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Synthesis of benzaldehyde-functionalized LewisX trisaccharide analogs for glyco-SAM formation

Sebastian Kopitzki [a,b], Karim Akbari Dilmaghani [c], Joachim Thiem [a,*]

[a] Department of Chemistry, Faculty of Science, University of Hamburg, Martin-Luther-King-Platz 6, 20146 Hamburg, Germany
[b] Midatech Biogune, Parque Tecnológico de Bizkaia, Edificio 800, Planta 2a, 48160 Derio, Spain
[c] Department of Chemistry, Faculty of Science, University of Urmia, 57159 Urmia, Iran

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ABSTRACT

LewisX (Le^x) antigen based carbohydrate–carbohydrate interactions are mediated by complexation of metal ions. Although theoretical studies about the influence of participating hydroxyl groups in the Le^x trisaccharide head group (Galβ(1-4)[Fucα(1-3)]Glc*N*Ac) could gave same rudimental information about the basic mechanism behind this interaction, a little is known about orientation and configuration of the hydroxyl groups required for the specific interaction mediated by Ca^{2+} complexation. Therefore, there is a need of non-natural derivatives to provide detailed information about the requirements for hydroxyl group arrangement in Le^x head group surface plasmon resonance and gold nanoparticle techniques have shown to be powerful tools to investigate carbohydrate–carbohydrate interactions. Benzaldehyde-functionalized glycans can be used for attachment to both gold nanoparticles and surface plasmon resonance sensor surfaces. Therefore, seven benzaldehyde equipped Le^x analogs including the natural trisaccharide were synthesized utilizing convergent approach. The derivatives were applied in ongoing carbohydrate–carbohydrate interaction studies by surface plasmon resonance experiments to prove theoretical postulate about the structural requirements of hydroxyl group arrangements in Le^x trisaccharides.

1. Introduction

Carbohydrate associated cellular recognition events can be classified into carbohydrate–protein-interactions (CPI), especially between sugars and lectins[1] and also selectins,[2] carbohydrate–RNA/DNA-interactions[3] (CR/DI), and carbohydrate–carbohydrate-interactions (CCI).[4] These interactions are associated with various cellular processes, including bacterial and viral infection, cancer metastasis, modulation and activation of the immune system, tissue differentiation and development, and many other intercellular recognition events.[5–7] Already in 1989 Hakomori et al. proposed interactions between glycosphingolipid (GSL) microdomains as an initial step for cell adhesion and identified the corresponding glycan structure as Le^x [Galβ(1-4)[Fucα(1-3)]Glc*N*Ac].[8] Primary search for a protein as the counterpart in this process failed and, finally, Le^x self-recognition was confirmed by [^{3}H]-GlcNH_2 labeling of F9 cells.[9] Le^x interactions provide the basis for initial cell recognition in morula compaction and in embryonic carcinoma cells.[10] There is evidence that Le^x based CCI plays a crucial in accruement of pregnancy in mouse model.[11–13] Since these fundamental findings many other CCIs were found and it could be shown that in the midst of carbohydrate based interactions CCI takes a special position. In general, this type of interaction is typically weak with K_D values in the millimolar or high micromolar range (also for CPI), compared with antigen–antibody interactions (10^{-8}–10^{-12} M).[14,15] CCIs are subjected strongly to multivalent effects and all known natural *hetero*- and *homo*-type CCIs are Ca^{2+}-dependent. For example, the trisaccharide Le^x {Galβ(1-4)[Fucα(1-3)]GlcNAc, Fig. 1} recognizes

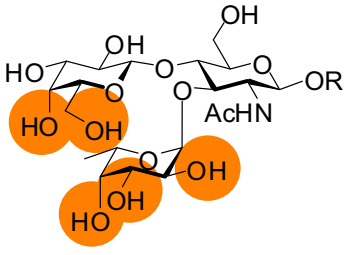

Fig. 1. LewisX trisaccharide antigen Galβ(1-4)[Fucα(1-3)]Glc*N*Ac. Colored cycles assign the hydroxyl groups, which are proposed to be relevant in Ca^{2+} induced self-recognition.

* Corresponding author. Tel.: +49 40 42838 4241; fax: +49 40 42383 4325; e-mail address: thiem@chemie.uni-hamburg.de (J. Thiem).

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itself (*homo* type), whereas GM3 [Neu5Acα(2-3)Galβ(1-4)GlcNAc] interacts with GG3 [GalNAcβ(1-4)Galβ(1-4)Glc, *hetero* type] only in the presence of calcium ions.[16,17] The mechanistic basement for carbohydrate self-recognition is the potential to complex metal ions.

Although many studies of Le^x based interaction using surface plasmon resonance (SPR),[18] atomic force microscopy (AFM),[19] and NMR[20–22] were conducted, still little is known about the influence of hydroxyl group orientation and configuration in the trisaccharide scaffold for complexation of Ca^{2+} ions. By NMR, molecular modeling experiments as well as crystal structure analysis a profile of important hydroxyl groups was created (Fig. 1).[23–25] In the fucose building block the hydroxyl groups at C-2, -3, and -4 are involved in Ca^{2+} complexation. In the galactose moiety only the positions 4 and 6 are participating in the interaction, whereas the glucosamine functionalities are less important. To get more detailed information about influence of the different hydroxyl groups seven Le^x analogs including the natural trisaccharide were to be synthesized and analyzed with regard to their binding behavior (Fig. 2).

