hz), 119.4, 95.3, 69.4, 68.1, 66.3, 66.2, 61.6, 20.7, 20.6, 20.3; IR (film, cm^{-1}): $\nu = 2968, 1750, 1713, 1645, 1488, 1314$; HRMS (ESI): calc. for $\text{C}_{28}\text{H}_{26}\text{F}_6\text{N}_2\text{O}_8\text{Na}$ ($\text{M}+\text{Na}$): 655.1491; found: 655.1502. **52b**: ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.71$ (s, 1 H), 8.10 (d, $J = 7.6$ Hz, 1 H), 7.69 (d, $J = 7.6$ Hz, 1 H), 7.66–7.48 (m, 2 H), 7.37–7.20 (m, 2 H), 7.17–7.02 (m, 1 H), 6.89–6.71 (m, 2 H), 6.00 (brs, 1 H), 5.53–5.41 (m, 1 H), 5.38–5.12 (m, 1 H), 4.42–4.16 (m, 2 H), 4.11–3.98 (m, 1 H), 3.84 (t, $J = 8.4$ Hz, 1 H), 2.20 (s, 3 H), 2.02 (s, 3 H), 1.91 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.2, 170.1, 169.6, 162.5, 143.2, 133.4, 132.1, 130.8, 129.2$ (q, $J_{\text{C-F}} = 31.0$ Hz), 128.7, 128.5, 125.6 (q, $J_{\text{C-F}} = 5.7$ Hz), 124.4, 124.0 (d, $J_{\text{C-F}} = 272$ Hz), 119.1, 96.0, 71.9, 70.9, 69.1, 65.5, 61.2, 20.6, 20.5, 20.2; IR (film, cm^{-1}): $\nu = 2932, 1747, 1721, 1646, 1488, 1371, 1314, 1209$; HRMS (ESI): calc. for $\text{C}_{28}\text{H}_{26}\text{F}_6\text{N}_2\text{O}_8\text{Na}$ ($\text{M}+\text{Na}$): 655.1491; found: 655.1501.

1,6-Di-*O*-*tert*-Butyldimethylsilyl-2-Deoxy-2-*p*-Methoxybenzylideneamino-*o*-Galactopyranoside 53B

A 250 mL oven-dried RBF was charged with **53A** (3.36 g, 11.3 mmol, 1 equiv.), ^7b TBSCl (3.58 g, 23.7 mmol, 2.1 equiv.), imidazole (1.69 g, 24.9 mmol, 2.2 equiv.) and THF/DMF (40 mL/10 mL). The solution was stirred at room temperature overnight. The solution was diluted with $\text{CH}_2\text{Cl}_2/\text{MeOH}$ (20:1), washed with brine (2×50 mL). The aqueous phase was then extracted with $\text{CH}_2\text{Cl}_2/\text{MeOH}$ (20:1, 2×100 mL). The organic phase was combined, concentrated *in vacuo*. The resulting residue was purified by silica gel flash chromatography (hexane/ethyl acetate = 10/1 $\rightarrow$ 5/1 $\rightarrow$ 1/1 with 1% Et_3N) to afford **53B** (1.94 g, 35%) as a viscous oil. ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.26$ (s, 1H), 7.67 (d, $J = 9.2$ Hz, 2H), 6.91 (d, $J = 9.2$ Hz, 2H), 4.79 (d, $J = 7.2$ Hz, 1 H), 4.06 (app t, $J = 3.6$ Hz, 1 H), 3.94 (dd, $J = 10.4, 6.0$ Hz, 1 H), 3.88 (dd, $J = 10.4, 4.8$ Hz, 1 H), 3.90–3.80 (m, 1 H), 3.85 (s, 3 H), 3.60 (t, $J = 5.6$ Hz, 1 H), 3.24 (dd, $J = 9.6, 7.6$ Hz, 1 H), 2.78 (d, $J = 4.8$ Hz, 1 H), 4.27 (brs, 1 H), 0.92 (s, 9 H), 0.78 (s, 9 H), 0.11 (s, 3 H), 0.10 (s, 3 H), 0.07 (s, 3 H), -0.01 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 164.9, 161.7, 131.9, 130.2, 113.7, 96.6, 75.6, 74.8, 72.6, 68.0, 62.8, 55.3, 25.8, 25.5, 18.2, 17.9, -4.3, -5.3, -5.45, -5.51$; IR (film, cm^{-1}): $\nu = 3419, 2927, 1644, 1605, 1577, 1512, 1249$.

3,4-Di-*O*-Benzyl-1,6-Di-*O*-*tert*-Butyldimethylsilyl-2-Deoxy-2-*p*-Methoxybenzylideneamino-*o*-Galactopyranoside 53C

A 250 mL RBF was charged with diol **53B** (1.17 g, 2.2 mmol, 1.0 equiv.), benzyl bromide (0.78 mL, 6.6 mmol, 3.0 equiv.) and DMF (10 mL). The solution was cooled to -20°C , and NaH (60%, 0.22 g, 5.5 mmol, 2.5 equiv.) was added in several portions. The reaction was allowed to warm to room temperature and stirred overnight. The reaction mixture was

diluted with ethyl acetate, washed with brine (2 × 50 mL), dried over Na₂SO₄, concentrated *in vacuo*. The residue was purified by silica gel flash chromatography (hexane/ethyl acetate = 20/1 → 10/1 with 1% Et₃N) to afford **53C** (1.158 g, 75%) as a viscous oil. ¹H NMR (CDCl₃, 400 MHz): δ = 8.30 (s, 1 H), 7.70 (d, *J* = 8.8 Hz, 2 H), 7.45–7.15 (m, 10 H), 6.94 (d, *J* = 8.8 Hz, 2 H), 4.97 (d, *J* = 11.6 Hz, 1 H), 4.82 (d, *J* = 7.2 Hz, 1 H), 4.56 (d, *J* = 11.6 Hz, 1 H), 4.62–4.53 (m, 2 H), 3.87 (s, 3 H), 3.88–3.83 (m, 1 H), 3.80–3.64 (m, 3 H), 3.60 (dd, *J* = 10.0, 7.2 Hz, 1 H), 3.49 (t, *J* = 6.4 Hz, 1 H), 0.91 (s, 9 H), 0.79 (s, 9 H), 0.07 (s, 3 H), 0.06 (s, 6 H), 0.01 (s, 3 H); ¹³C NMR (CDCl₃, 100 MHz): δ = 163.2, 161.4, 138.9, 138.5, 129.8, 129.5, 128.2, 128.1, 128.0, 127.7, 127.4, 113.8, 97.2, 81.3, 75.7, 74.9, 74.3, 72.3, 72.3, 62.3, 55.3, 25.9, 25.6, 18.2, 18.0, –4.1, –5.2, –5.4, –5.5; IR (film, cm^{–1}): ν = 2928, 1847, 1606, 1512, 1248.

3,4-Di-*O*-Benzyl-2-Deoxy-2-Amino-*D*-Galactopyranose **53D**

A 25 mL RBF was charged with **53C** (105 mg, 0.15 mmol, 1.0 equiv.), 6N HCl (0.2 mL, 1.2 mmol, 8.0 equiv.) and acetone (1.0 mL). The solution was stirred at 50 °C overnight, concentrated *in vacuo*, and the residue was purified by silica gel flash chromatography (CH₂Cl₂/MeOH = 20/1 → 5/1) to afford 56 mg (95%) of **53D** as a viscous oil. ¹H NMR (CD₃OD, 400 MHz): δ = 7.51–7.24 (m, 10 H), 5.33 (d, *J* = 3.6 Hz, 1 H), 4.65–4.61 (m, 2 H), 4.59–4.52 (m, 2 H), 4.23–4.18 (m, 1 H), 4.11–4.02 (m, 2 H), 3.72–3.62 (m, 2 H), 3.57 (dd, *J* = 10.8, 3.6 Hz, 1 H); ¹³C NMR (CD₃OD, 100 MHz): δ = 139.6, 138.6, 129.2, 129.1, 128.9, 128.8, 128.7, 128.4, 91.2, 77.1, 75.6, 73.5, 72.2, 72.1, 61.9, 52.1

1,6-Di-*O*-Acetyl-3,4-Di-*O*-Benzyl-2-Deoxy-2-*o*-Trifluoromethylbenzylideneamino-*D*-Galactopyranoside **53E**

A 25 mL RBF was charged with **53D** (40 mg, 0.1 mmol, 1.0 equiv.), 1M NaOH (0.12 mL, 0.12 mmol, 1.2 equiv.), and CH₂Cl₂ (0.5 mL). To this pale yellow solution was then added 2 trifluoromethylbenzylaldehyde (0.02 mL, 0.12 mmol, 1.2 equiv.). The resulting mixture was stirred at room temperature overnight. Then the mixture was diluted with ethyl acetate, washed with brine, dried over Na₂SO₄, concentrated *in vacuo*. The crude residue was used directly without further purification. A 25 mL RBF was charged with the crude residue, acetic anhydride (0.15 mL), and pyridine (0.30 mL). After the reaction mixture was stirred at room temperature overnight, it was azeotroped with toluene for three times (3 × 15 mL). The residue was then purified by silica gel flash chromatography (hexane/ethyl acetate = 5/1 → 2/1 with 1% Et₃N) to afford **53E** (45 mg, 75%) as a viscous oil. ¹H NMR (CDCl₃, 400 MHz): δ = 8.76 (d, *J* = 2.4 Hz, 1 H), 8.11 (d, *J* = 7.6 Hz, 1 H), 7.70 (d, *J* = 7.6 Hz, 1 H), 7.62–7.47 (m, 2 H), 7.34–7.23 (m, 10 H), 5.85 (d, *J* = 7.2 Hz, 1 H), 4.99 (d, *J* = 11.6 Hz, 1 H), 4.67–4.53 (m, 3 H), 4.23 (dd, *J* = 11.2, 6.8 Hz, 1 H), 4.15 (dd, *J* = 11.2, 6.4 Hz, 1 H), 3.96–3.88 (m, 4 H), 1.99 (s, 6 H); ¹³C NMR (CDCl₃, 100 MHz): δ = 170.5, 169.1, 161.5, 138.0, 137.7, 133.9, 132.0, 130.4, 129.3, 129.0, 128.4, 128.3, 127.83, 127.77, 127.7, 125.6 (q, *J*_{C-F} = 5.7 Hz), 124.0 (d, *J*_{C-F} = 272 Hz), 93.3, 80.7, 74.4, 73.5, 72.6, 71.4, 63.1, 20.8, 20.6; IR (film, cm^{–1}): ν = 2936, 1749, 1644, 1368, 1228.

6-*O*-Acetyl-3,4-Di-*O*-Benzyl-2-Deoxy-2-*o*-Trifluoromethylbenzylideneamino-*D*-Galactopyranose **53F**

A 50 mL oven dried Schlenk flask was charged with **53E** (500 mg, 0.83 mmol, 1.0 equiv.) and THF (5.0 mL). The solution was cooled to 0 °C, and a solution of NH₃ in methanol (7 N, 3.6 mL, 25.0 mmol, 30 equiv.) was added. The resulting mixture was warmed to room temperature and stirred. When the reaction was complete as monitored by TLC, the mixture was evaporated and purified by flash chromatography on silica gel (hexane/ethyl acetate = 2/1 → 1/2 with 1% Et₃N) to afford **53F** (300 mg, 65%) as a viscous oil. ¹H NMR (CDCl₃, 400 MHz): δ = 8.77 (d, *J* = 2.4 Hz, 1 H), 6.19 (d, *J* = 8.0 Hz, 1 H), 7.70 (d, *J* = 7.2 Hz, 1 H),

7.63–7.52 (m, 2H), 7.38–7.21 (m, 10 H), 4.99 (d, $J = 11.6$ Hz, 1 H), 4.94 (d, $J = 7.2$ Hz, 1 H), 4.68–4.50 (m, 3 H), 4.32–4.11 (m, 2 H), 3.84–3.68 (m, 4 H), 2.02 (s, 3 H); IR (film, cm^{-1}): $\nu = 3423, 2894, 1742, 1644, 1455, 1314$.

6-O-Acetyl-3,4-Di-O-Benzyl-2-Deoxy-2-o-Trifluoromethylbenzylideneamino- β -Galactopyranosyl *N*-Phenyl Trifluoroacetimidate 53

Viscous oil: 377 mg, 99%; ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.82$ (d, $J = 1.2$ Hz, 1 H), 8.16 (d, $J = 7.6$ Hz, 1 H), 7.73 (d, $J = 7.6$ Hz, 1 H), 7.64–7.53 (m, 2 H), 7.37–7.21 (m, 12 H), 7.06 (t, $J = 3.6$ Hz, 1 H), 6.76 (d, $J = 7.6$ Hz, 2 H), 5.91 (brs, 1 H), 5.01 (d, $J = 11.6$ Hz, 1 H), 4.73–4.57 (m, 3 H), 4.28 (dd, $J = 11.2, 6.8$ Hz, 1 H), 4.17 (dd, $J = 11.2, 5.6$ Hz, 1 H), 4.07–4.01 (m, 1 H), 3.90–3.62 (m, 3 H), 1.97 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.5, 161.9, 143.6, 137.9, 137.6, 133.9, 131.9, 130.5, 128.5$ (q, $J_{\text{C-F}} = 31.0$ Hz), 128.6, 128.41, 128.38, 128.36, 127.9, 127.8, 127.7, 125.7 (q, $J_{\text{C-F}} = 5.6$ Hz), 124.1, 124.0 (d, $J_{\text{C-F}} = 272$ Hz), 119.2, 96.3, 80.5, 74.5, 73.6, 72.6, 71.5, 71.3, 63.0, 20.7; IR (film, cm^{-1}): $\nu = 2890, 1744, 1598, 1368, 1315$; HRMS (ESI): calc. for $\text{C}_{38}\text{H}_{35}\text{F}_6\text{N}_2\text{O}_6$ (M+H): 729.2399; found: 729.2405.

6-O-Acetyl-3,4-Di-O-Benzyl-2-Deoxy-2-o-Trifluoromethylbenzylideneamino- β -Glucopyranosyl *N*-Phenyl Trifluoroacetimidate 32

Viscous oil: 7.76 g, 98%, β only; ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.76$ (s, 1 H), 8.20 (d, $J = 7.6$ Hz, 1 H), 7.73 (d, $J = 7.6$ Hz, 1 H), 7.63–7.54 (m, 2 H), 7.37–7.06 (m, 13 H), 6.83–6.74 (m, 2 H), 5.92 (brs, 1 H), 4.86 (d, $J = 10.8$ Hz, 1 H), 4.73–4.57 (m, 3 H), 4.40–4.26 (m, 2 H), 4.06–3.94 (m, 1 H), 3.75–3.58 (m, 3 H), 2.05 (s, 3 H). ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.7, 161.7, 143.3, 137.5, 137.4, 133.4, 132.0, 130.7, 128.6, 128.5, 128.3, 128.14, 128.09, 127.9, 127.8, 126.2, 125.7$ (q, $J_{\text{C-F}} = 5.6$ Hz), 124.3, 124.0 (d, $J_{\text{C-F}} = 272$ Hz), 119.2, 95.6, 83.2, 76.1, 75.2, 75.1, 73.9, 73.0, 62.6, 20.8. IR (film, cm^{-1}): $\nu = 3032, 2978, 1738, 1719, 1644, 1488, 1313$. HRMS (ESI): calc. for $\text{C}_{38}\text{H}_{34}\text{F}_6\text{N}_2\text{O}_6\text{Na}$ (M+Na): 751.2219; found: 751.2217.