SPR constitutes the most powerful tool to investigate carbohydrate based interactions.[26–29] Therefore, gold sensor surfaces and nanoparticles should be functionalized after SAM formation following the recently published protocol.[30] The phenomenon of self-assembly of thiol-functionalized molecules on gold surfaces, first introduced by Whitesides and Bain in 1988,[31] is quite advantageous to mimic the glycocalyx. In particular, the concept of glyco-SAMs is well suited for investigation of molecular interactions of carbohydrates. It allows the control of density and orientation of carbohydrate ligands, and there are several means for their characterization.[30,32–36] Here the synthesis of seven Le^x trisaccharide analogs is presented utilizing novel orthogonal protected glycosyl donors and subsequent modification of the allyl function by olefin cross metathesis.[30,37] As a follow up these compounds are to be coupled to nanoparticles and amino SAM via imine formation and provided to binding experiments.

Since the discovery of the role of Le^x trisaccharide, also known as CD15 antigen, in different pathological processes many synthetic approaches toward this important glycan employing almost all

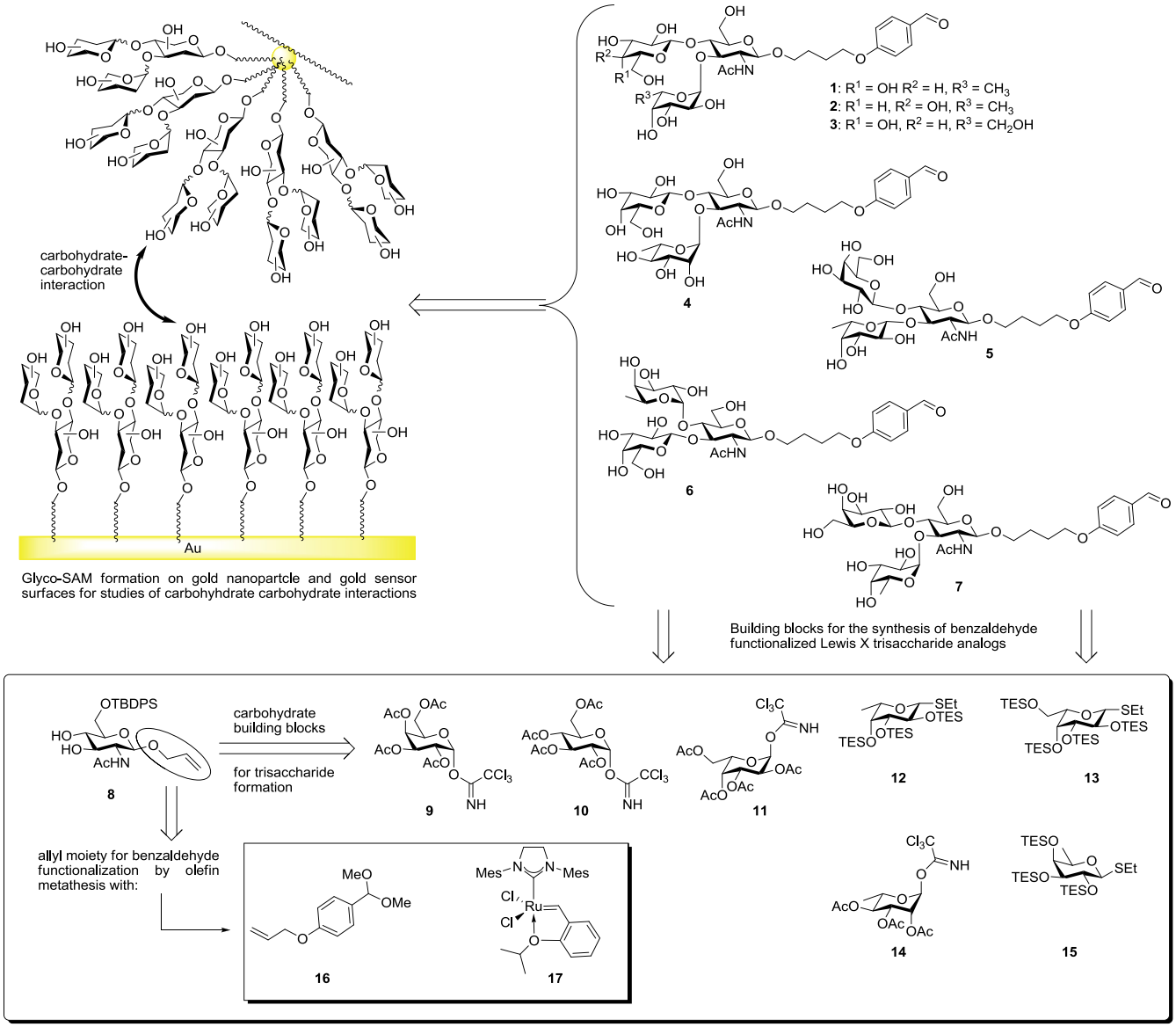


Fig. 2. LewisX trisaccharide analogs **1**–**7** for systematic study of carbohydrate–carbohydrate interactions. Glyco-SAM formation on aminooxy or amine functionalized gold nanoparticles and surfaces could be achieved be attachment of benzaldehyde derivatives via oxime/imine formation. Trisaccharide analogs were obtained by selective assembly of glycosyl donors **9**–**15** on acceptor **8** and subsequent olefin metathesis with benzaldehyde precursor **16** and catalyst **17**.

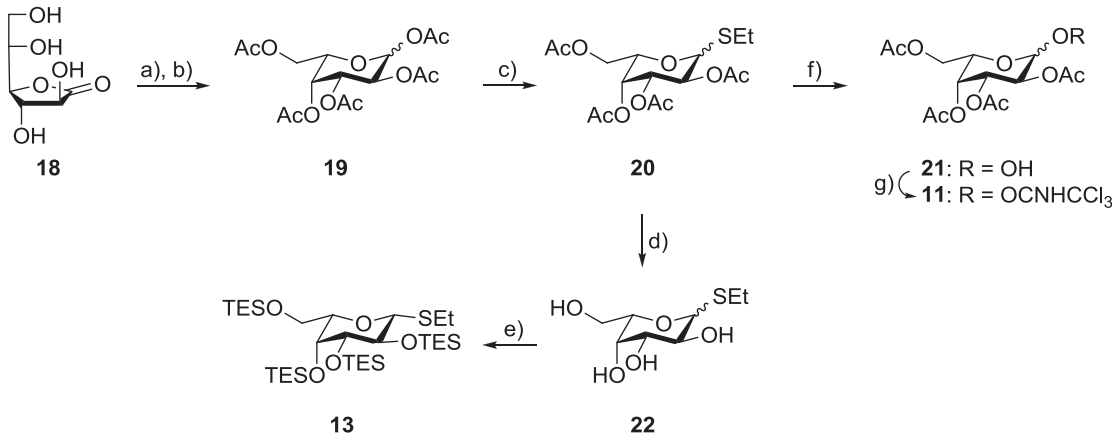
types of glycosyl donors, such as glycosyl bromides, thioglycosides, and trichloroacetimidates were applied. For example, 1979 Sinaÿ and Jacquinet used Hg(II)–bromide to promote the condensation of tetra-*O*-acetyl-α-D-galactopyranosyl bromide with a selectively protected *N*-acetyl-D-glucosamine derivative in position 4 followed by 3-O deprotection and glycosylation with tri-*O*-benzyl-L-fucopyranosyl bromide.[38] R. R. Schmidt and Toepfer glycosylated first position 3 of 4,6-*O*-benzyliden-*N*-acetyl-D-glucosamine derivative with a fucopyranosyl trichloroacetimidates. After selective ring opening the 4-position was glycosylated with a galactopyranosyl trichloroacetimidate.[39] Dekany et al. were utilizing a straight thioglycoside activation approach with DMTST (dimethyl(methylthio) sulfonium triflate) as promoter, whereas first the fucose and then the galactose unit were introduced into the *N*-acetyl-glucosamine building block.[40] Furthermore, diverse mixed forms (glycosyl bromide+thioglycoside/thioglycoside+trichloroacetimidate)[41,42] as well as chemoenzymatic approaches are described in literature.[43]

For the present work also an approach was chosen, in which both trichloroacetimidates and thioglycosides were applied in a convergent 1+1+1 synthesis using different activation methods. For formation of 1,2-*trans* glycosidic bonds in the trisaccharides **1**–**7** the construction should utilize the neighboring group participation of 2-*O*-acetyl-trichloracetimidates **9**, **10**, **11**, and **14**. In contrast, whereas the 1,2-*cis* glycosidic bonds should be realized utilizing the thioglycosides 1**2**, 1**3**, and **15**, in which neighboring group participation active protecting group in position 2 are lacking (Fig. 2). For this purpose often benzyl groups were used.[44–46] Furthermore perbenzylated thioglycosides show increased reactivity compared to acyl derivatives.[47,48] However, benzyl protecting groups are not compatible with the allylic anchor moiety due to required hydrogenolysis for deprotection. Kosma et al. described the synthesis of Le^x-trisaccharide analogs with allylic aglycon utilizing the elaborate thioethyl 3,4-*O*-isopropylidene-2-*O*-4-methoxybenzyl-β-L-fucopyranoside.[49] To circumvent a long synthetic pathway toward this donor the use of a persilylated donor could be a solution. Penades et al. in their syntheses of Le^x and Le^y derivatives applied a pertrimethylsilylated fucose donor.[50] However, these protecting groups do not seem to be stable enough for the pursued glycosylation condition. Therefore, the more stable triethylsilyl (TES) protecting group was chosen in donors **12**, **13**, and **15** (Fig. 2). It can be removed in aqueous acetic THF and bears less steric hindrance than triisopropyl or *tert*-butyldimethylsilyl protecting groups. Under anhydrous conditions TES groups are sufficiently stable against electrophiles, Lewis acids and so called 'soft acids' such as Ag^+-, Hg^{2+}, and Cu^{2+} ions.[51] The followed synthetic pathway toward target compounds **1**–**7** consists of subsequent glycosylations at positions 4 and 3 of the bivalent acceptor **8** followed by olefin metathesis and global deprotection.