3,4,6-Tri-O-Acetyl-1-*tert*-Butyldimethylsilyl-2-Deoxy-2-*p*-Methoxybenzylideneamino- β -Glucopyranoside 33B

A 250 mL oven dried RBF was charged with **33A** (13.0 g, 30.7 mmol, 1.0 equiv.), 2 TBSCl (5.10 g, 33.8 mmol, 1.1 equiv.), imidazole (4.2 g, 61.4 mmol, 2.0 equiv.) and DMF (120 mL). The resulting mixture was stirred at room temperature overnight. The reaction mixture was diluted with ethyl acetate, washed with brine (2×50 mL), concentrated *in vacuo*. The residue was purified by silica gel flash chromatography (hexane/ethyl acetate = 5/1 $\rightarrow$ 3/1 with 1% Et_3N) to afford **33B** (16.4 g, 99%) as a viscous oil. ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.13$ (s, 1 H), 7.63 (d, $J = 8.8$ Hz, 2 H), 6.89 (d, $J = 8.8$ Hz, 2 H), 5.45 (t, $J = 9.6$, 1 H), 5.06 (app t, $J = 9.6$ Hz, 1 H), 4.93 (d, $J = 7.6$ Hz, 1 H), 4.28 (dd, $J = 12.0, 6.0$ Hz, 1 H), 4.18–3.97 (m, 2 H), 3.84 (s, 3 H), 3.24 (dd, $J = 7.6, 10.0$ Hz, 1 H), 2.08 (s, 3 H), 2.03 (s, 3 H), 1.88 (s, 3 H), 0.79 (s, 9 H), 0.06 (s, 3 H), 0.00 (s, 3 H).

1-*tert*-Butyldimethylsilyl-2-Deoxy-2-*p*-Methoxybenzylideneamino- β -Glucopyranoside 33C

A 250 mL oven dried RBF was charged with **33B** (6.5 g, 12.0 mmol, 1.0 equiv.), sodium methoxide (0.52 g, 9.6 mmol, 0.8 equiv.), and $\text{CH}_2\text{Cl}_2/\text{MeOH}$ (50 mL/100 mL). The resulting solution was stirred at room temperature. When the reaction mixture was complete as monitored by TLC, it was evaporated and then purified by flash chromatography on silica gel (ethyl acetate $\rightarrow$ $\text{CH}_2\text{Cl}_2/\text{MeOH} = 5/1$) to afford **33C** (4.80 g, 96%) as a viscous oil. ^1H NMR (CD_3OD , 400 MHz): $\delta = 8.21$ (s, 1 H), 7.72 (d, $J = 8.8$ Hz, 2 H), 6.98 (d, $J = 8.8$ Hz, 2 H), 4.88 (d, $J = 7.2$ Hz, 1 H), 3.92–3.86 (m, 1 H), 3.85 (s, 3 H), 3.76–3.72 (m, 1 H), 3.47–3.38 (m, 2 H), 2.97 (dd, $J = 9.6, 7.2$ Hz, 1 H), 0.78 (s, 9 H), 0.09 (s, 3 H), 0.02 (s, 3 H).

3,4,6-Tri-*O*-Benzyl-1-*tert*-Butyldimethylsilyl-2-Deoxy-2-*p*-Methoxybenzylideneamino- β -Glucopyranoside **33D**

A 250 mL RBF was charged with **33C** (12.3 g, 30.0 mmol, 1.0 equiv.), benzyl bromide (16.2 mL, 135 mmol, 4.5 equiv.) and DMF (100 mL). The solution was cooled to $-20\text{ }^{\circ}\text{C}$, and NaH (60%, 5.40 g, 135 mmol, 4.5 equiv.) was added in several portions. The mixture was warmed to room temperature and stirred overnight. The reaction mixture was diluted with ethyl acetate (100 mL), washed with brine ($2 \times 30\text{ mL}$), dried over Na_2SO_4 , concentrated *in vacuo*. The residue was purified by silica gel flash chromatography (hexane/ethyl acetate = 20/1 $\rightarrow$ 10/1 $\rightarrow$ 5/1 with 1% Et_3N) to afford **33D** (15.6 g, 76%) as a viscous oil. ^1H NMR (CDCl_3 , 400 MHz): δ = 8.24 (s, 1 H), 7.68 (d, J = 8.8 Hz, 2 H), 7.36–7.27 (m, 12 H), 7.17–7.09 (m, 3 H), 6.94 (d, J = 8.8 Hz, 1 H), 4.91–4.87 (m, 2 H), 4.68–4.55 (m, 5 H), 3.93 (t, J = 9.2 Hz, 1 H), 3.86 (s, 3 H), 3.80–3.62 (m, 4 H), 3.23 (dd, J = 9.2, 7.2 Hz, 1 H), 0.81 (s, 9 H), 0.10 (s, 3 H), 0.02 (s, 3 H).

3,4,6-Tri-*O*-Benzyl-2-Deoxy-2-Amino- β -Glucopyranose **33E**

A 250 mL RBF was charged with **33D** (15.1 g, 22.2 mmol, 1.0 equiv.), 6N HCl (18.5 mL, 110 mmol, 5.0 equiv.) and acetone (200 mL). The solution was stirred at $40\text{ }^{\circ}\text{C}$. When the reaction mixture was complete as monitored by TLC, it was then evaporated and purified by flash chromatography on silica gel (hexane/ethyl acetate = 2/1 $\rightarrow$ $\text{CH}_2\text{Cl}_2/\text{MeOH}$ = 10/1) to afford **33E** (8.17 g, 82%) as a viscous oil. ^1H NMR ($\text{CDCl}_3+\text{CD}_3\text{OD}$, 400 MHz): δ = 7.25–7.18 (m, 13 H), 7.03–6.98 (m, 2 H), 5.38 (s, 1 H), 4.86 (d, J = 10.4 Hz, 1 H), 4.69 (d, J = 10.4 Hz, 1 H), 4.62 (d, J = 10.4 Hz, 1 H), 4.47–4.36 (m, 2 H), 3.70–3.53 (m, 4 H), 3.10 (d, J = 7.2 Hz, 1 H); ^{13}C NMR ($\text{CDCl}_3+\text{CD}_3\text{OD}$, 100 MHz): δ = 137.3, 137.1, 137.0, 128.21, 128.17, 127.8, 127.7, 127.5, 127.4, 86.9, 78.5, 74.9, 74.5, 73.2, 69.9, 67.8, 54.0; IR (film, cm^{-1}): ν = 3435, 2978, 1585, 1487.

3,4,6-Tri-*O*-Benzyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- β -Glucopyranose **33F**

A 250 mL RBF was charged with **33E** (4.50 g, 10.0 mmol, 1.0 equiv.), 2-trifluoromethylbenzaldehyde (1.5 mL, 11.0 mmol, 1.1 equiv.), pyridine (8.1 mL, 100 mmol, 100 equiv.) and CH_2Cl_2 (100 mL). The resulting solution was stirred under reflux overnight. The reaction mixture was azeotroped with toluene and purified by flash chromatography on silica gel (Hexane/ethyl acetate = 2/1 $\sim$ 1/2) to afford 3.11 g (52%) of **33F** as a viscous oil. ^1H NMR (CDCl_3 , 400 MHz): δ = 8.71 (d, J = 2.0 Hz, 1 H), 8.21 (d, J = 6.0 Hz, 1 H), 7.69 (d, J = 6.0 Hz, 1 H), 7.58–7.47 (m, 2 H), 7.35–7.05 (m, 15 H), 5.01 (d, J = 8.0 Hz, 1 H), 4.82 (d, J = 10.8 Hz, 1 H), 4.70–4.47 (m, 5 H), 3.92 (t, J = 8.0 Hz, 1 H), 3.83–3.65 (m, 3 H), 3.60 (dd, J = 9.6, 3.6 Hz, 1 H), 3.34 (dd, J = 8.0, 9.6 Hz, 1 H); IR (film, cm^{-1}): ν = 3403, 2820, 1640, 1454, 1359, 1312.

3,4,6-Tri-*O*-Benzyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- β -Glucopyranosyl *N*-Phenyl Trifluoroacetimidate **33²¹**

Viscous oil: 3.95 g, 98%, $\alpha:\beta$ = 1:3; **33 α** : ^1H NMR (CDCl_3 , 400 MHz): δ = 8.77 (s, 1 H), 8.35 (d, J = 7.6 Hz, 1 H), 7.75 (d, J = 7.6 Hz, 1 H), 7.67–7.55 (m, 2 H), 7.43–6.55 (m, 20 H), 6.49 (brs, 1 H), 4.89 (d, J = 10.8 Hz, 1 H), 4.77–4.68 (m, 2 H), 4.65–4.53 (m, 3 H), 4.32–4.20 (m, 2 H), 3.96–3.85 (m, 2 H), 3.83–3.72 (m, 2 H); ^{13}C NMR (CDCl_3 , 100 MHz): δ = 160.6, 137.9, 137.8, 137.7, 133.4, 132.0, 130.7, 129.4 (q, $J_{\text{C-F}}$ = 31.0 Hz), 128.5, 128.44, 128.38, 128.3, 128.2, 128.0, 127.92, 127.88, 127.85, 127.7, 127.6, 125.6 (q, $J_{\text{C-F}}$ = 5.6 Hz), 123.9 (d, $J_{\text{C-F}}$ = 273 Hz), 95.7, 80.2, 75.3, 74.2, 73.8, 73.5, 60.4; IR (film, cm^{-1}): ν = 2876, 1667, 1594, 1488, 1313; HRMS (ESI): calc. for $\text{C}_{43}\text{H}_{38}\text{F}_6\text{N}_2\text{O}_5\text{Na}$ ($\text{M}+\text{Na}$): 799.2583; found: 799.2598. **33 β** : ^1H NMR (CDCl_3 , 400 MHz): δ = 8.79 (s, 1 H), 8.22 (d, J = 7.6 Hz, 1 H), 7.75 (d, J = 7.6 Hz, 1 H), 7.63–7.54 (m, 2 H), 7.43–7.05 (m, 18 H), 6.85–6.74 (m, 2 H), 6.07 (brs, 1 H), 4.89 (d, J = 10.8 Hz, 1 H), 4.77–4.56 (m, 5 H), 4.10–3.63 (m, 6 H); ^{13}C

NMR (CDCl₃, 100 MHz): δ = 161.5, 137.9, 137.8, 137.7, 135.2, 133.5, 131.9, 130.6, 129.5 (q, J_{C-F} = 31.0 Hz), 129.3, 128.6, 128.4, 128.3, 128.2, 127.9, 127.8, 127.6, 126.2, 125.7 (q, J_{C-F} = 5.5 Hz), 124.1, 123.9 (d, J_{C-F} = 273 Hz), 95.8, 83.0, 76.2, 76.0, 75.2, 75.1, 73.4, 60.4; IR (film, cm⁻¹): ν = 3031, 2865, 1644, 1597, 1488, 1314; HRMS (ESI): calc. for C₄₃H₃₈F₆N₂O₅Na (M+Na): 799.2584; found: 799.2598.

General Glycosylation Procedure Using Ni(4-F-PhCN)₄(OTf)₂: Formation of Disaccharide 5 and Transfer Product 7

A 10 mL oven dried Schlenk flask was charged with donor **10** (31 mg, 0.05 mmol, 1.0 equiv), thioglycoside acceptor **3** (53 mg, 0.10 mmol, 2.0 equiv), and CH₂Cl₂ (0.3 mL). Then a 0.25 mL of preformed solution of Ni(4-F-PhCN)₄(OTf)₂, which was generated *in situ* from a reaction of Ni(4-F-PhCN)₄Cl₂ (12 mg, 0.02 mmol, 10 mol%) and AgOTf (11 mg, 0.4 mmol, 20 mol%) in dichloromethane (1.0 mL) for 30 min, was added to the solution. The resulting mixture was stirred at 35 °C overnight. When the reaction was complete as monitored by TLC (toluene/acetonitrile = 4/1), the mixture was evaporated, and purified by flash chromatography on silica gel (hexane/ethyl acetate = 9/1 → 5/1 → 3/2 with 1% Et₃N) to afford disaccharide **5** (28 mg, 58%, α only) and thioglycoside **7** (4 mg, 14%, α only) as viscous oil.

Phenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1→3)-4,6-O-Benzylidene-2-Deoxy-2-(2,2,2-Trichloroethyl)amino-1-Thiol- β -D-Glucopyranoside 5

$[\alpha]_D^{24}$ = 28.2 (c = 2.1, CH₂Cl₂); ¹H NMR (CDCl₃, 400 MHz): δ = 8.43 (d, J = 2.0 Hz, 1 H), 8.22 (d, J = 7.6 Hz, 1 H), 7.62 (d, J = 7.6 Hz, 1 H), 7.56–7.33 (m, 7 H), 7.23–7.16 (m, 1 H), 7.14–7.03 (m, 2 H), 6.93 (d, J = 7.2 Hz, 2 H), 5.65–5.51 (m, 2 H), 5.37 (d, J = 3.6 Hz, 1 H), 5.19 (s, 1 H), 5.09 (t, J = 5.6 Hz, 2 H), 4.98 (d, J = 12.0 Hz, 1 H), 4.61 (d, J = 12.0 Hz, 1 H), 4.38–4.26 (m, 4 H), 4.06 (dd, J = 12.0, 2.0 Hz, 1 H), 3.92–3.65 (m, 3 H), 3.62 (dd, J = 10.4, 3.6 Hz, 1 H), 3.56–3.49 (m, 1 H), 2.11 (s, 3 H), 2.02 (s, 3 H), 1.82 (s, 3 H); ¹³C NMR (CDCl₃, 100 MHz): δ = 170.7, 169.7, 169.6, 160.4, 153.8, 136.3, 132.4, 131.9, 130.7, 129.1, 128.9, 128.3, 128.2, 127.9, 126.3, 125.5, 101.5, 99.0, 95.2, 87.1, 82.0, 76.7, 74.6, 72.3, 70.7, 70.0, 68.7, 68.5, 67.8, 62.1, 55.7, 20.8, 20.7, 20.3; IR (film, cm⁻¹): ν = 3335, 2872, 1746, 1643, 1523, 1368, 1314, 1226; HRMS (ESI): calc. for C₄₂H₄₃Cl₃F₃N₂O₁₃S (M+H): 977.1504; found: 977.1505.

Phenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino-1-Thiol- α -D-Glucopyranoside 7

¹H NMR (CDCl₃, 400 MHz): δ = 8.66 (d, J = 2.0 Hz, 1 H), 8.27 (d, J = 7.6 Hz, 1 H), 7.70–7.47 (m 5 H), 7.33–7.22 (m, 2 H), 5.72–5.62 (m, 2 H), 5.14 (app t, J = 9.6 Hz, 1 H), 4.72–4.65 (m, 1 H), 4.30 (dd, J = 5.6, 12.0 Hz, 1 H), 4.02 (dd, J = 5.6, 10.0 Hz, 1 H), 3.97 (dd, J = 2.0, 12.0 Hz, 1 H), 2.05 (s, 3 H), 2.00 (s, 3 H), 1.89 (s, 3 H). ¹³C NMR (CDCl₃, 100 MHz): δ = 170.6, 169.9, 169.7, 160.3, 133.2, 132.3, 131.7, 130.9, 129.2, 129.0, 127.3, 125.4, 86.3, 72.2, 71.7, 68.6, 68.4, 62.1, 20.7, 20.6, 20.4. IR (film, cm⁻¹): ν = 2932, 1744, 1643, 1366, 1314, 1221. HRMS (ESI): calc. for C₂₆H₂₇F₃NO₇S (M+H): 554.1460; found: 554.1473.

Phenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- β -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1→3)-4,6-O-Benzylidene-2-Deoxy-2-(2,2,2-Trichloroethyl)amino-1-Thiol- β -D-Glucopyranoside 4

Viscous oil: 16 mg, 33%, α : β = 21:1; ¹H NMR (CDCl₃, 400 MHz): δ = 8.17 (s, 1 H), 7.48–7.31 (m, 11 H), 7.16–7.14 (m, 2 H), 6.63–6.60 (m, 1 H), 5.65 (t, J = 9.6 Hz, 1 H), 5.55 (app t, J = 9.2 Hz, 1 H), 5.36 (d, J = 4.0 Hz, 1 H), 5.18–4.94 (m, 4 H), 4.60 (d, J = 12.0 Hz, 1 H),

4.42–4.03 (m, 5 H), 3.72–3.45 (m, 5 H), 2.12 (s, 3 H), 2.04 (s, 3 H), 1.83 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): δ = 170.9, 170.8, 170.7, 132.7, 132.5, 129.2, 128.4, 128.0, 126.0, 125.7, 100.5, 99.6, 95.2, 77.2, 74.6, 71.0, 70.1, 70.0, 68.6, 68.5, 20.9, 20.7, 20.6; IR (film, cm^{-1}): ν = 3343, 2824, 1744, 1648, 1532, 1368, 1323, 1230; HRMS (ESI): calc. for $\text{C}_{42}\text{H}_{43}\text{Cl}_3\text{F}_3\text{N}_2\text{O}_{13}\text{S}$ (M+H): 977.1504; found: 977.1512.

Phenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2-*p*-Trifluoromethylbenzylideneamino-1-Thiol- α -D-Glucopyranoside 6

Viscous oil: 9 mg, 33%, α only; ^1H NMR (CDCl_3 , 400 MHz): δ = 8.34 (s, 1 H), 7.90 (d, J = 8.0 Hz, 2 H), 7.69 (d, J = 8.0 Hz, 2 H), 7.48–7.45 (m, 2 H), 7.33–7.24 (m, 3 H), 5.72–5.64 (m, 2 H), 5.13 (app t, J = 10.0 Hz, 1 H), 4.75–4.67 (m, 1 H), 4.32 (dd, J = 12.0, 5.2 Hz, 1 H), 4.00–3.93 (m, 2 H), 2.06 (s, 3 H), 2.00 (s, 3 H), 1.88 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): δ = 170.6, 170.2, 169.5, 162.4, 133.1, 131.8, 131.7, 129.0, 127.4, 125.7 (q, $J_{\text{C-F}}$ = 5.5 Hz), 86.5, 72.1, 71.9, 68.8, 68.4, 62.1, 20.74, 20.70, 20.6; IR (film, cm^{-1}): ν = 2923, 1748, 1647, 1454, 1370, 1324, 1234; HRMS (ESI): calc. for $\text{C}_{26}\text{H}_{27}\text{F}_3\text{NO}_7\text{S}$ (M+H): 554.1460; found: 554.1463.

Ethyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2-*o*-Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 3)-4,6-O-Benzylidene-2-Deoxy-2-(2,2,2-Trichloroethyl)amino-1-Thiol- β -D-Glucopyranoside 18

Viscous oil: 32 mg, 43%, α : β = 10:1; ^1H NMR (CDCl_3 , 400 MHz): δ = 8.42 (d, J = 2.0 Hz, 1 H), 8.23 (d, J = 7.6 Hz, 1 H), 7.64–7.33 (m, 4 H), 7.22–7.07 (m, 1 H), 7.11–7.04 (m, 2 H), 6.91 (d, J = 7.2 Hz, 2 H), 5.76 (t, J = 10.0 Hz, 1 H), 5.49 (d, J = 8.8 Hz, 1 H), 5.18 (s, 1 H), 5.09 (app t, J = 10.0 Hz, 2 H), 5.02 (d, J = 12.0 Hz, 1 H), 4.57 (d, J = 12.0 Hz, 1 H), 4.40–4.23 (m, 3 H), 4.19 (t, J = 9.2 Hz, 1 H), 4.10 (dd, J = 12.0, 2.0 Hz, 1 H), 3.85–3.73 (m, 2 H), 3.71 (t, J = 10.0 Hz, 1 H), 3.62 (dd, J = 10.0, 4.0 Hz, 1 H), 3.51 (td, J = 9.6, 4.8 Hz, 1 H), 2.76 (q, J = 7.2 Hz, 2 H), 2.12 (s, 3 H), 2.03 (s, 3 H), 1.83 (s, 3 H), 1.27 (t, J = 7.2 Hz, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): δ = 170.7, 169.8, 169.6, 160.4, 153.9, 136.3, 131.9, 130.8, 129.0, 128.3, 128.0, 126.2, 125.5, 101.5, 99.1, 95.2, 85.1, 82.2, 77.2, 74.6, 72.3, 70.7, 70.1, 68.6, 67.8, 62.3, 55.6, 24.3, 20.9, 20.8, 20.4, 14.8; IR (film, cm^{-1}): ν = 3332, 2872, 1746, 1643, 1527, 1368, 1314, 1227; HRMS (ESI): calc. for $\text{C}_{38}\text{H}_{43}\text{Cl}_3\text{F}_3\text{N}_2\text{O}_{13}\text{S}$ (M+H): 929.1504; found: 929.1516.

Ethyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2-*o*-Trifluoromethylbenzylideneamino-1-Thiol- α -D-Glucopyranoside 25

Viscous oil: 11 mg, 22%, α only; ^1H NMR (CDCl_3 , 400 MHz): δ = 8.61 (d, J = 2.0 Hz, 1 H), 8.21 (d, J = 7.6 Hz, 1 H), 7.67 (d, J = 7.6 Hz, 1 H), 7.62–7.53 (m, 2 H), 5.58 (t, J = 9.6 Hz, 1 H), 5.41 (d, J = 5.6 Hz, 1 H), 5.13 (app t, J = 10.0 Hz, 1 H), 4.64–4.57 (m, 1 H), 4.38 (dd, J = 12.0, 4.8 Hz, 1 H), 4.12 (dd, J = 12.0, 2.0 Hz, 1 H), 3.95 (dd, J = 10.0, 5.6 Hz, 1 H), 2.66–2.48 (m, 2 H), 2.11 (s, 3 H), 2.04 (s, 3 H), 1.86 (s, 3 H), 1.30 (t, J = 7.2 Hz, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): δ = 170.7, 170.0, 169.7, 160.0, 133.2, 132.3, 130.8, 129.1, 125.4 (q, $J_{\text{C-F}}$ = 5.5 Hz), 83.5, 72.2, 71.8, 68.8, 67.7, 62.2, 23.6, 20.8, 20.7, 20.4, 14.4; IR (film, cm^{-1}): ν = 2930, 1748, 1644, 1453, 1368, 1315, 1227; HRMS (ESI): calc. for $\text{C}_{22}\text{H}_{26}\text{F}_3\text{NO}_7\text{S}$ (M+H): 506.1460; found: 506.1456.

Naphthyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2-*o*-Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 3)-4,6-O-Benzylidene-2-Deoxy-2-(2,2,2-Trichloroethyl)amino-1-Thiol- β -D-Glucopyranoside 19

Viscous oil: 30 mg, 59%, α only; $[\alpha]_D^{24}$ = 6.1 (c = 1.0, CH_2Cl_2); ^1H NMR (CDCl_3 , 400 MHz): δ = 8.53–8.47 (m, 1 H), 8.40 (d, J = 2.0 Hz, 1 H), 8.20 (d, J = 7.6 Hz, 1 H), 7.92–7.83 (m, 3 H), 7.64–7.43 (m, 5 H), 7.18–7.13 (m, 1 H), 7.08–7.03 (m, 2 H), 6.89 (d, J = 7.2 Hz, 2

H), 5.63 (d, $J = 8.4$ Hz, 1 H), 5.54 (t, $J = 9.6$ Hz, 1 H), 5.34 (d, $J = 4.0$ Hz, 1 H), 5.17 (s, 1 H), 5.13–5.05 (m, 2 H), 4.99 (d, $J = 12.0$ Hz, 1 H), 4.62 (d, $J = 12.0$ Hz, 1 H), 4.34–4.23 (m, 4 H), 4.08–4.02 (m, 1 H), 3.81–3.65 (m, 3 H), 3.60 (dd, $J = 10.4, 4.0$ Hz, 1 H), 3.46 (td, $J = 9.6, 4.8$ Hz, 1 H), 2.10 (s, 3 H), 2.02 (s, 3 H), 1.82 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.7, 169.8, 169.7, 160.5, 153.7, 136.3, 134.1, 133.2, 131.9, 130.8, 129.7, 128.9, 128.7, 128.3, 127.9, 126.9, 126.4, 125.7, 125.5, 101.5, 99.1, 95.1, 82.1, 77.2, 74.7, 72.3, 70.6, 70.0, 68.6, 67.8, 62.1, 55.8, 20.8, 20.7, 20.4$; IR (film, cm^{-1}): $\nu = 3335, 2965, 1744, 1643, 1532, 1368, 1314, 1225$; HRMS (ESI): calc. for $\text{C}_{46}\text{H}_{45}\text{Cl}_3\text{F}_3\text{N}_2\text{O}_{13}\text{S}$ (M+H): 1027.1660; found: 1027.1650.

Naphthyl 3,4,6-Tri-*O*-Acetyl-2-Deoxy-2-*o*-Trifluoromethylbenzylideneamino-1-Thiol- α -*D*-Glucopyranoside 26

Viscous oil: 3 mg, 10%, α only; ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.71$ (d, $J = 2.0$ Hz, 1 H), 8.57–8.46 (m, 2 H), 7.86–7.26 (m, 9 H), 5.77 (t, $J = 9.6$ Hz, 1 H), 5.65 (d, $J = 5.6$ Hz, 1 H), 4.83–4.74 (m, 1 H), 4.29 (dd, $J = 12.0, 4.8$ Hz, 1 H), 4.05 (dd, $J = 10.0, 5.6$ Hz, 1 H), 3.90–3.83 (m, 1 H), 3.63–3.52 (m, 1 H), 2.07 (s, 3 H), 1.94 (s, 3 H), 1.92 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.6, 169.8, 147.8, 134.1, 133.1, 132.3, 130.9, 129.14, 129.09, 128.9, 128.3, 127.2, 126.8, 126.2, 125.1, 124.1, 87.0, 74.1, 72.2, 71.8, 68.8, 62.1, 20.7, 20.5$; IR (film, cm^{-1}): $\nu = 2924, 1745, 1644, 1439, 1369, 1313, 1221$; HRMS (ESI): calc. for $\text{C}_{30}\text{H}_{29}\text{F}_3\text{NO}_7\text{S}$ (M+H): 604.1617; found: 604.1615.

4-Methylphenyl 3,4,6-Tri-*O*-Acetyl-2-Deoxy-2-*o*-Trifluoromethylbenzylideneamino- α -*D*-Glucopyranosyl-(1 $\rightarrow$ 3)-4,6-*O*-Benzylidene-2-Deoxy-2-(2,2,2-Trichloroethyl)amino-1-Thiol- β -*D*-Glucopyranoside 20

Viscous oil: 37 mg, 38%, $\alpha:\beta = 11:1$; ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.42$ (d, $J = 2.0$ Hz, 1 H), 8.20 (d, $J = 7.2$ Hz, 1 H), 7.63–7.52 (m, 3 H), 7.39 (d, $J = 8.0$ Hz, 2 H), 7.18–7.13 (m, 3 H), 7.07–7.04 (m, 2 H), 6.91 (d, $J = 8.0$ Hz, 2 H), 5.60–5.53 (m, 2 H), 5.36 (d, $J = 4.0$ Hz, 1 H), 5.17 (s, 1 H), 5.15–5.04 (m, 2 H), 5.00 (d, $J = 12.0$ Hz, 1 H), 4.59 (d, $J = 12.0$ Hz, 1 H), 4.36–4.23 (m, 4 H), 4.07–4.04 (m, 1 H), 3.78–3.66 (m, 2 H), 3.61 (dd, $J = 10.4, 4.0$ Hz, 1 H), 3.54–3.48 (m, 1 H), 2.36 (s, 3 H), 2.11 (s, 3 H), 2.02 (s, 3 H), 1.82 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.7, 169.8, 169.7, 160.5, 153.7, 138.6, 136.3, 133.2, 130.8, 129.9, 129.0, 128.3, 128.0, 125.5, 101.5, 99.0, 95.2, 82.1, 77.2, 74.6, 72.3, 70.6, 70.0, 68.6, 67.8, 62.1, 55.6, 21.2, 20.8, 20.7, 20.4$; IR (film, cm^{-1}): $\nu = 3383, 2958, 1746, 1642, 1539, 1368, 1314, 1224$; HRMS (ESI): calc. for $\text{C}_{43}\text{H}_{45}\text{Cl}_3\text{F}_3\text{N}_2\text{O}_{13}\text{S}$ (M+H): 991.1660; found: 991.1673.

4-Methylphenyl 3,4,6-Tri-*O*-Acetyl-2-Deoxy-2-*o*-Trifluoromethylbenzylideneamino-1-Thiol- α -*D*-Glucopyranoside 27

Viscous oil: 11 mg, 20%, α only; ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.65$ (d, $J = 2.0$ Hz, 1 H), 8.28 (d, $J = 8.0$ Hz, 1 H), 7.69 (d, $J = 8.0$ Hz, 1 H), 7.64–7.53 (m, 2 H), 7.38 (d, $J = 8.0$ Hz, 2 H), 7.11 (d, $J = 8.0$ Hz, 2 H), 5.66 (t, $J = 9.6$ Hz, 1 H), 5.62 (d, $J = 5.6$ Hz, 1 H), 5.14 (app t, $J = 10.0$ Hz, 1 H), 4.73–4.68 (m, 1 H), 4.30 (dd, $J = 12.0, 4.8$ Hz, 1 H), 4.01 (dd, $J = 10.0, 5.6$ Hz, 1 H), 3.97 (dd, $J = 12.0, 2.0$ Hz, 1 H), 2.32 (s, 3 H), 2.06 (s, 3 H), 2.01 (s, 3 H), 1.89 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.6, 170.0, 169.7, 137.6, 132.5, 130.9, 129.8, 129.2, 129.1, 86.7, 72.2, 71.7, 68.8, 68.2, 62.2, 21.1, 20.8, 20.7, 20.4$; IR (film, cm^{-1}): $\nu = 2924, 1748, 1643, 1492, 1369, 1315, 1228$; HRMS (ESI): calc. for $\text{C}_{27}\text{H}_{29}\text{F}_3\text{NO}_7\text{S}$ (M+H): 568.1617; found: 568.1616.

4-Methoxyphenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 3)-4,6-O-Benzylidene-2-Deoxy-2-(2,2,2-Trichloroethyl)amino-1-Thiol- β -D-Glucopyranoside 21

Viscous oil: 37 mg, 38%, α : β = 11:1; ^1H NMR (CDCl_3 , 400 MHz): δ = 8.41 (d, J = 2.0 Hz, 1 H), 8.20 (d, J = 7.2 Hz, 1 H), 7.63–7.44 (m, 5 H), 7.18–7.13 (m, 1 H), 7.09–7.04 (m, 2 H), 6.92–6.84 (m, 4 H), 5.62–5.52 (m, 2 H), 5.35 (d, J = 4.0 Hz, 1 H), 5.17 (s, 1 H), 5.10 (app t, J = 10.0 Hz, 1 H), 5.03–4.93 (m, 2 H), 4.62 (d, J = 12.0 Hz, 1 H), 4.35–4.22 (m, 4 H), 4.09–4.02 (m, 1 H), 3.83 (s, 3 H), 3.81–3.67 (m, 3 H), 3.61 (dd, J = 4.0, 10.4 Hz, 1 H), 3.53–3.44 (m, 1 H), 2.11 (s, 3 H), 2.02 (s, 3 H), 1.82 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): δ = 170.7, 169.8, 169.7, 160.2, 136.3, 135.9, 131.8, 130.7, 128.9, 128.3, 127.9, 127.1, 125.5, 121.6, 114.7, 101.5, 99.0, 95.2, 87.1, 82.0, 77.2, 76.4, 74.6, 72.3, 70.6, 70.0, 68.6, 67.8, 62.1, 55.5, 55.3, 20.8, 20.7, 20.4; IR (film, cm^{-1}): ν = 3342, 2958, 1745, 1642, 1539, 1493, 1368, 1314, 1226; HRMS (ESI): calc. for $\text{C}_{43}\text{H}_{45}\text{Cl}_3\text{F}_3\text{N}_2\text{O}_{14}\text{S}$ ($\text{M}+\text{H}$): 1007.1609; found: 1007.1597.