2. Results and discussion

2.1. Synthesis of monosaccharide building blocks

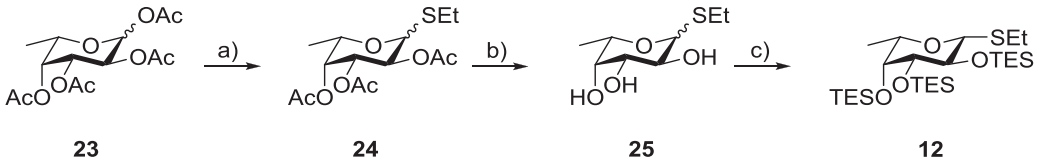
First, all monosaccharide building blocks were synthesized. The acceptor **8** was obtained according to the procedure of R. Roy.[52] The common glycosyl trichloroacetimidate donors **9**, **10**, and **14** of glucose, galactose, and rhamnose were achieved from the corresponding peracetates under standard conditions by deacetylation of the anomeric acetates followed by treatment with trichloroacetonitrile and a catalytic amount of DBU. The synthesis of the L-galactose donors **11** and **13** started from L-galactono-1,4-lactone (**18**). This precursor is a side product of the beet sugar industry and therefore, cheap and commercially available.[53] By reduction of the lactone **18** with sodium borohydride in ice cooled aqueous methanol solution at pH 3–5 and subsequent acetylation of the crude using standard conditions the peracetylated L-galactose **19** was obtained in 68% yield over two steps (Scheme 1).[54,55] Then, L-galactose derivatives **19** were glycosylated to the thioethyl glycoside **20** with ethanethiol under BF_3 etherate catalysis. From this precursor, first the L-galactopyranosyl trichloroacetimidate **11** was synthesized by NIS/triflic acid mediated hydrolysis to the hemiacetal **21** and subsequent standard trichloroacetimidate formation in good overall yield of 71%. Then, the novel thioglycoside donor **13** was obtained in 79% yield after protecting group replacement by Zemplén deacetylation via the intermediate **22** and silylation with triethylsilyl chloride in pyridine (Scheme 1).



Scheme 1. Synthesis of L-galactopyranosyl donors **11** and **13**. Reagents and conditions: (a) $NaBH_4$, H^+, MeOH/H_2O, 0 °C→rt, 2 h; (b) Ac_2O, py, 16 h, rt, over two steps 68%; (c) ethanethiol, $BF_3{\cdot}Et_2O$, DCM, 0 °C→rt, 20 h, 75%; (d) NaOMe, MeOH, rt, 13 h, quant.; (e) TESCl, py, cat. DMAP, 18 h, 79%; (f) NIS, TfOH, THF/H_2O, 0 °C→rt, 2 h; (g) trichloroacetonitrile, DBU, DCM, 0 °C, 2 h, via two steps 71%.

The L-fucose donor **12** was synthesized according to donor **13** with an overall yield of 58% in a three step procedure consisting of thioglycoside formation, deacetylation, and fully triethylsilyl protection of the free hydroxyl groups (Scheme 2).

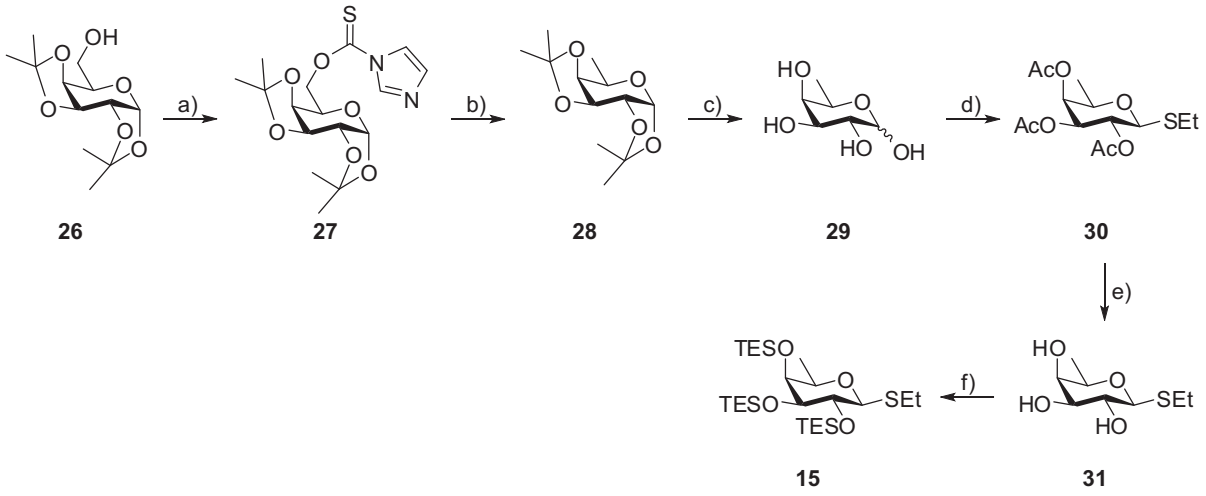
For the synthesis of the D-fucopyranosyl donor **15**, first, D-galactose was converted into D-fucose (Scheme 3). Barton and McCombie could show that thiocarbonyl compounds can be deoxygenated in a radical reaction with tributyltin hydride.[56] In deoxygenation reaction of carbohydrates both phenoxythiocarbonyl



Scheme 2. Synthesis of L-fucopyranosyl donor **12**. Reagents and conditions: (a) ethanethiol, $BF_3 \cdot Et_2O$, DCM, 0 °C→rt, 20 h, 72%; (b) NaOMe, MeOH, rt, 13 h, 96%; (c) TESCl, py, cat. DMAP, 18 h, 84%.

and thiocarbonylimidazoyl derivatives were successfully applied, whereas the last mentioned gave slightly better yields.[57,58] Therefore, diisopropylidene galactose **26** was reacted with 1,1′-thiocarbonyldiimidazole (TCDI) in THF to give compound **27**. In the following deoxygenation with Bu_3SnH in toluene under reflux the corresponding D-fucose compound **28** was obtained in poor 30% yield. However, the isolated amount was sufficient to continue the synthetic pathway. The deprotection of the isopropylidene groups was carried out in 0.2 M H_2SO_4 solution at 60 °C for 12 h. The crude **29** was acetylated with acetic anhydride in pyridine to yield the peracetylated D-fucose, which was transformed to the thioglycoside **30** according to the synthesis of compound **24** in overall yield of 49% over three steps. Then, the target donor **15** was achieved after Zemplén deacetylation and TES protection as described before (Scheme 3).

circumvent this disadvantage the concept of partially 'light protected' acceptors was developed. This concept was successfully tested at 6-*O*-pivaloyl- or 6-*O*-benzyl-2-deoxy-2-phthalimido-glucose derivatives by the groups of Ogawa,[65] Sinaÿ,[66] and Matta.[67] The undesired β(1→3) side product was only observed in less than 25%. Roy et al. reported only the formation of the desired (1→4)-glycosylated product **32**, when they used 2,3,4,6-tetra-*O*-acetyl-α-D-galactopyranosyl trichloroacetimidate **9** in the glycosylation of 6-*O*-*tert*-butyldiphenylsilyl-glucosamine acceptor **8** under BF_3 etherate catalysis in 68% yield.[52] In our hands this reaction gave a mixture of the desired product **32** (43%) besides the β(1→3) product **33** (23%) and the trisaccharide **34** (16%) (Table 1, entry 1). Similar results were obtained by Davis et al., when they reacted the donor **9** with a 6-*O*-*tert*-butyldimethylsilyl derivative of acceptors **8**.[68] By the change of the promoter system from BF_3



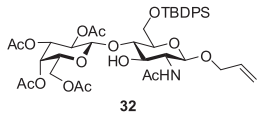
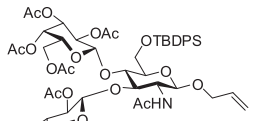
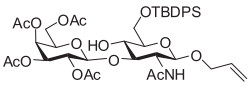
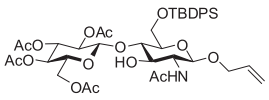
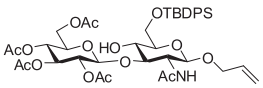
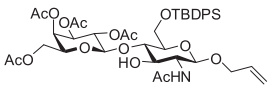
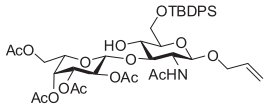
Scheme 3. Synthesis of D-fucopyranosyl donor **15**. Reagents and conditions: (a) TDCI, THF, rt, 40 h, 60%; (b) Bu_3SnH, toluene, reflux, 15 h, ~30%; (c) 0.2 M H_2SO_4, 60 °C, 12 h; (d) 1. Ac_2O, py, rt, 12 h; 2: ethanethiol, $BF_3 \cdot Et_2O$, DCM, 0 °C→rt, 20 h, via three steps 49%; (e) NaOMe, MeOH, rt, 13 h, quant; (f) TESCl, py, cat. DMAP, 18 h, 86%.

2.2. Synthesis of disaccharide intermediates

With these donors in hand the subsequent glycosylation toward the target trisaccharides were conducted. First, the regioselective glycosylations with donors **9**–**11** were performed on the *N*-acetyl glucosamine acceptor **8** to achieve the disaccharide intermediates **32**, **33**, **35**, and **37** (Table 1). Previously several approaches were described for the synthesis of the *N*-acetyllactosamine moiety in the Le^x trisaccharide.[59–61] These showed that 4-OH of acyl protected hexopyranoses in $^4C_1$ conformation were particularly unreactive. The corresponding benzylated compounds performed slightly better.[62] Improvements could also be achieved by a conformational change in the precursor molecule. E.g., Sinaÿ and Schmitt used successfully the $^1C_4$ conformer of 2-acetamido-1,6-anhydro-2-deoxy-β-D-glucopyranose,[63] and alternatively acyclic *N*-acetyl-glucosamine derivative were used by Paulsen et al.[64] These synthetic approaches require enormous protecting group replacement procedures. To etherate to TMSOTf the regioselectivity of the glycosylation reaction was increased from 1.8 [43% (1→4)/23% (1→3), Table 1, entry 1] to 2.9 [56% (1→4)/16% (1→3), Table 1, entry 2]. However, this led to both the Le^x and the Le^a precursor **32** and **33**, respectively. Surprisingly, when acceptor **8** was glycosylated with the *gluco*-donor **10** the position 3 was preferentially glycosylated instead of position 4 as previously observed (Table 1, entry 3). The (1→3)-disaccharide **35** was obtained in 49% yield, whereas the (1→4)-disaccharide **36** was isolated in only 25% yield. The formation of a corresponding trisaccharide was not observed. This was also the case when, the acceptor **8** was reacted with the L-galactose donor **11**. Again, the regioselectivity toward the desired (1→4)-disaccharide **37** was achieved (Table 1, entry 4). The (1→4)-disaccharide **37** was yielded in 45% versus the (1→3)-disaccharide **38** in 20%, respectively.