4-Methoxyphenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino-1-Thiol- α -D-Glucopyranoside 28

Viscous oil: 17 mg, 30%, α only; ^1H NMR (CDCl_3 , 400 MHz):²² δ = 8.65 (d, J = 2.0 Hz, 1 H), 8.32–8.25 (m, 1 H), 7.72–7.54 (m, 3 H), 7.42 (d, J = 8.8 Hz, 2 H), 6.84 (d, J = 8.8 Hz, 2 H), 5.65 (t, J = 9.6 Hz, 1 H), 5.52 (d, J = 5.6 Hz, 1 H), 5.14 (app t, J = 6.0 Hz, 1 H), 4.77–4.71 (m, 1 H), 4.31 (dd, J = 12.0, 4.8 Hz, 1 H), 4.03–3.95 (m, 2 H), 3.79 (s, 3 H), 2.06 (s, 3 H), 2.03 (s, 3 H), 1.89 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): δ = 170.7, 169.9, 169.7, 160.2, 159.6, 134.9, 133.2, 132.3, 130.9, 129.2, 129.0, 125.4 (q, $J_{\text{C-F}}$ = 5.5 Hz), 124.1, 123.0, 114.6, 87.3, 72.2, 68.8, 68.1, 63.1, 60.9, 55.3, 20.7, 20.5, 20.4; IR (film, cm^{-1}): ν = 2934, 1747, 1644, 1494, 1369, 1315, 1227; HRMS (ESI): calc. for $\text{C}_{27}\text{H}_{29}\text{F}_3\text{NO}_8\text{S}$ ($\text{M}+\text{H}$): 584.1566; found: 584.1567.

4-Fluorophenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 3)-4,6-O-Benzylidene-2-Deoxy-2-(2,2,2-Trichloroethyl)amino-1-Thiol- β -D-Glucopyranoside 22

Viscous oil: 23 mg, 58%, α : β = 20:1; ^1H NMR (CDCl_3 , 400 MHz): δ = 8.44 (d, J = 2.0 Hz, 1 H), 8.21 (d, J = 7.2 Hz, 1 H), 7.62–7.50 (m, 5 H), 7.21–7.17 (m, 1 H), 7.10–7.02 (m, 4 H), 6.92 (d, J = 7.2 Hz, 2 H), 5.69 (d, J = 8.4 Hz, 1 H), 5.58 (t, J = 9.6 Hz, 1 H), 5.37 (d, J = 3.6 Hz, 1 H), 5.19 (s, 1 H), 5.11 (app t, J = 10.0 Hz, 1 H), 5.04–4.93 (m, 2 H), 4.64 (d, J = 12.0 Hz, 1 H), 4.36–4.18 (m, 4 H), 4.10–4.04 (m, 1 H), 3.77–3.59 (m, 4 H), 3.51 (td, J = 9.6, 4.8 Hz, 1 H), 2.13 (s, 3 H), 2.04 (s, 3 H), 1.84 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): δ = 170.7, 169.8, 169.7, 163.0 (d, $J_{\text{C-F}}$ = 248 Hz), 160.5, 153.7, 136.2, 135.7, 135.6, 133.1, 131.8, 130.8, 129.0, 128.2, 127.9, 125.5, 116.3, 116.1, 101.5, 99.0, 95.2, 87.0, 81.9, 77.2, 74.6, 72.3, 70.6, 70.0, 68.6, 68.4, 67.8, 62.1, 55.5, 20.8, 20.7, 20.3; IR (film, cm^{-1}): ν = 3382, 2958, 1744, 1643, 1490, 1368, 1314, 1223; HRMS (ESI): calc. for $\text{C}_{42}\text{H}_{41}\text{Cl}_3\text{F}_4\text{N}_2\text{O}_{13}\text{S}$ ($\text{M}+\text{H}$): 995.1409; found: 995.1434.

4-Fluorophenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino-1-Thiol- α -D-Glucopyranoside 29

Viscous oil: 2 mg, 9%, α only; ^1H NMR (CDCl_3 , 400 MHz):²² δ = 8.65 (d, J = 2.0 Hz, 1 H), 8.27 (d, J = 8.0 Hz, 1 H), 7.69 (d, J = 8.0 Hz, 1 H), 7.64–7.53 (m, 2 H), 7.50–7.45 (m, 2 H), 7.03–6.97 (m, 2 H), 5.64 (t, J = 10.0 Hz, 1 H), 5.60 (d, J = 5.6 Hz, 1 H), 5.14 (app t, J = 10.0 Hz, 1 H), 4.71–4.63 (m, 1 H), 4.30 (dd, J = 12.4, 5.2 Hz, 1 H), 4.03–3.94 (m, 2 H), 2.06 (s, 3 H), 2.02 (s, 3 H), 1.89 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): δ = 170.6, 169.9, 169.7, 161.2, 160.4, 134.5, 134.4, 133.1, 132.3, 131.0, 129.1, 129.0, 127.9, 125.5 (q, $J_{\text{C-F}}$ = 5.7 Hz), 116.3, 116.0, 86.8, 72.1, 71.6, 68.7, 68.3, 62.2, 20.72, 20.69, 20.4; IR (film, cm^{-1}): ν =

2922, 1748, 1644, 1491, 1368, 1315, 1227; HRMS (ESI): calc. for $C_{26}H_{26}F_4NO_7S$ (M+H): 572.1366; found: 572.1368.

2-Fluorophenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 3)-4,6-O-Benzylidene-2-Deoxy-2-(2,2,2-Trichloroethyl)amino-1-Thiol- β -D-Glucopyranoside 23

Viscous oil: 30 mg, 60%, α only; $[\alpha]_D^{24} = 21.9$ ($c = 1.5$, CH_2Cl_2); 1H NMR ($CDCl_3$, 400 MHz): $\delta = 8.41$ (d, $J = 2.0$ Hz, 1 H), 8.21 (d, $J = 7.6$ Hz, 1 H), 7.63–7.33 (m, 5 H), 7.20–7.03 (m, 5 H), 6.89 (d, $J = 7.6$ Hz, 2 H), 5.69 (d, $J = 8.4$ Hz, 1 H), 5.57 (t, $J = 10.0$ Hz, 1 H), 5.35 (d, $J = 3.6$ Hz, 1 H), 5.17 (s, 1 H), 5.14–4.97 (m, 3 H), 4.59 (d, $J = 12.0$ Hz, 1 H), 4.42–4.24 (m, 4 H), 4.14–4.05 (m, 1 H), 3.82–3.54 (m, 3 H), 3.63 (dd, $J = 10.0$, 3.6 Hz, 1 H), 3.52–3.44 (m, 1 H), 2.12 (s, 3 H), 2.03 (s, 3 H), 1.83 (s, 3 H); ^{13}C NMR ($CDCl_3$, 100 MHz): $\delta = 170.7$, 169.8, 169.7, 162.0 (d, $J_{C-F} = 245$ Hz), 160.5, 153.9, 136.2, 135.8, 131.9, 130.9, 130.8, 129.0, 128.35, 128.27, 127.9, 125.5, 124.8, 124.7, 116.2, 116.0, 101.6, 99.1, 95.1, 86.6, 82.0, 76.3, 74.7, 72.3, 70.7, 70.1, 68.6, 68.4, 67.9, 62.3, 55.9, 20.81, 20.76, 20.4; IR (film, cm^{-1}): $\nu = 3332$, 2965, 1743, 1642, 1474, 1368, 1314, 1224; HRMS (ESI): calc. for $C_{42}H_{42}Cl_3F_4N_2O_{13}S$ (M+H): 995.1409; found: 995.1409.

2-Fluorophenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino-1-Thiol- α -D-Glucopyranoside 30

Viscous oil: 1.3 mg, 4%, α only; 1H NMR ($CDCl_3$, 400 MHz): $\delta = 8.67$ (d, $J = 2.0$ Hz, 1 H), 8.29 (d, $J = 8.0$ Hz, 1 H), 7.74–7.53 (m, 5 H), 7.13–7.06 (m, 2 H), 5.76 (d, $J = 6.0$ Hz, 1 H), 5.70 (t, $J = 9.6$ Hz, 1 H), 5.18–5.02 (m, 2 H), 4.70–4.63 (m, 1 H), 4.27 (dd, $J = 12.0$, 4.8 Hz, 1 H), 4.03 (dd, $J = 9.6$, 5.6 Hz, 1 H), 3.85 (dd, $J = 12.0$, 2.0 Hz, 1 H), 2.06 (s, 3 H), 1.97 (s, 3 H), 1.90 (s, 3 H); IR (film, cm^{-1}): $\nu = 2925$, 1749, 1644, 1474, 1370, 1315, 1228; HRMS (ESI): calc. for $C_{26}H_{26}F_4NO_7S$ (M+H): 572.1366; found: 572.1368.

2-Trifluoromethylphenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 3)-4,6-O-Benzylidene-2-Deoxy-2-(2,2,2-Trichloroethyl)amino-1-Thiol- β -D-Glucopyranoside 24

Viscous oil: 31 mg, 61%, α only; $[\alpha]_D^{24} = 19.8$ ($c = 3.3$, CH_2Cl_2); 1H NMR ($CDCl_3$, 400 MHz): $\delta = 8.42$ (d, $J = 2.0$ Hz, 1 H), 8.22 (d, $J = 7.6$ Hz, 1 H), 7.70 (d, $J = 7.6$ Hz, 1 H), 7.70 (d, $J = 7.6$ Hz, 1 H), 7.63 (d, $J = 7.6$ Hz, 1 H), 7.60–7.48 (m, 3 H), 7.46–7.40 (m, 1 H), 7.22–7.15 (m, 1 H), 7.10–7.03 (m, 2 H), 6.90 (d, $J = 7.6$ Hz, 2 H), 5.65–5.53 (m, 2 H), 5.34 (d, $J = 4.0$ Hz, 1 H), 5.20 (s, 1 H), 5.14–4.94 (m, 3 H), 4.53 (d, $J = 12.0$ Hz, 1 H), 4.44–4.37 (m, 1 H), 4.33–4.22 (m, 3 H), 4.13–4.05 (m, 2 H), 3.85 (t, $J = 4.8$ Hz, 2 H), 3.77 (t, $J = 6.4$ Hz, 1 H), 3.61 (dd, $J = 10.0$, 3.6 Hz, 1 H), 3.50 (td, $J = 9.6$, 4.8 Hz, 1 H), 2.11 (s, 3 H), 2.02 (s, 3 H), 1.82 (s, 3 H); ^{13}C NMR ($CDCl_3$, 100 MHz): $\delta = 170.7$, 169.8, 169.6, 160.5, 154.0, 136.2, 135.5, 132.3, 131.9, 130.8, 128.9, 128.3, 128.0, 125.5, 101.6, 99.2, 95.0, 81.9, 77.2, 74.8, 72.3, 70.7, 70.0, 68.6, 68.4, 67.9, 62.5, 55.6, 20.77, 20.75, 20.4; IR (film, cm^{-1}): $\nu = 3382$, 2987, 1748, 1642, 1521, 1441, 1369, 1313, 1226; HRMS (ESI): calc. for $C_{43}H_{42}Cl_3F_6N_2O_{13}S$ (M+H): 1045.1377; found: 1045.1379.

Phenyl 3,4,6-Tri-O-Benzyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 3)-4,6-O-Benzylidene-2-Deoxy-2-(2,2,2-Trichloroethyl)amino-1-Thiol- β -D-Glucopyranoside 39

Viscous oil: 36 mg, 64%, $\alpha:\beta = 6:1$; 1H NMR ($CDCl_3$, 400 MHz):²³ $\delta = 8.53$ (d, $J = 2.0$ Hz, 1 H), 8.33 (d, $J = 7.6$ Hz, 1 H), 7.62–7.13 (m, 26 H), 6.92 (d, $J = 7.6$ Hz, 2 H), 5.82 (d, $J = 9.2$ Hz, 1 H), 5.22 (d, $J = 4.0$ Hz, 1 H), 5.18 (s, 1 H), 4.87–4.04 (m, 13 H), 3.81–3.36 (m, 8 H); ^{13}C NMR ($CDCl_3$, 100 MHz): $\delta = 159.8$, 154.1, 138.1, 138.0, 136.3, 133.6, 132.2, 132.9, 132.0, 131.8, 130.4, 128.9, 128.4, 128.3, 128.23, 128.18, 128.14, 128.10, 127.92,

127.91, 127.89, 127.8, 127.7, 127.5, 126.1, 125.5 (q, $J_{C-F} = 5.6$ Hz), 125.4, 123.8 (d, $J_{C-F} = 273$ Hz), 101.4, 99.5, 95.3, 87.8, 81.9, 80.9, 77.8, 77.2, 75.7, 75.6, 75.0, 74.6, 73.7, 70.9, 70.0, 68.5, 55.2; IR (film, cm^{-1}): $\nu = 3389, 2867, 1743, 1640, 1454, 1368, 1314$; HRMS (ESI): calc. for $\text{C}_{57}\text{H}_{55}\text{Cl}_3\text{F}_3\text{N}_2\text{O}_{10}\text{S}$ (M+H): 1121.2595; found: 1121.2575.

Phenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 3)-4-O-Benzyl-2-O-Benzoyl-6-O-tert-Butyldimethylsilyl-1-Thiol- β -D-Galactopyranoside 40

Viscous oil: 25 mg, 55%, α only; $[\alpha]_D^{24} = 73.9$ ($c = 1.8$, CH_2Cl_2); ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.62$ (s, 1 H), 8.08 (d, $J = 7.6$ Hz, 2 H), 7.95 (d, $J = 7.6$ Hz, 1 H), 7.63–7.54 (m, 2 H), 7.50–7.15 (m, 14 H), 5.87–5.76 (m, 1 H), 5.49 (t, $J = 9.6$ Hz, 1 H), 5.18 (d, $J = 11.2$ Hz, 1 H), 5.12 (d, $J = 3.2$ Hz, 1 H), 4.99 (t, $J = 9.6$ Hz, 1 H), 4.82–4.75 (m, 1 H), 4.47 (d, $J = 11.2$ Hz, 1 H), 4.18–4.02 (m, 3 H), 3.94–3.55 (m, 6 H), 2.01 (s, 3 H), 1.79 (s, 3 H), 1.74 (s, 3 H), 0.85 (s, 9 H), 0.01 (s, 3 H), -0.01 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.5, 168.7, 168.3, 164.9, 161.3, 138.8, 133.1, 132.9, 132.1, 131.3, 130.7, 130.1, 129.8, 128.7, 128.6, 128.4, 128.0, 127.6, 127.5, 127.1, 125.4$ (q, $J_{C-F} = 5.7$ Hz), 98.2, 86.6, 81.0, 79.3, 77.2, 74.7, 72.8, 72.7, 70.5, 68.1, 67.9, 61.5, 61.4, 25.8, 20.6, 20.5, 20.3, 18.2, $-5.4, -5.5$; IR (film, cm^{-1}): $\nu = 2928, 1728, 1668, 1602, 1365, 1314, 1263$; HRMS (ESI): calc. for $\text{C}_{52}\text{H}_{61}\text{F}_3\text{NO}_{13}\text{Si}$ (M+H): 1024.3585; found: 1024.3585.