Then, the synthesized disaccharides **32** (for Le^x, $Le^{x\text{-}\beta\text{-}Fuc}$, $Le^{x\text{-}L\text{-}Gal}$, and $Le^{x\text{-}Rham}$) **33** (for Le^a), **35** (for $Le^{x\text{-}Glc}$), and **37** (for $Le^{x\text{-}D\rightarrow L}$) were delivered to the trisaccharide syntheses.

Table 1
Regioselective glycosylation of *N*-acetyl-glucosamine acceptor **8**

Entry	Donor	Conditions	Product	Yield
1	**9**	1 equiv $BF_3 \cdot Et_2O$, DCM, −45 °C, 1 h	 **32**  **34**	**32** (43%) **33** (23%) **34** (16%)
2	**9**	10% TMSOTf, DCM, −45 °C, 1 h	 **33**	**32** (56%) **33** (19%) **34** (7%)
3	**10**	10% TMSOTf, DCM, −45 °C, 1 h	 **35**  **36**	**35** (25%) **36** (49%)
4	**11**	10% TMSOTf, DCM, −45 °C, 1 h	 **37**  **38**	**37** (45%) **38** (20%)

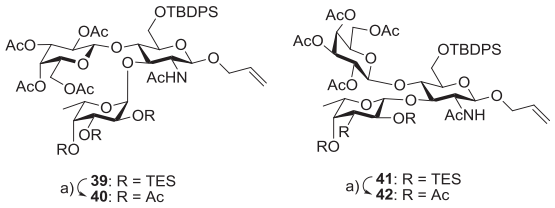
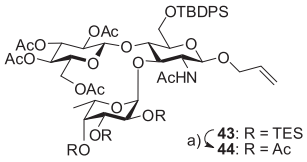
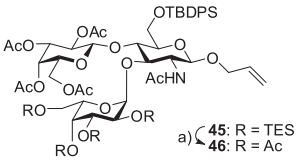
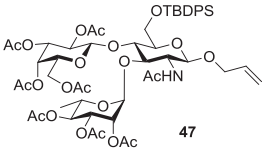
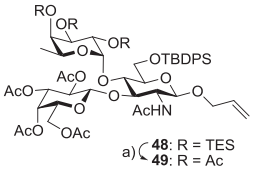
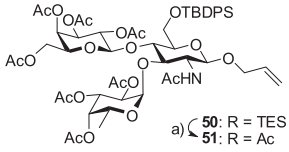
2.3. Synthesis of allylic Le^x trisaccharide analogs

The trisaccharide formation was the key step in formation of benzaldehyde functionalized Le^x analogs. A novel synthetic approach had to be developed utilizing the pertriethylsilyl protected thioglycoside donors. The usually used perbenzylated glycosyl trichloroacetimidates[40] or bromides[38] could not be applied due to in compatibility of the allylic aglycon in the hydrogenation deprotection procedure. Kosma et al. and Nifantev et al. have used a perbenzoylated fucopyranosyl bromide on an allyl glycosidic acceptor, but both groups obtained poor α/β stereoselectivities because of neighboring group participation. In general, electrophiles, such as NIS are used to activate thioglycosides, which provide potential side reactions on allylic double bonds. On the other hand, the synthesis of TES protected glycosyl trichloroacetimidates is in principal possible, but elaborative and complex.[69] Therefore, different activation methods were tested for the glycosylation of the lactosamine acceptor **32** with the fucose donor **12** (Table 2, entries 1–5).

Kunz et al. described the synthesis of sialyl–Le^x with a thioethyl fucopyranoside, which was activated by copper(II)–bromide and tetrabutyl ammonium bromide.[42] Here the thioglycoside was attacked by the thiophilic copper and substituted by a bromide ion.[70] The corresponding glycopyranosyl bromide donor was anomerized in situ by tetrabutyl ammonium bromide according to a Lemieux procedure to increase the stereoselectivity.[71] Unfortunately, these conditions led to an anomeric mixture of compound **39** and **41** in a ratio of nearly 1:1 in 68% yield (Table 2, entry 1). The mixture of TES-protected trisaccharides **39** and **41** could not be separated by common column chromatography. After protecting group replacement of triethylsilyl groups in acidic wet THF and subsequent acetylation the mixture of the resulting trisaccharides **40** and **42** was separable. Therefore, all product mixtures containing TES-protected residues were afterward transformed into the corresponding acetates. Due to the fact that $CuBr_2$ activation of thioethyl glycoside **12** showed poor stereoselectivity, different methods were tested for improvement. In general, diverse promoter systems provide different transition states at the anomeric center and thus lead to different reaction mechanisms ($sp^3 \rightarrow S_N2$ vs $sp^2 \rightarrow S_N1$). This effect has a significant influence on the α/β ratio, in particular, in case of non neighboring group participation.[72,73] Although Lemieux et al. could successfully activate thioglycosides with IDCP (*Iodonium dicollidin perchlorate*) in the presence of allyl groups, this activation methods seemed to be unfavorable due to instability and hence elaborative preparation prior to use.[74–76] In spite of possible side reactions of the allylic aglycon by electrophiles, first standard activation methods, such as NIS and trifluoromethanesulfonic acid,[77] DMTST,[78,79] methyltriflate[80] as well as dimethyldisulfide and trifluoromethanesulfonic anhydride were tested (Table 2, entries 2–5).[81] Instead of the usual procedure, first the donor was dissolved, cooled to reaction temperature, and mixed with the promoter system to minimize side reactions. Then, after 30 min of preactivation the acceptor was added. In the case of NIS/triflic acid neither the desired product was observed nor a sufficient amount of starting material was recovered (Table 2, entry 2). Applying methyltriflate and dimethyldisulfide based promotion glycosylations were successful (Table 2, entries 3–5). DMTST was freshly prepared prior to use from dimethyldisulfide and methyltriflate and obtained as salt.[82] Using the DMTST promoter system the stereoselectivity could be increased significantly, but with moderate yield of 39% (Table 2, entry 3). Reasons for this result could be side reactions with the allylic aglycon[83] and the equimolar use of the promoter (usually 4–5-fold excess).[78] In case of methyltriflate promotion indeed, the stereoselectivity was improved, but with lower yield of 21% (Table 2, entry 4). Normally, the S-methylation of thioglycosides with methyltriflate is preferred in the presence of acceptor hydroxyl groups to form the reactive glycosyl sulfoniumion.[84] In our hands O-methylation was found, which lowered the yield. A MALDI-TOF experiment of the reaction mixture showed the undesired bands of O-methylation (**32**: m/z=852.3 $[M+Na^+] \rightarrow$ **32**^{Me}: m/z=866.3 $[M+Na^+]$). The best yield and stereoselectivity was observed with the promoter system consisting of dimethyldisulfide and trifluoromethanesulfonic anhydride (Table 2, entry 5). With a yield of 67% for the trisaccharides **40**/**42** and a α/β ratio of 8.3:1 the glycosylation gave similar results as previously published by Kunz et al. for the system of $CuBr_2$ and TBAB.

Due to this satisfactory result the following glycosylations to give trisaccharides **44**, **46**, **49**, and **51** were conducted under similar conditions with the dimethyldisulfide/methyltriflate promoter system. The Le^a derivative **49** was obtained in 59% yield (α/β=7.8:1)

Table 2
Synthesis of LewisX trisaccharide analogs

Entry	Acceptor	Donor	Conditions	Product
1	**32**	**12**	$CuBr_2$, nBu_4NBr, DMF, rt, 24 h	 a) **39**: R = TES, **40**: R = Ac; **41**: R = TES, **42**: R = Ac
2	**32**	**12**	NIS, TfOH, −20 °C, DCM, 1 h	—
3	**32**	**12**	DMTST, DCM, rt, 1 h	**40**/**42** (39%, 4.3:1)
4	**32**	**12**	MeOTf, DCM, −40 °C, 1 h	**40**/**42** (67%, 8.3:1)
5	**32**	**12**	Me_2S_2–Tf_2O, DCM, −40 °C, 1 h	**40**/**42** (21%, 5.6:1)
6	**35**	**12**	Me_2S_2–Tf_2O, DCM, −40 °C, 1 h	 a) **43**: R = TES, **44**: R = Ac
7	**32**	**13**	Me_2S_2–Tf_2O, DCM, −40 °C, 1 h	 a) **45**: R = TES, **46**: R = Ac
8	**32**	**14**	Me_2S_2–Tf_2O, DCM, −40 °C, 1 h	 **47**
9	**33**	**12**	TMSOTf, DCM, −40 °C, 1 h	 a) **48**: R = TES, **49**: R = Ac
10	**37**	**15**	Me_2S_2–Tf_2O, DCM, −40 °C, 1 h	 a) **50**: R = TES, **51**: R = Ac

Reagents and condition for desilylation and re-acetylation: (a) 1. THF/H_2O, acetic acid; 2. Ac_2O, pyridine.

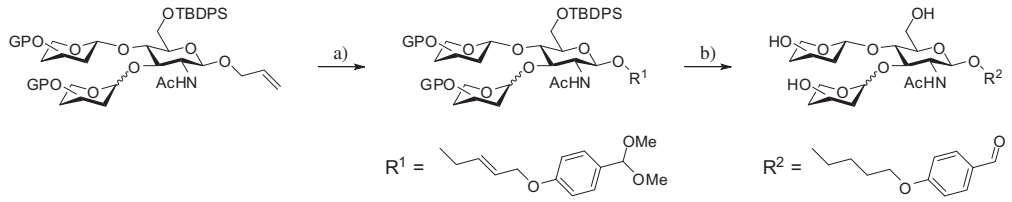
and the Le^x analogs **44** ($Le^{x\text{-}Glc}$), **46** ($Le^{x\text{-}L\text{-}Gal}$), and **51** ($Le^{x\text{-}D\rightarrow L}$) were achieved in 63% ($\alpha/\beta$=9.5:1), 53% ($\alpha/\beta$=8.7:1), and 59% ($\alpha/\beta$=6.9:1), respectively (Table 2, entries 6–8, 10). The trisaccharide **47** ($Le^{x\text{-}Rham}$) was synthesized by Schmidt glycosylation with acceptor **32** and trichloroacetimidate **14** in 42% yield (Table 2, entry 9). Due to the neighboring participation properties of the 2-*O*-acetyl group in donor **14** only the α-configuration was obtained.