Phenyl 6-O-Acetyl-3,4-Di-O-Benzyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 3)-4-O-Benzyl-2-O-Benzoyl-6-O-tert-Butyldimethylsilyl-1-Thiol- β -D-Galactopyranoside 41

Viscous oil: 33 mg, 61%, α only; $[\alpha]_D^{24} = 30.4$ ($c = 0.1$, CH_2Cl_2); ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.69$ (d, $J = 2.0$ Hz, 1 H), 8.02 (d, $J = 6.8$ Hz, 2 H), 7.95 (d, $J = 7.6$ Hz, 1 H), 7.60 (d, $J = 7.6$ Hz, 1 H), 7.48–7.32 (m, 7 H), 7.26–7.17 (m, 8 H), 7.14–7.07 (m, 6 H), 6.99–6.93 (m, 4 H), 5.92–5.76 (m, 1 H), 5.14 (d, $J = 7.2$ Hz, 1 H), 5.05 (d, $J = 3.2$ Hz, 1 H), 4.80 (d, $J = 9.6$ Hz, 1 H), 4.62 (d, $J = 11.6$ Hz, 1 H), 4.48 (d, $J = 11.2$ Hz, 1 H), 4.40 (d, $J = 10.8$ Hz, 1 H), 4.33 (d, $J = 11.6$ Hz, 1 H), 4.27 (d, $J = 10.8$ Hz, 1 H), 4.02–3.97 (m, 3 H), 3.92–3.88 (m, 1 H), 3.81 (dd, $J = 12.0, 3.2$ Hz, 1 H), 3.77–3.63 (m, 2 H), 3.49 (m, 3 H), 3.46 (t, $J = 9.6$ Hz, 1 H), 1.98 (s, 3 H), 0.83 (s, 9 H), 0.03 (s, 3 H), -0.03 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.5, 165.1, 160.5, 138.9, 138.1, 137.8, 133.1, 132.1, 132.0, 130.3, 130.0, 129.7, 128.7, 128.5, 128.3, 128.2, 128.1, 128.0, 127.9, 127.60, 127.57, 127.52, 127.47, 127.4, 127.1, 97.3, 86.8, 80.1, 79.2, 79.0, 77.2, 75.5, 75.0, 74.6, 74.3, 71.9, 69.6, 62.4, 61.3, 25.8, 20.8, 18.1, -5.4, -5.6$; IR (film, cm^{-1}): $\nu = 2925, 1735, 1642, 1454, 1362, 1314$; HRMS (ESI): calc. for $\text{C}_{62}\text{H}_{69}\text{F}_3\text{NO}_{11}\text{Si}$ (M+H): 1120.4313; found: 1120.4309.

Phenyl 6-O-Acetyl-3,4-Di-O-Benzyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino-1-Thiol- α -D-Glucopyranoside 49

Viscous oil: 5 mg, 8%, α only; ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.75$ (d, $J = 2.0$ Hz, 1 H), 8.39 (d, $J = 8.0$ Hz, 1 H), 7.73–7.52 (m, 3 H), 7.48–7.44 (m, 2 H), 7.37–7.08 (m, 13 H), 5.55 (d, $J = 5.2$ Hz, 1 H), 4.88 (d, $J = 10.8$ Hz, 1 H), 4.69 (d, $J = 10.4$ Hz, 1 H), 4.63–4.52 (m, 3 H), 4.34–4.26 (m, 2 H), 4.17 (dd, $J = 12.0, 2.0$ Hz, 1 H), 3.95 (dd, $J = 10.0, 5.6$ Hz, 1 H), 3.65 (dd, $J = 9.6, 8.8$ Hz, 1 H), 3.35–3.26 (m, 1 H), 1.95 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.7, 159.5, 137.81, 137.75, 133.7, 132.2, 131.8, 130.7, 128.91, 128.85, 128.5, 128.3, 128.1, 128.0, 127.7, 127.1, 125.6$ (q, $J_{C-F} = 5.7$ Hz), 87.0, 81.8, 77.5, 75.23, 75.18, 75.1, 70.0, 63.1, 20.8; IR (film, cm^{-1}): $\nu = 2923, 1742, 1641, 1454, 1364, 1314$; HRMS (ESI): calc. for $\text{C}_{36}\text{H}_{35}\text{F}_3\text{NO}_5\text{S}$ (M+H): 650.2188; found: 650.2195.

2-Trifluorophenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 3)-4-O-Benzyl-2-O-Benzoyl-6-O-*tert*-Butyldimethylsilyl-1-Thiol- β -D-Galactopyranoside 42

Viscous oil: 38 mg, 71%, α only; $[\alpha]_D^{24} = 30.4$ ($c = 0.1$, CH_2Cl_2); ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.62$ (d, $J = 2.0$ Hz, 1 H), 8.04 (d, $J = 7.2$ Hz, 2 H), 7.98 (d, $J = 7.6$ Hz, 2 H), 7.94 (d, $J = 7.6$ Hz, 1 H), 7.62–7.52 (m, 3 H), 7.47–7.38 (m, 3 H), 7.32–7.10 (m, 8 H), 5.99–5.87 (m, 1 H), 5.48 (t, $J = 9.6$ Hz, 1 H), 5.22 (d, $J = 10.8$ Hz, 1 H), 5.13 (d, $J = 3.2$ Hz, 1 H), 4.82–4.74 (m, 1 H), 4.79 (d, $J = 8.8$ Hz, 1 H), 4.15–4.02 (m, 3 H), 3.89–3.71 (m, 4 H), 3.65 (dd, $J = 10.0$, 3.2 Hz, 1 H), 3.58 (t, $J = 6.4$ Hz, 1 H), 2.01 (s, 3 H), 1.78 (s, 3 H), 1.73 (s, 3 H), 0.85 (s, 9 H), 0.02 (s, 3 H), –0.01 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.5$, 169.7, 169.2, 164.8, 161.4, 138.7, 134.0, 133.0, 132.1, 132.0, 130.7, 129.9, 129.8, 128.5, 128.3, 128.1, 128.0, 127.3, 127.1, 126.4 (q, $J_{\text{C-F}} = 5.6$ Hz), 125.4 (q, $J_{\text{C-F}} = 5.8$ Hz), 98.1, 86.3, 80.9, 79.3, 77.2, 74.8, 72.6, 70.4, 68.1, 67.8, 61.5, 61.3, 25.8, 20.7, 20.5, 20.4, 18.2, –5.4, –5.5; IR (film, cm^{-1}): $\nu = 2930$, 1738, 1640, 1452, 1366, 1312, 1224; HRMS (ESI): calc. for $\text{C}_{53}\text{H}_{60}\text{F}_6\text{NO}_{13}\text{SSi}$ ($\text{M}+\text{H}$): 1092.3459; found: 1092.3451.

Phenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 4)-2,3-Di-O-Isopropylidene-1-Thiol- α -L-Rhamnopyranoside 43

Viscous oil: 30 mg, 81%, α only; ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.66$ (d, $J = 2.0$ Hz, 1 H), 8.20 (d, $J = 7.6$ Hz, 1 H), 7.69 (d, $J = 7.6$ Hz, 1 H), 7.63–7.52 (m, 2 H), 7.48–7.44 (m, 2 H), 7.33–7.23 (m, 3 H), 5.76 (s, 1 H), 5.66 (t, $J = 9.6$ Hz, 1 H), 5.24 (app t, $J = 9.6$ Hz, 1 H), 5.02 (d, $J = 3.6$ Hz, 1 H), 4.53–4.44 (m, 2 H), 4.38–4.25 (m, 3 H), 4.15–4.06 (m, 2 H), 3.71 (dd, $J = 10.0$, 3.6 Hz, 1 H), 3.47 (dd, $J = 10.0$, 7.6 Hz, 1 H), 2.12 (s, 3 H), 2.04 (s, 3 H), 1.89 (s, 3 H), 1.55 (s, 3 H), 1.37 (s, 3 H), 1.17 (d, $J = 6.0$ Hz, 1 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.9$, 170.0, 169.8, 161.3, 133.6, 132.2, 131.7, 131.4, 130.8, 130.0, 128.3, 127.4, 125.6 (q, $J_{\text{C-F}} = 5.4$ Hz), 109.4, 100.0, 83.7, 82.1, 76.7, 76.5, 72.7, 70.8, 68.3, 67.7, 66.5, 61.5, 28.2, 26.5, 20.8, 20.7, 20.4, 16.9; IR (film, cm^{-1}): $\nu = 2932$, 1747, 1641, 1578, 1379, 1314, 1220; HRMS (ESI): calc. for $\text{C}_{35}\text{H}_{41}\text{F}_3\text{NO}_{11}\text{S}$ ($\text{M}+\text{H}$): 740.2352; found: 740.2351.

Phenyl 6-O-Acetyl-3,4-Di-O-Benzyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 4)-2,3-Di-O-Isopropylidene-1-Thiol- α -L-Rhamnopyranoside 44

Viscous oil: 30 mg, 72%, α only; ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.78$ (d, $J = 2.0$ Hz, 1 H), 8.36 (d, $J = 7.6$ Hz, 1 H), 7.30 (d, $J = 7.6$ Hz, 1 H), 7.67–7.53 (m, 2 H), 7.49–7.45 (m, 2 H), 7.38–7.13 (m, 13 H), 5.77 (s, 1 H), 4.94–4.87 (m, 2 H), 4.73 (d, $J = 10.4$ Hz, 1 H), 4.65–4.57 (m, 2 H), 4.51 (dd, $J = 12.0$, 2.0 Hz, 1 H), 4.40–4.25 (m, 6 H), 3.38 (dd, $J = 10.0$, 8.8 Hz, 1 H), 3.64 (dd, $J = 10.0$, 3.6 Hz, 1 H), 3.45 (dd, $J = 10.0$, 7.6 Hz, 1 H), 2.08 (s, 3 H), 1.56 (s, 3 H), 1.36 (s, 3 H), 1.13 (d, $J = 6.4$ Hz, 1 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.9$, 160.6, 138.0, 137.9, 133.7, 133.5, 132.1, 131.4, 130.6, 129.0, 128.5, 128.29, 128.27, 128.2, 128.0, 127.9, 127.6, 127.4, 125.7 (q, $J_{\text{C-F}} = 5.6$ Hz), 109.4, 100.8, 83.8, 81.8, 80.8, 76.5, 76.0, 75.1, 69.2, 66.7, 62.7, 28.2, 26.5, 21.0, 16.8; IR (film, cm^{-1}): $\nu = 2926$, 1739, 1638, 1455, 1381, 1314; HRMS (ESI): calc. for $\text{C}_{45}\text{H}_{49}\text{F}_3\text{NO}_9\text{S}$ ($\text{M}+\text{H}$): 836.3080; found: 836.3088.

2-Trifluorophenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 4)-2,3-Di-O-Isopropylidene-1-Thiol- α -L-Rhamnopyranoside 45

Viscous oil: 40 mg, 98%, α only; $[\alpha]_D^{24} = -48.9$ ($c = 0.8$, CH_2Cl_2); ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.66$ (d, $J = 2.0$ Hz, 1 H), 8.21 (d, $J = 7.6$ Hz, 1 H), 7.75 (d, $J = 7.6$ Hz, 1 H), 7.68 (d, $J = 7.6$ Hz, 2 H), 7.61–7.46 (m, 3 H), 7.37–7.32 (m, 1 H), 5.79 (s, 1 H), 5.66 (t, $J = 10.0$ Hz, 1 H), 5.24 (t, $J = 9.6$ Hz, 1 H), 5.03 (d, $J = 3.6$ Hz, 1 H), 4.53–4.41 (m, 3 H), 4.24 (dd, $J = 10.0$, 6.0 Hz, 1 H), 4.28–4.20 (m, 1 H), 4.14 (dd, $J = 10.0$, 2.0 Hz, 1 H), 3.71 (dd, $J = 10.0$, 3.6 Hz, 1 H), 3.48 (dd, $J = 10.0$, 7.6 Hz, 1 H), 2.12 (s, 3 H), 2.04 (s, 3 H), 1.88 (s, 3 H), 1.55

(s, 3 H), 1.37 (s, 3 H), 1.17 (d, $J = 6.4$ Hz, 1 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.8$, 170.0, 169.8, 161.1, 133.6, 133.3, 133.2, 132.2, 130.8, 129.4, 129.1, 128.4, 127.3, 126.8 (q, $J_{\text{C-F}} = 5.6$ Hz), 125.6 (q, $J_{\text{C-F}} = 5.6$ Hz), 125.4, 123.6 (d, $J_{\text{C-F}} = 275$ Hz), 109.5, 100.0, 84.4, 81.9, 76.7, 76.5, 72.6, 70.9, 68.4, 67.8, 67.0, 61.6, 28.2, 26.6, 20.8, 20.7, 20.4, 16.9; IR (film, cm^{-1}): $\nu = 2937$, 1749, 1642, 1577, 1381, 1312, 1222; HRMS (ESI): calc. for $\text{C}_{36}\text{H}_{40}\text{F}_6\text{NO}_{11}\text{S}$ (M+H): 808.2226; found: 808.2228.

2-Trifluorophenyl 6-O-Acetyl-3,4-Di-O-Benzyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 4)-2,3-Di-O-Isopropylidene-1-Thiol- α -L-Rhamnopyranoside 46

Viscous oil: 35 mg, 78%, α only; $[\alpha]_D^{24} = -7.6$ ($c = 1.0$, CH_2Cl_2); ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.76$ (d, $J = 2.0$ Hz, 1 H), 8.35 (d, $J = 7.6$ Hz, 1 H), 7.76–7.44 (m, 6 H), 7.37–7.26 (m, 6 H), 7.21–7.12 (m, 5 H), 5.80 (s, 1 H), 4.93–4.87 (m, 2 H), 4.72 (d, $J = 10.4$ Hz, 1 H), 4.63–4.57 (m, 2 H), 4.61 (dd, $J = 10.4$, 6.0 Hz, 1 H), 4.43–4.18 (m, 6 H), 3.77 (t, $J = 9.6$ Hz, 1 H), 3.61 (dd, $J = 10.0$, 3.2 Hz, 1 H), 3.45 (dd, $J = 10.0$, 7.6 Hz, 1 H), 2.06 (s, 3 H), 1.55 (s, 3 H), 1.35 (s, 3 H), 1.12 (d, $J = 6.4$ Hz, 1 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.8$, 160.4, 138.0, 137.9, 133.5, 133.3, 132.2, 132.1, 130.9, 130.6, 129.3, 128.5, 128.3, 128.2, 127.9, 127.8, 127.6, 127.1, 126.7 (q, $J_{\text{C-F}} = 5.8$ Hz), 125.7 (q, $J_{\text{C-F}} = 5.5$ Hz), 120.4, 109.5, 100.7, 84.5, 81.5, 80.8, 76.7, 76.5, 75.9, 75.1, 69.3, 67.2, 62.7, 28.1, 26.5, 20.9, 16.8; IR (film, cm^{-1}): $\nu = 2935$, 1740, 1641, 1454, 1381, 1312; HRMS (ESI): calc. for $\text{C}_{46}\text{H}_{48}\text{F}_6\text{NO}_9\text{S}$ (M+H): 904.2954; found: 904.2957.

2,6-Dimethylphenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 4)-2,3-Di-O-Isopropylidene-1-Thiol- α -L-Rhamnopyranoside 47

Viscous oil: 28 mg, 74%, α only; $[\alpha]_D^{24} = -70.8$ ($c = 4.8$, CH_2Cl_2); ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.66$ (d, $J = 2.0$ Hz, 1 H), 8.21 (d, $J = 8.0$ Hz, 1 H), 7.69 (d, $J = 7.6$ Hz, 1 H), 7.63–7.53 (m, 2 H), 7.17–7.05 (m, 2 H), 5.67 (t, $J = 10.0$ Hz, 1 H), 5.40 (s, 1 H), 5.24 (app t, $J = 9.6$ Hz, 1 H), 5.02 (d, $J = 3.6$ Hz, 1 H), 4.55–4.42 (m, 3 H), 4.36 (dd, $J = 7.2$, 5.6 Hz, 1 H), 4.22–4.05 (m, 3 H), 3.72 (dd, $J = 10.0$, 3.6 Hz, 1 H), 3.43 (dd, $J = 10.0$, 7.6 Hz, 1 H), 2.53 (s, 6 H), 2.12 (s, 3 H), 2.05 (s, 3 H), 1.89 (s, 3 H), 1.53 (s, 3 H), 1.36 (s, 3 H), 1.15 (d, $J = 6.4$ Hz, 1 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.9$, 170.0, 169.9, 161.2, 143.0, 133.2, 132.1, 131.5, 130.8, 128.8, 128.31, 128.28, 125.6 (q, $J_{\text{C-F}} = 5.6$ Hz), 123.9 (d, $J_{\text{C-F}} = 263$ Hz), 109.4, 99.9, 84.4, 81.9, 77.6, 76.5, 72.6, 70.8, 68.3, 67.72, 67.68, 61.6, 28.2, 26.6, 22.1, 20.8, 20.7, 20.4, 17.0; IR (film, cm^{-1}): $\nu = 2936$, 1746, 1641, 1459, 1378, 1314, 1220; HRMS (ESI): calc. for $\text{C}_{37}\text{H}_{45}\text{F}_3\text{NO}_{11}\text{S}$ (M+H): 768.2665; found: 768.2668.

Phenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Galactopyranosyl-(1 $\rightarrow$ 3)-4,6-O-Benzylidene-2-Deoxy-2-(2,2,2-Trichloroethyl)amino-1-Thiol- β -D-Glucopyranoside 54

Viscous oil: 65 mg, 67%, α only; $[\alpha]_D^{24} = 15.1$ ($c = 4.6$, CH_2Cl_2); ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.47$ (d, $J = 2.0$ Hz, 1 H), 8.17 (d, $J = 7.2$ Hz, 1 H), 7.63 (d, $J = 7.2$ Hz, 1 H), 7.57–7.46 (m, 4 H), 7.39–7.30 (m, 3 H), 7.23–7.18 (m, 1 H), 7.14–7.08 (m, 2 H), 6.97 (d, $J = 7.2$ Hz, 2 H), 5.66 (d, $J = 8.4$ Hz, 1 H), 5.47–5.38 (m, 3 H), 5.19 (s, 1 H), 5.09–5.03 (m, 1 H), 5.00 (d, $J = 12.0$ Hz, 1 H), 4.63 (d, $J = 12.0$ Hz, 1 H), 4.54 (t, $J = 6.4$ Hz, 1 H), 4.31 (dd, $J = 10.4$, 4.8 Hz, 1 H), 4.38–4.24 (m, 1 H), 4.20–4.05 (m, 2 H), 3.85 (dd, $J = 10.4$, 3.6 Hz, 1 H), 3.77–3.68 (m, 2 H), 3.57–3.48 (m, 1 H), 2.15 (s, 3 H), 2.09 (s, 3 H), 1.83 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.5$, 170.1, 169.7, 160.5, 153.9, 136.4, 132.4, 131.8, 130.6, 129.1, 128.9, 128.4, 128.2, 128.0, 125.5, 101.5, 99.7, 95.3, 87.5, 82.2, 76.1, 74.6, 70.0, 68.5, 68.2, 67.3, 66.8, 66.7, 62.3, 55.8, 20.9, 20.7, 20.3; IR (film, cm^{-1}): $\nu = 3340$, 2937, 1745, 1644, 1528, 1374, 1314, 1220; HRMS (ESI): calc. for $\text{C}_{42}\text{H}_{43}\text{Cl}_3\text{F}_3\text{N}_2\text{O}_{13}\text{S}$ (M+H): 977.1504; found: 977.1509.

Phenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino-1-Thiol- α -D-Galactopyranoside 60

Viscous oil: 10 mg, 16%, α only; ^1H NMR (CDCl_3 , 400 MHz):²² δ = 8.69 (d, J = 2.0 Hz, 1 H), 8.30–8.26 (m, 1 H), 7.72–7.47 (m, 5 H), 7.33–7.22 (m, 3 H), 5.75 (d, J = 5.6 Hz, 1 H), 5.58–5.47 (m, 2 H), 4.84 (t, J = 6.4 Hz, 1 H), 4.19 (dd, J = 10.4, 5.6 Hz, 1 H), 4.13–4.04 (m, 2 H), 2.19 (s, 3 H), 1.92 (s, 3 H), 1.89 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): δ = 170.4, 170.1, 169.7, 160.3, 132.3, 131.9, 130.7, 129.2, 128.9, 127.2, 125.5, 86.8, 77.2, 69.6, 67.4, 66.9, 62.0, 20.7, 20.62, 20.55; IR (film, cm^{-1}): ν = 2927, 1748, 1642, 1439, 1372, 1314, 1227; HRMS (ESI): calc. for $\text{C}_{26}\text{H}_{27}\text{F}_3\text{NO}_7\text{S}$ ($\text{M}+\text{H}$): 554.1460; found: 554.1460.

Phenyl 6-O-Acetyl-3,4-Di-O-Benzyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Galactopyranosyl-(1 $\rightarrow$ 3)-4,6-O-Benzylidene-2-Deoxy-2-(2,2,2-Trichloroethyl)amino-1-Thiol- β -D-Glucopyranoside 55

Viscous oil: 30 mg, 56%, $\alpha:\beta$ = 14:1; ^1H NMR (CDCl_3 , 400 MHz):²³ δ = 8.59 (d, J = 2.0 Hz, 1 H), 8.26 (d, J = 7.2 Hz, 1 H), 7.64–7.45 (m, 4 H), 7.36–7.17 (m, 14 H), 7.12–7.06 (m, 2 H), 6.95 (d, J = 7.6 Hz, 2 H), 5.60 (d, J = 8.8 Hz, 1 H), 5.36 (d, J = 3.6 Hz, 1 H), 5.20 (s, 1 H), 4.94 (t, J = 12.0 Hz, 2 H), 4.82 (d, J = 10.0 Hz, 1 H), 4.64–4.52 (m, 4 H), 4.33–4.25 (m, 2 H), 4.20–3.96 (m, 6 H), 3.84–3.72 (m, 3 H), 3.53–3.46 (m, 1 H), 2.05 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): δ = 170.4, 160.4, 154.2, 138.2, 138.0, 136.3, 134.0, 133.1, 132.1, 131.7, 130.3, 129.0, 128.9, 128.5, 128.4, 128.3, 128.2, 128.0, 127.9, 127.5, 127.4, 125.6 (q, $J_{\text{C-F}}$ = 5.6 Hz), 125.5, 123.9 (d, $J_{\text{C-F}}$ = 273 Hz), 101.4, 100.1, 95.5, 81.9, 77.2, 76.1, 74.6, 73.2, 72.6, 70.3, 69.0, 68.5, 64.8, 55.5, 21.0; IR (film, cm^{-1}): ν = 3350, 2924, 1741, 1640, 1524, 1370, 1313, 1234; HRMS (ESI): calc. for $\text{C}_{52}\text{H}_{51}\text{Cl}_3\text{F}_3\text{N}_2\text{O}_{11}\text{S}$ ($\text{M}+\text{H}$): 1073.2231; found: 1073.2237.

Phenyl 6-O-Acetyl-3,4-Di-O-Benzyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino-1-Thiol- α -D-Galactopyranoside 61

Viscous oil: 2 mg, 6%, α only; ^1H NMR (CDCl_3 , 400 MHz): δ = 8.54 (d, J = 2.0 Hz, 1 H), 8.20 (d, J = 7.6 Hz, 1 H), 7.71 (d, J = 7.6 Hz, 1 H), 7.63–7.45 (m, 4 H), 7.35–7.15 (m, 13 H), 4.95–4.99 (m, 2 H), 4.60 (d, J = 11.6 Hz, 1 H), 4.54 (d, J = 12.0 Hz, 1 H), 4.49 (d, J = 12.0 Hz, 1 H), 4.33 (dd, J = 11.2, 6.8 Hz, 1 H), 4.17 (dd, J = 11.2, 5.2 Hz, 1 H), 3.87–3.83 (m, 2 H), 3.77–3.72 (m, 2 H), 2.02 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): δ = 170.6, 160.6, 138.3, 137.7, 132.8, 132.2, 130.3, 129.7, 129.4, 129.1, 128.64, 128.59, 128.2, 128.0, 127.7, 127.6, 127.3, 125.6 (q, $J_{\text{C-F}}$ = 5.6 Hz), 124.0 (d, $J_{\text{C-F}}$ = 273 Hz), 86.3, 81.6, 76.4, 74.2, 72.4, 71.7, 70.4, 63.8, 20.8; IR (film, cm^{-1}): ν = 2924, 1740, 1642, 1439, 1314, 1234; HRMS (ESI): calc. for $\text{C}_{36}\text{H}_{35}\text{F}_3\text{NO}_5\text{S}$ ($\text{M}+\text{H}$): 650.2188; found: 650.2181.

2-Trifluoromethylphenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Galactopyranosyl-(1 $\rightarrow$ 3)-4,6-O-Benzylidene-2-Deoxy-2-(2,2,2-Trichloroethyl)amino-1-Thiol- β -D-Glucopyranoside 56

Viscous oil: 38 mg, 73%, α only; $[\alpha]_D^{24}$ = 12.3 (c = 1.7, CH_2Cl_2); ^1H NMR (CDCl_3 , 400 MHz): δ = 8.46 (d, J = 2.0 Hz, 1 H), 8.18 (d, J = 7.2 Hz, 1 H), 7.78 (d, J = 7.6 Hz, 1 H), 7.71 (d, J = 7.2 Hz, 1 H), 7.64 (d, J = 7.2 Hz, 1 H), 7.59–7.34 (m, 4 H), 7.23–7.18 (m, 1 H), 7.13–7.07 (m, 2 H), 6.94 (d, J = 7.2 Hz, 2 H), 5.64 (d, J = 8.8 Hz, 1 H), 5.48–5.36 (m, 3 H), 5.20 (s, 1 H), 5.08 (d, J = 12.0 Hz, 1 H), 4.92–4.83 (m, 1 H), 4.64–4.60 (m, 1 H), 4.56 (d, J = 12.0 Hz, 1 H), 4.28 (dd, J = 10.4, 4.8 Hz, 1 H), 4.21–4.03 (m, 3 H), 3.95–3.73 (m, 4 H), 3.52–3.44 (m, 1 H), 2.15 (s, 3 H), 2.12 (s, 3 H), 1.83 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): δ = 170.5, 170.1, 169.7, 160.6, 154.1, 136.3, 132.2, 131.8, 130.6, 129.0, 128.45, 128.36, 128.0, 126.9 (q, $J_{\text{C-F}}$ = 5.6 Hz), 125.5, 101.6, 99.8, 95.1, 82.0, 77.2, 76.1, 74.7, 70.0, 68.4, 68.2, 67.2, 67.0, 66.9, 60.4, 55.5, 21.0, 20.8, 20.4; IR (film, cm^{-1}): ν = 3339, 2927, 1745, 1644,

1526, 1374, 1312, 1225; HRMS (ESI): calc. for $C_{43}H_{42}Cl_3F_6N_2O_{13}S$ (M+H): 1045.1377; found: 1045.1367.

Phenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Galactopyranosyl-(1 $\rightarrow$ 3)-4-O-Benzyl-2-O-Benzoyl-6-O-*tert*-Butyldimethylsilyl-1-Thiol- β -D-Galactopyranoside 57

Viscous oil: 46 mg, 52%, α : β = 8:1; 1H NMR ($CDCl_3$, 400 MHz): δ = 8.66 (d, J = 2.0 Hz, 1 H), 8.12–8.07 (m, 2 H), 7.95 (d, J = 7.6 Hz, 1 H), 7.66–7.18 (m, 18 H), 5.79 (t, J = 9.6 Hz, 1 H), 5.41 (dd, J = 3.2, 10.8 Hz, 1 H), 4.83–4.77 (m, 1 H), 4.44 (d, J = 11.6 Hz, 1 H), 4.20 (t, J = 8.0 Hz, 1 H), 4.11–4.03 (m, 2 H), 3.94–3.85 (m, 2 H), 3.80–3.67 (m, 3 H), 3.62–3.57 (m, 1 H), 2.08 (s, 3 H), 1.96 (s, 3 H), 1.82 (s, 3 H), 0.86 (s, 9 H), 0.02 (s, 3 H), –0.01 (s, 3 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 170.1, 169.9, 169.2, 165.0, 161.3, 138.8, 133.1, 132.8, 132.5, 132.2, 132.1, 131.9, 130.5, 130.0, 129.7, 128.7, 128.5, 128.0, 127.5, 127.1, 125.4 (q, J_{C-F} = 5.7 Hz), 98.8, 86.7, 80.9, 79.3, 77.2, 74.7, 73.0, 68.1, 67.9, 67.0, 66.7, 61.5, 61.0, 25.8, 20.7, 20.6, 20.3, 18.2, –5.4, –5.5; IR (film, cm^{-1}): ν = 2929, 1747, 1642, 1453, 1371, 1314, 1249; HRMS (ESI): calc. for $C_{52}H_{61}F_3NO_{13}SSi$ (M+H): 1024.3585; found: 1024.3581.

Phenyl 6-O-Acetyl-3,4-Di-O-Benzyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Galactopyranosyl-(1 $\rightarrow$ 3)-4-O-Benzyl-2-O-Benzoyl-6-O-*tert*-Butyldimethylsilyl-1-Thiol- β -D-Galactopyranoside 58

Viscous oil: 29 mg, 51%, α only; $[\alpha]^{24}_D$ = 116.3 (c = 0.3, CH_2Cl_2); 1H NMR ($CDCl_3$, 400 MHz): δ = 8.73 (d, J = 2.0 Hz, 1 H), 8.03–7.94 (m, 3 H), 7.61–7.56 (m, 2 H), 7.46–7.05 (m, 24 H), 5.82 (t, J = 9.6 Hz, 1 H), 5.13–5.07 (m, 2 H), 4.83–4.74 (m, 2 H), 4.42–4.34 (m, 3 H), 4.26 (d, J = 11.2 Hz, 1 H), 4.10–3.93 (m, 8 H), 3.75–3.66 (m, 2 H), 3.57 (t, J = 10.8 Hz, 1 H), 1.91 (s, 3 H), 0.84 (s, 9 H), 0.00 (s, 3 H), –0.02 (s, 3 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 170.1, 164.9, 160.9, 138.9, 138.1, 133.5, 133.2, 132.1, 131.9, 130.1, 130.0, 129.7, 128.7, 128.4, 128.29, 128.27, 128.2, 127.9, 127.7, 127.5, 127.4, 125.3 (q, J_{C-F} = 5.3 Hz), 97.6, 86.9, 79.3, 78.5, 77.2, 74.6, 74.4, 73.3, 72.7, 71.9, 70.4, 69.1, 63.0, 61.4, 25.8, 20.8, 18.2, –5.4, –5.6; IR (film, cm^{-1}): ν = 2927, 1733, 1638, 1454, 1314, 1261; HRMS (ESI): calc. for $C_{62}H_{69}F_3NO_{11}SSi$ (M+H): 1120.4313; found: 1120.4311.

2-Trifluoromethylphenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Galactopyranosyl-(1 $\rightarrow$ 3)-4-O-Benzyl-2-O-Benzoyl-6-O-*tert*-Butyldimethylsilyl-1-Thiol- β -D-Galactopyranoside 59

Viscous oil: 34 mg, 62%, α only; $[\alpha]^{24}_D$ = 85.5 (c = 1.6, CH_2Cl_2); 1H NMR ($CDCl_3$, 400 MHz): δ = 8.64 (d, J = 2.0 Hz, 1 H), 8.07–7.92 (m, 4 H), 7.63–7.54 (m, 3 H), 7.46–7.38 (m, 3 H), 7.32–7.15 (m, 8 H), 5.90 (t, J = 9.6 Hz, 1 H), 5.38 (dd, J = 3.2, 10.8 Hz, 1 H), 5.16–5.10 (m, 2 H), 5.03 (d, J = 2.0 Hz, 1 H), 4.78 (d, J = 10.0 Hz, 1 H), 4.44 (d, J = 10.8 Hz, 1 H), 4.18 (t, J = 7.2 Hz, 1 H), 4.10–4.02 (m, 2 H), 3.88–3.67 (m, 5 H), 3.58 (t, J = 6.4 Hz, 1 H), 2.07 (s, 3 H), 1.95 (s, 3 H), 1.80 (s, 3 H), 0.85 (s, 9 H), 0.02 (s, 3 H), –0.01 (s, 3 H); ^{13}C NMR ($CDCl_3$, 100 MHz): δ = 170.2, 170.0, 169.2, 165.0, 161.4, 138.6, 134.1, 133.1, 132.1, 132.0, 130.5, 130.3, 129.7, 129.6, 129.1, 128.7, 128.5, 128.3, 128.1, 127.8, 127.3, 127.1, 126.4 (q, J_{C-F} = 5.8 Hz), 125.4 (q, J_{C-F} = 5.8 Hz), 122.7, 122.3 (d, J_{C-F} = 272 Hz), 98.7, 86.3, 80.7, 79.3, 77.2, 74.8, 72.7, 68.0, 67.8, 67.0, 66.6, 61.5, 61.1, 25.8, 20.68, 20.66, 20.3, 18.2, –5.4, –5.5; IR (film, cm^{-1}): ν = 2929, 1746, 1641, 1452, 1372, 1312, 1249; HRMS (ESI): calc. for $C_{53}H_{60}F_6NO_{13}SSi$ (M+H): 1092.3459; found: 1092.3456.

Phenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2-Azido- α -D-Glucopyranosyl-(1 $\rightarrow$ 3)-4,6-O-Benzylidene-2-Deoxy-2-(2,2,2-Trichloroethyl)amino-1-Thiol- β -D-Glucopyranoside 68

Viscous oil: 15 mg, 18%, α only; $[\alpha]_D^{24} = 60.8$ ($c = 0.5$, CH_2Cl_2); ^1H NMR (CDCl_3 , 400 MHz): $\delta = 7.52\text{--}7.45$ (m, 4 H), $7.37\text{--}7.32$ (m, 6 H), $5.65\text{--}5.57$ (m, 2 H), $5.45\text{--}5.36$ (m, 2 H), $5.13\text{--}5.01$ (m, 2 H), 4.90 (d, $J = 12.0$ Hz, 1 H), 4.65 (d, $J = 12.0$ Hz, 1 H), 4.40 (dd, $J = 10.4$, 4.8 Hz, 1 H), $4.34\text{--}4.23$ (m, 2 H), $4.16\text{--}4.11$ (m, 1 H), 4.01 (dd, $J = 12.0$, 3.2 Hz, 1 H), $3.85\text{--}3.77$ (m, 2 H), $3.60\text{--}3.47$ (m, 2 H), 3.19 (dd, $J = 10.8$, 4.0 Hz, 1 H), 2.09 (s, 3 H), 2.07 (s, 3 H), 2.03 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.7$, 170.0 , 169.5 , 153.7 , 136.8 , 132.5 , 132.0 , 129.2 , 128.34 , 128.32 , 125.9 , 101.4 , 98.9 , 95.1 , 86.8 , 74.6 , 70.0 , 69.7 , 68.5 , 68.4 , 67.6 , 62.0 , 60.5 , 55.9 , 20.8 , 20.7 , 20.6 ; IR (film, cm^{-1}): $\nu = 2923$, 2108 , 1748 , 1453 , 1367 , 1215 ; HRMS (ESI): calc. for $\text{C}_{34}\text{H}_{37}\text{Cl}_3\text{N}_4\text{O}_{13}\text{SK}$ (M+K): 885.0781 ; found: 885.0792 .

Phenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2-Azido-1-Thiol- α -D-Glucopyranoside 69

Viscous oil: 16 mg, 40%, α only; ^1H NMR (CDCl_3 , 400 MHz): $\delta = 7.53\text{--}7.46$ (m, 2 H), $7.38\text{--}7.29$ (m, 3 H), 5.64 (d, $J = 5.6$ Hz, 1 H), 5.34 (dd, $J = 10.4$, 9.2 Hz, 1 H), 5.04 (dd, $J = 10.4$, 9.6 Hz, 1 H), $4.67\text{--}4.56$ (m, 1 H), 4.30 (dd, $J = 12.4$, 4.8 Hz, 1 H), 4.09 (dd, $J = 10.4$, 5.6 Hz, 1 H), 4.03 (dd, $J = 12.4$, 2.0 Hz, 1 H), 2.11 (s, 3 H), 2.06 (s, 3 H), 2.04 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.5$, 169.8 , 134.1 , 132.2 , 129.2 , 128.1 , 86.4 , 72.0 , 68.6 , 68.4 , 61.9 , 61.6 , 20.7 , 20.6 ; IR (film, cm^{-1}): $\nu = 2918$, 2109 , 1748 , 1367 , 1227 ; HRMS (ESI): calc. for $\text{C}_{18}\text{H}_{21}\text{N}_3\text{O}_7\text{NaS}$ (M+Na): 446.0998 ; found: 446.0997 .

2-Trifluoromethylphenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2-Azido- α -D-Glucopyranosyl-(1 $\rightarrow$ 3)-4,6-O-Benzylidene-2-Deoxy-2-(2,2,2-Trichloroethyl)amino-1-Thiol- β -D-Glucopyranoside 70

Viscous oil: 6 mg, 13%, α only; $[\alpha]_D^{24} = 28.0$ ($c = 0.1$, CH_2Cl_2); ^1H NMR (CDCl_3 , 400 MHz): $\delta = 7.79$ (d, $J = 7.6$ Hz, 1 H), 7.71 (d, $J = 7.6$ Hz, 1 H), $7.55\text{--}7.35$ (m, 7 H), $5.65\text{--}5.60$ (m, 2 H), $5.44\text{--}5.36$ (m, 2 H), 5.01 (app t, $J = 10.0$ Hz, 1 H), 4.93 (d, $J = 12.0$ Hz, 1 H), 4.57 (d, $J = 12.0$ Hz, 1 H), 4.39 (dd, $J = 10.8$, 4.8 Hz, 1 H), $4.28\text{--}4.17$ (m, 2 H), $4.07\text{--}4.03$ (m, 1 H), $3.93\text{--}3.81$ (m, 3 H), $3.70\text{--}3.52$ (m, 3 H), 3.17 (dd, $J = 10.8$, 3.6 Hz, 1 H), 2.09 (s, 3 H), 2.07 (s, 3 H), 2.03 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.5$, 170.0 , 169.5 , 154.0 , 136.7 , 132.3 , 129.2 , 128.5 , 128.3 , 125.9 , 101.5 , 99.0 , 94.9 , 81.3 , 77.2 , 74.8 , 69.7 , 68.4 , 67.7 , 62.2 , 60.4 , 20.74 , 20.68 , 20.65 ; IR (film, cm^{-1}): $\nu = 3346$, 2923 , 2108 , 1745 , 1536 , 1371 , 1314 , 1260 ; HRMS (ESI): calc. for $\text{C}_{35}\text{H}_{36}\text{Cl}_3\text{F}_3\text{N}_4\text{O}_{13}\text{NaS}$ (M+Na): 937.0915 ; found: 937.0922 .

Phenyl 3,4,6-Tri-O-Acetyl-2-Deoxy-2-Azido- α -D-Glucopyranosyl-(1 $\rightarrow$ 4)-2,3-Di-O-Isopropylidene-1-Thiol- α -L-Rhamnopyranoside 71

Viscous oil: 17 mg, 49%, α only; ^1H NMR (CDCl_3 , 400 MHz): $\delta = 7.52\text{--}7.43$ (m, 2 H), $7.36\text{--}7.27$ (m, 3 H), 5.75 (s, 1 H), 5.50 (t, $J = 9.6$ Hz, 1 H), 5.15 (app t, $J = 10.0$ Hz, 1 H), 5.08 (d, $J = 4.0$ Hz, 1 H), $4.47\text{--}4.31$ (m, 3 H), $4.26\text{--}4.17$ (m, 2 H), 4.05 (dd, $J = 2.0$, 10.0 Hz, 1 H), $3.52\text{--}3.38$ (m, 2 H), 2.104 (s, 3 H), 2.096 (s, 3 H), 2.05 (s, 3 H), 1.53 (s, 3 H), 1.35 (s, 3 H), 1.28 (d, $J = 6.0$ Hz, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.7$, 170.0 , 169.7 , 133.1 , 131.9 , 129.1 , 127.7 , 109.5 , 98.5 , 83.5 , 82.2 , 76.6 , 76.3 , 70.6 , 67.9 , 67.5 , 66.0 , 61.3 , 61.1 , 28.2 , 26.5 , 20.8 , 20.7 , 20.6 , 17.2 ; IR (film, cm^{-1}): $\nu = 2982$, 2108 , 1749 , 1380 , 1221 ; HRMS (ESI): calc. for $\text{C}_{27}\text{H}_{35}\text{N}_3\text{O}_{11}\text{NaS}$ (M+Na): 632.1890 ; found: 632.1888 .

3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 4)-2,3-Di-O-Isopropylidene-L-Rhamnopyranosyl-(1 $\rightarrow$ 6)-1,2,3,4-Bis-(Di-O-Isopropylidene)- α -D-Galactopyranoside 64

After the solution of disaccharide thioglycoside **45** (16 mg, 0.02 mmol), galactosyl acceptor **63** (10 mg, 0.04 mmol) and 4 Å MS (100 mg) in 2.0 mL of dry CH_2Cl_2 under argon was stirred at room temperature for 1 h and then cooled to -78°C , NIS (14 mg, 0.06 mmol) was

added. The reaction was allowed to warm to room temperature and stirred for 20 min and was then cooled to -78°C . AgOTf (3 mg, 0.01 mg) was added to the reaction, and the resulting mixture was warmed to 0°C for 1 h and then slowly to room temperature overnight. TLC showed that the reaction was not complete, an additional amount of NIS (10 mg, 0.04 mmol) and AgOTf (3 mg, 0.01 mg) were added. The solution was stirred at 35°C for 3 h. The reaction mixture was filtered through a Celite pad, evaporated, and purified by flash chromatography on silica gel (hexane/ethyl acetate = 3/1 $\rightarrow$ 2/1 $\rightarrow$ 3/2) to afford trisaccharide **64** (15 mg, 85%, $\alpha:\beta = 3:2$). **α,α -64**: $[\alpha]_{\text{D}}^{24} = 29.8$ ($c = 0.5$, CH_2Cl_2); ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.65$ (d, $J = 2.0$ Hz, 1 H), 8.18–8.15 (m, 1 H), 7.72–7.67 (m, 1 H), 7.58–7.51 (m, 2 H), 5.64 (t, $J = 9.6$ Hz, 1 H), 5.54 (d, $J = 4.8$ Hz, 1 H), 5.23 (app t, $J = 9.6$ Hz, 1 H), 5.02–4.98 (m, 2 H), 4.63 (dd, $J = 8.0$, 2.4 Hz, 1 H), 4.53–4.42 (m, 2 H), 4.32 (dd, $J = 10.0$, 2.8 Hz, 1 H), 4.26–4.20 (m, 3 H), 4.14–4.08 (m, 1 H), 3.87–3.80 (m, 2 H), 3.70 (dd, $J = 10.0$, 3.2 Hz, 1 H), 3.57 (dd, $J = 10.0$, 6.8 Hz, 1 H), 3.37 (dd, $J = 10.0$, 7.6 Hz, 1 H), 2.12 (s, 3 H), 2.03 (s, 3 H), 1.88 (s, 3 H), 1.57 (s, 3 H), 1.53 (s, 3 H), 1.41 (s, 3 H), 1.34 (s, 6 H), 1.32 (s, 3 H), 1.20 (d, $J = 6.4$ Hz, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.9$, 170.0, 169.9, 161.2, 133.3, 132.0, 130.8, 129.3, 128.2, 125.6 (q, $J_{\text{C-F}} = 5.6$ Hz), 124.0 (d, $J_{\text{C-F}} = 275$ Hz), 109.3, 109.1, 108.7, 99.9, 96.9, 96.2, 81.7, 77.2, 76.0, 75.6, 72.7, 71.1, 70.9, 70.6, 70.4, 68.3, 67.6, 66.5, 65.7, 64.9, 61.6, 28.2, 26.4, 26.2, 26.0, 24.9, 24.5, 20.8, 20.7, 20.5, 16.9; IR (film, cm^{-1}): $\nu = 2934$, 1752, 1640, 1455, 1381, 1314, 1242; HRMS (ESI): calc. for $\text{C}_{41}\text{H}_{55}\text{F}_3\text{NO}_{17}$ (M+H): 890.3422; found: 890.3420. **α,β -64**: $[\alpha]_{\text{D}}^{24} = 25.5$ ($c = 0.2$, CH_2Cl_2); ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.65$ (d, $J = 2.0$ Hz, 1 H), 8.16 (d, $J = 7.2$ Hz, 1 H), 7.60 (d, $J = 7.2$ Hz, 1 H), 7.62–7.51 (m, 2 H), 5.63 (t, $J = 10.0$ Hz, 1 H), 5.49 (d, $J = 4.8$ Hz, 1 H), 5.22 (t, $J = 9.6$ Hz, 1 H), 5.02 (d, $J = 3.6$ Hz, 1 H), 4.82 (d, $J = 2.0$ Hz, 1 H), 4.61 (dd, $J = 10.0$, 2.0 Hz, 1 H), 4.49–4.43 (m, 2 H), 4.35–4.22 (m, 4 H), 4.12–3.98 (m, 3 H), 3.77 (dd, $J = 9.6$, 8.8 Hz, 1 H), 3.71 (dd, $J = 12.0$, 3.2 Hz, 1 H), 3.57–3.44 (m, 2 H), 2.12 (s, 3 H), 2.03 (s, 3 H), 1.88 (s, 3 H), 1.57 (s, 3 H), 1.51 (s, 3 H), 1.44 (s, 3 H), 1.38 (s, 3 H), 1.35 (s, 3 H), 1.31 (s, 3 H), 1.25 (d, $J = 6.0$ Hz, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.9$, 170.0, 161.3, 130.8, 128.3, 110.7, 109.1, 108.6, 99.9, 98.8, 96.2, 81.5, 77.2, 74.6, 72.5, 70.7, 70.6, 70.5, 68.4, 67.8, 67.7, 65.5, 61.6, 28.0, 26.5, 26.1, 26.0, 24.8, 24.5, 20.8, 20.7, 20.5, 17.6; IR (film, cm^{-1}): $\nu = 2927$, 1752, 1644, 1456, 1381, 1315, 1223; HRMS (ESI): calc. for $\text{C}_{41}\text{H}_{55}\text{F}_3\text{NO}_{17}$ (M+H): 890.3422; found: 890.3428.

3,4,6-Tri-O-Acetyl-2-Deoxy-2- α -Trifluoromethylbenzylideneamino- α -D-Glucopyranosyl-(1 $\rightarrow$ 3)-4,6-O-Benzylidene-2-Deoxy-2-(2,2,2-Trichloroethyl)amino- β -D-Glucopyranosyl-(1 $\rightarrow$ 6)-1,2,3,4-Bis-(Di-O-Isopropylidene)- α -D-Galactopyranoside **65**

Viscous oil: 5 mg, 81%, β only; **α,β -65**: $[\alpha]_{\text{D}}^{24} = 5.9$ ($c = 1.6$, CH_2Cl_2); ^1H NMR (CDCl_3 , 400 MHz): $\delta = 8.44$ (d, $J = 2.0$ Hz, 1 H), 8.24 (d, $J = 7.2$ Hz, 1 H), 7.64–7.52 (m, 3 H), 7.21–7.16 (m, 1 H), 7.09 (t, $J = 7.6$ Hz, 1 H), 6.93 (d, $J = 7.6$ Hz, 2 H), 5.64 (d, $J = 4.8$ Hz, 1 H), 5.60 (t, $J = 9.6$ Hz, 1 H), 5.53 (d, $J = 4.8$ Hz, 1 H), 5.36 (d, $J = 4.0$ Hz, 1 H), 5.18 (s, 1 H), 5.12 (d, $J = 7.2$ Hz, 1 H), 5.09 (d, $J = 9.6$ Hz, 1 H), 4.82 (d, $J = 8.4$ Hz, 1 H), 4.61 (dd, $J = 8.0$, 2.4 Hz, 1 H), 4.53–4.14 (m, 7 H), 4.07–3.95 (m, 2 H), 3.82–3.40 (m, 7 H), 2.14 (s, 3 H), 2.03 (s, 3 H), 1.84 (s, 3 H), 1.58 (s, 3 H), 1.46 (s, 3 H), 1.35 (s, 3 H), 1.34 (s, 3 H); ^{13}C NMR (CDCl_3 , 100 MHz): $\delta = 170.7$, 169.9, 169.6, 160.3, 136.4, 133.2, 131.9, 130.7, 129.0, 128.9, 128.3, 127.9, 125.5, 109.4, 108.6, 102.1, 101.5, 99.1, 96.2, 95.4, 83.3, 77.2, 75.5, 74.6, 72.3, 71.1, 70.8, 70.6, 70.3, 68.9, 68.6, 67.8, 65.8, 62.3, 59.3, 56.5, 26.2, 26.0, 24.3, 22.7, 20.9, 20.8, 20.4; IR (film, cm^{-1}): $\nu = 3468$, 2926, 1747, 1634, 1586, 1455, 1375, 1314; HRMS (ESI): calc. for $\text{C}_{48}\text{H}_{57}\text{Cl}_3\text{F}_3\text{N}_2\text{O}_{19}$ (M+H): 1127.2573; found: 1127.2569.

3,4,6-Tri-O-Acetyl-2-Deoxy-2-N-Acetyl- α -D-Glucopyranosyl-(1 $\rightarrow$ 3)-4,6-Di-O-Acetyl-2-Deoxy-2-(2,2,2-Trichloroethyl)amino- β -D-Glucopyranosyl-(1 $\rightarrow$ 6)-1,2,3,4-Bis-(Di-O-Isopropylidene)- α -D-Galactopyranoside 66

A 25 mL RBF was charged with **65** (5 mg, 0.0044 mmol, 1.0 equiv.), 6N HCl (4.5 μ L, 0.027 mmol, 6.0 equiv.) and acetone (1.0 mL). The solution was stirred under reflux for 5 minutes, concentrated *in vacuo*. The crude amine salt was used directly without further purification. To another A 25 mL RBF was charged with this crude amine intermediate, acetic anhydride (0.5 mL), and pyridine (1.0 mL). After the reaction mixture had been stirring at room temperature overnight, it was azeotroped with toluene for three times. The resulting residue was purified by silica gel flash chromatography (hexane/ethyl acetate = 1/2 $\rightarrow$ 1/3) to afford trisaccharide **66** (5 mg, 99%) as a viscous oil. **66**: [α]_D²⁴ = 12.3 (*c* = 0.6, CH₂Cl₂); ¹H NMR (CDCl₃, 400 MHz): δ = 5.75 (d, *J* = 8.4 Hz, 1 H), 5.66 (d, *J* = 9.6 Hz, 1 H), 5.20–4.99 (m, 5 H), 4.66 (d, *J* = 8.4 Hz, 1 H), 4.60 (dd, *J* = 8.0, 2.4 Hz, 1 H), 4.51 (d, *J* = 12.0 Hz, 1 H), 4.39 (dt, *J* = 10.0, 4.0 Hz, 1 H), 4.32 (dd, *J* = 5.2, 2.4 Hz, 1 H), 4.23–4.16 (m, 4 H), 4.09–3.94 (m, 4 H), 3.76–3.52 (m, 3 H), 2.14 (s, 3 H), 2.11 (s, 3 H), 2.04 (s, 3 H), 2.014 (s, 3 H), 2.009 (s, 3 H), 1.97 (s, 3 H), 1.56 (s, 3 H), 1.44 (s, 3 H), 1.34 (s, 3 H), 1.33 (s, 3 H); ¹³C NMR (CDCl₃, 100 MHz): δ = 171.0, 170.8, 170.6, 109.4, 108.7, 98.4, 96.2, 95.3, 77.2, 74.7, 71.6, 71.2, 71.1, 70.9, 70.6, 70.2, 69.2, 68.1, 68.0, 67.7, 61.9, 56.4, 51.2, 26.2, 25.0, 24.3, 23.0, 22.7, 20.84, 20.82, 20.74, 20.69, 20.6; IR (film, cm⁻¹): ν = 3347, 2924, 1747, 1669, 1539, 1455, 1374, 1231; HRMS (ESI): calc. for C₃₉H₅₅Cl₃N₂O₂₂Na (M+Na): 1031.2210; found: 1031.2197.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

We would like to thank the University of Iowa and National Institutes of Health (R01 GM098285) for their financial support.

REFERENCES

- (1). (a) Boons, G-J. Glycoscience: Chemistry and Chemical Biology. Fraser-Reid, B.; Tatsuta, K.; Thiem, J., editors. Vol. 1. Springer-Verlag; Berlin Heidelberg: 2001. p. 551-581. (b) Toshima K, Tatsuta K. Chem. Rev. 1993; 93:1503-1531.
- (2). Garegg, PJ. Advanced In Carbohydrate Chemistry and Biochemistry. Vol. 52. Academic Press; New York: 1997. p. 179-205.
- (3). (a) Hsu C-H, Hung S-C, Wu C-Y, Wong C-H. Angew. Chem. Int. ed. 2011; 50:11872-11923. (b) Kaeothip S, Demchenko AV. Carbohydr. Res. 2011; 346:1371-1388. [PubMed: 21663897] (c) Zhu X, Schmidt RR. Angew. Chem. Int. Ed. 2009; 48:1900-1934.
- (4). (a) Wu -Y, Wong C-H. Top. Curr. Chem. 2011; 301:223-252. [PubMed: 21290217] (b) Premathilake HD, Demchenko AV. Top. Curr. Chem. 2011; 301:189-221. [PubMed: 21120713] (c) Shiao TZ, Roy R. Top. Curr. Chem. 2011; 301:69-108. [PubMed: 21298410]
- (5). Li Z, Gildersleeve JC. J. Am. Chem. Soc. 2006; 128:11612-11619. [PubMed: 16939286]
- (6). (a) Kihlberg J, Eichler E, Bundle DR. Carbohydr. Res. 1991; 211:59-75. [PubMed: 1773432] (b) Knapp S, Nandan SR. J. Org. Chem. 1994; 58:281-283. (c) Leigh DA, Smart JP, Truscetto AM. Carbohydr. Res. 1995; 276:417-424. [PubMed: 8542609] (d) Belot F, Jacquinet JC. Carbohydr. Res. 1996; 290:79-86. [PubMed: 8805783] (e) Du YG, Lin JH, Linhardt RJ. J. Carbohydr. Chem. 1997; 16:1327-1344. (f) Yu H, Yu B, Wu XY, Hui YZ, Han XW. J. Chem. Soc., Perkin Trans. 1. 2000:1445-1453. (g) Zhu T, Boons G-J. Carbohydr. Res. 2000; 329:709-715. [PubMed: 11125813] (h) Sherman AA, Yudina ON, Mironov YV, Sukhova EV, Shashkov AS, Menshov VM, Nifantiev NE. Carbohydr. Res. 2001; 336:13-46. [PubMed: 11675024] (i) Cheshev PE, Kononov LO, Tsvetkov YE, Shashkov AS, Nifantiev NE. Russ. J. Bioorg. Chem. 2002; 28:419-

- 429.(j) Geurtsen R, Boons G-J. Tetrahedron Lett. 2002; 43:9429–9431.(k) Tanaka H, Adachi M, Takahashi T. Tetrahedron Lett. 2004; 45:1433–1436.(l) Xue J, Khaja SD, Locke RD, Matta KL. Synlett. 2004:861–865.(m) Codee JDC, Stubba B, Schiattarella M, Overkleeft HS, van Boeckel CAA, van Boom JH, van der Marel GA. J. Am. Chem. Soc. 2005; 127:3767–3773. [PubMed: 15771511] (n) Sun JS, Han XW, Yu B. Org. Lett. 2005; 7:1935–1938. [PubMed: 15876023] (o) Li Z, Gildersleeve JC. Tetrahedron. Lett. 2007; 48:559–562. [PubMed: 19043616] (p) Kato M, Hirai G, Sodeoka M. Chem. Lett. 2011; 40:877–879.
- (7). (a) Mensah EA, Nguyen HM. J. Am. Chem. Soc. 2009; 131:8778–8780. [PubMed: 19496537] (b) Mensah EA, Yu F, Nguyen HM. J. Am. Chem. Soc. 2010; 132:14288–14302. [PubMed: 20860359]
- (8). The use of C(2)-*N*-*p*-methoxylbenzylidene glucosyl bromide donor with stoichiometric amount of HgCN₂ was previously investigated, see: Hardy FF, Buchanan JG, Baddiley J. J. Chem. Soc. 1963:3360–3366.. Paulsen H. Angew. Chem. Int. Ed. 1982; 21:155–173..
- (9). (a) Mann G, Baranano D, Hartwig JF, Rheingold AL, Guzei IA. J. Am. Chem. Soc. 1998; 120:9205–9219.(b) Baranano D, Hartwig JF. J. Am. Chem. Soc. 1995; 117:2937–2938.(c) Louie J, Hartwig JF. J. Am. Chem. Soc. 2008; 130:15228–15229. [PubMed: 18950157]
- (10). (a) Tanaka H, Iwata Y, Takahashi D, Adachi M, Takahashi T. J. Am. Chem. Soc. 2005; 127:1630–1631. [PubMed: 15700984] (b) Park NH, Nguyen HM. Org. Lett. 2009; 11:2433–22436. [PubMed: 19473048]
- (11). (a) Yu B, Tao H. Tetrahedron Lett. 2001; 42:2405–2407.(b) Cai S, Yu B. Org. Lett. 2003; 5:3827–3830. [PubMed: 14535720]
- (12). C(2)-benzylidene trichloroacetimidate donor **2** was formed as a 1:3 mixture of α - and β -isomers, favoring the β -isomer. However, only the minor α -isomer of **2** could be glycosylated.
- (13). Bindschadler P, Dialer LO, Seeberger PH. J. Carbohydr. Chem. 2009; 28:395–420.
- (14). (a) Fitzgerald C, Collins M, van Duyne S, Mikoleit M, Brown T, Fields P. J. Clin. Microbiol. 2007; 45:3323–3334. [PubMed: 17634307] (b) Perepelov AV, Liu B, Senchenkova SN, Shevelev SD, Feng L, Shashkov AS, Wang L, Knirel YA. Carbohydr. Res. 2010; 345:1808–1811. [PubMed: 20594547]
- (15). (a) O'Hara CM, Brenner FW, Miller JM. Clin. Microbiol. Rev. 2000; 13:534–546. [PubMed: 11023955] (b) Kocharova NA, Zatonsky GV, Torzewska A, Maciejka Z, Bystrova OV, Shashkov AS, Knirel YA, Rozalski A. Carbohydr. Res. 2003; 338:1009–1016. [PubMed: 12681927]
- (16). In general, thioglycoside donors can be efficiently activated with the reagent combination of NIS/TfOH (see reference 12). Because the benzylidene group is acid-sensitive, activation of 2-trifluorophenyl thioglycoside donors were explored with NIS/AgOTf.
- (17). Cao SD, Gan ZH, Roy R. Carbohydr. Res. 1999; 318:75–81. [PubMed: 10515050]
- (18). (a) Paulsen H, Kalar C, Stenzel W. Chem. Ber. 1978; 111:2358–2359.(b) Lemieux R, U. Ratcliffe RM. Can. J. Chem. 1979; 57:1244–1251.
- (19). (a) Grundler G, Schmidt RR. Liebigs. Ann. Chem. 1984:1826–1847.(b) Schmidt RR, Stumpp M. Liebigs. Ann. Chem. 1983:3352–3353.
- (20). Interestingly, treatment of donor **67** with thioglycoside acceptor **17** in the presence of TMSOTf as the activating reagent resulted in the consumption of 2-trifluorophenyl thioglycoside **17**. The desired disaccharide **70**, however, was not observed in the reaction.
- (21). Bindschadler P, Dialer LO, Seeberger PH. J. Carbohydr. Chem. 2009; 28:395–420.
- (22). The thioglycoside by-product was contaminated with a small amount of elimination product because we were unable to cleanly separate this elimination product from the thioglycoside by silica gel flash chromatography.
- (23). The desired α -disaccharide contained a small amount of β -isomer because we were unable to cleanly separate the minor β -isomer from the desired α -disaccharide by flash chromatography.

Previous work:

This work:

Scheme 1.
Nickel-Catalyzed 1,2-*Cis*-2-Amino Glycosylation

Scheme 2.
Initial Studies with Trichloroacetimidate Donors

Scheme 3.
Activation of 2-Trifluoromethylphenyl Thioglycosides

Scheme 4.
Glycosylation with C(2)-Azido Imidate Donor

Table 1

Studies with *N*-Phenyl Trifluoroacetimidate^a

entry	acceptors	donor/acceptor ratio	disaccharides yield (%) ^b (α:β) ^c	thioglycosides yield(%)
1	3 : R = Ph	1/2	5 :58 (α only)	7 : 14
2	11 : R = Et	1/2	18 : 43(10:1)	25 : 22
3	12 : R = 1-Naphthyl	1/2	19 : 59 (α only)	26 : 10
4	13 : R = 4-Me-Ph	1/2	20 : 38 (11:1)	27 :20
5	14 : R = 4-MeO-Ph	1/2	21 : 37 (11:1)	28 : 30
6	15 : R = 4-F-Ph	1/2	22 : 58 (20:1)	29 : 9
7	16 : R = 2-F-Ph	1/2	23 : 60 (α only)	30 : 4
8	17 : R = 2-CF ₃ -Ph	1/2	24 :61 (α only)	31 : 0
9	17 : R = 2-CF ₃ -Ph	2/1	24 : 58 (α only)	31 : 0

^a All reactions were run in 10 mol % Ni(4-F-PhCN)₄(OTf)₂ at 35 °C for 12 h.^b Isolated Yield.^c ¹H NMR ratio.

Table 2

Activation of Glycosyl Imidate with Various Catalysts.^a

Entry	Catalysts	Disaccharide 5 Yield (%) ^b ($\alpha:\beta$) ^c	Thioglycoside 7 Yield (%)
1	TMSOTf	13 (10:1)	40
2	$Cu(OTf)_2$	26 (10:1)	30
3	$Rh(COD)_2OTf$	43 (6:1)	20
4	$Ir(COD)_2OTf$	45 (8:1)	26
5	$Pd(4-F-PhCN)_2(OTf)$	36 (20:1)	23
6	$Ph_3PAuOTf$	43 (α only)	24
7	$Fe(OTf)_2$	11 (11:1)	1

^aAll reactions were run in 10 mol % catalyst at 35 °C for 12 h.^bIsolated Yield.^c¹H NMR ratio.

Table 3

Coupling of Thioglycosides with Glucosamine Donors^a

entry	donors	acceptors	disaccharides yield ^d (α:β) ^e	thioglycosides (yield) ^f
1	33	3	 39: 64% (6:1) ^b	48: 0%
2	10	34	40: R = Ac 55% (α only) ^b	7: 24%
3	32	34	41: R = Bn 61% (α only) ^b	49: 8%
4	10	35	42: 71% (α only) ^c	31: 0%
5	10	36	43: R = Ac 81% (α only) ^b	7: 15%
6	32	36	44: R = Bn 72% (α only) ^b	49: 9%
7	10	37	45: R = Ac 98% (α only) ^b	31: 0%
8	32	37	46: R = Bn 78% (α only) ^b	50: 0%

entry	donors	acceptors	disaccharides yield ^d ($\alpha:\beta$) ^e	thioglycosides (yield) ^f
9	10	38	47: 74% (α only) ^b	51:0%

^a All reactions were conducted with 10 mol % Ni(4-F-PhCN)₄(OTf)₂ for 14 h.

^b Donor/Acceptor = 1:2.

^c Donor/Acceptor = 2:1.

^d Isolated yields.

^e ¹H NMR ratio.

^f Transfer products were obtained as single α -isomers.

Table 4

Coupling of Thioglycosides with Galacto samine Donors^a

entry	donors	acceptors	disaccharides yield ^d (α:β) ^e	thioglycosides (yield) ^f
1	52	3	54: R = Ac 67% (α only) ^b	60: 16%
2	53	3	55: R = Bn 56% (14:1) ^b	61: 6%
3	52	17	56: 73% (α only) ^b	62: 0%
4	52	34	57: R = Ac 52% (8:1) ^b	60: 24%
5	53	34	58: R=Bn 51% (α only) ^b	61: 40%
6	52	35	59: 62% (α only) ^b	62: 0%

^a All reactions were conducted with 10 mol % $\text{Ni(4-F-PhCN)}_4(\text{OTf})_2$ for 14 h.^b Donor/Acceptor = 1:2.^c Donor/Acceptor = 2:1.^d Isolated yields.^e ¹H NMR ratio.^f Transfer products were obtained as single α-isomers.