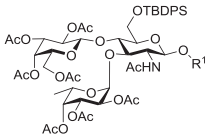
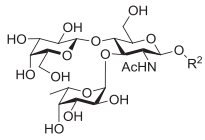
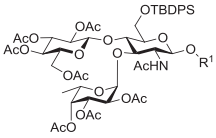
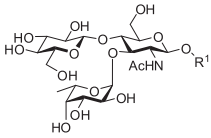
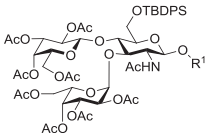
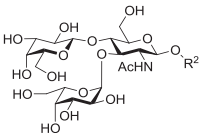
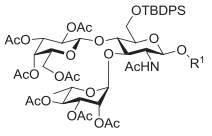
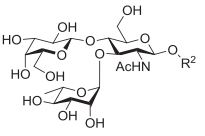
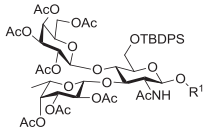
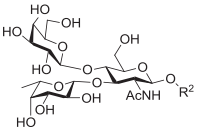
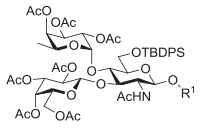
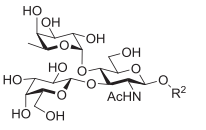
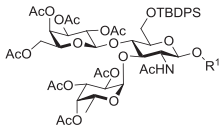
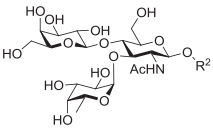
2.4. Synthesis of benzaldehyde functionalized Le^x trisaccharide analogs by cross metathesis and their deprotection

In previous publications the development, optimization as well as application of benzaldehyde functionalization of allyl glycosides toward *online*-SAM formation was shown.[30,37] This approach was also successfully applied for the functionalization of the above described allyl glycosides of Le^x analogs. For this purpose the allyl glycosides **40**, **42**, **44**, **46**, **47**, **49**, and **51** were reacted with 9–10 equiv of the benzaldehyde derivative **16** in an olefin metathesis using the Grubbs–Hoveyda second generation catalyst **17** (10 mol %) for 6 h in dichloromethane under reflux.[85–92] The benzaldehyde functionalized Le^x analogs **52**–**57** were obtained in excellent yield of 74%–87%, only in the reaction of compound **58** a moderate yield of 55% was observed (Table 3).

Finally, the seven Le^x analogs were deprotected and the double bond was hydrogenated in a four step procedure. The characterization of the target compounds **1**–**7** was carried out after complete transformation. First, the aldehyde function in the metathesis products **52**–**58** was deprotected by treatment with trifluoroacetic acid in aqueous THF for 1 h. To avoid reduction of the benzaldehyde moiety the palladium catalyst on charcoal was poisoned with

Table 3
Synthesis of benzaldehyde functionalized LewisX trisaccharide analogs and their final deprotection



Entry	Starting material	Cross metathesis product[b]	Deprotected product[c]
1	**40**	 **52** (81%)	 **1** (81%)
2	**44**	 **53** (87%)	 **2** (81%)
3	**46**	 **54** (85%)	 **3** (81%)
4	**47**	 **55** (84%)	 **4** (81%)
5	**42**	 **56** (79%)	 **5** (81%)
6	**49**	 **57** (74%)	 **6** (81%)
7	**51**	 **58** (55%)	 **7** (81%)

Reagents and conditions for cross metathesis and deprotection: (a) 9–10 equiv **16**, 10 mol % catalyst **17**, DCM, reflux, 6 h; (b) 1. THF, H_2O, TFA, rt, 1 h; 2. Pd/C, H_2, DPS, EtOAc, 24 h, rt; 3. TBAF, AcOH, THF, rt, 12 h; 4. NaOMe, MeOH, rt, 24 h.
[b] Only (*E*)-configurated products were found.
[c] Yields via four steps.

diphenylsulfide prior to use in the hydrogenation of the double bond.[93]The silyl deprotecting group was removed with TBAF and acetic acid in THF. After Zemplén deacetylation the aldehyde functionalized Le^x analogs **1**–**7** were obtained in excellent overall yields of 63%–78% (Table 3).

3. Conclusion

The Le^x trisaccharide itself as well as six non-natural analogs were synthesized by monosaccharide building block assembly. In this approach the non neighboring group TES protecting group in various fucopyranosyl and galactopyranosyl donors provided excellent stereoselectivity for the formation of the 1,2-*cis* configured anomeric bond. Followed by olefin metastasis the allylic aglycon was transformed into a benzaldehyde handle.

These benzaldehyde functionalized Le^x analogs were subjected to gold nanoparticle attachment and used in carbohydrate–carbohydrate interaction studies. The results are going to be published elsewhere in due course.

4. Experimental section

4.1. General remarks

Reagents of commercial quality were purchased from Aldrich, Sigma or Merck and were used without further purification.

Solvents were dried according to standard methods. All reactions were carried out under an argon atmosphere with dry solvents under anhydrous conditions, unless otherwise noted. Analytical thin-layer chromatography (TLC) was performed on precoated aluminum plates (Silica Gel $60F_{254}$, Merck5554), compound spots were visualized by UV light (254 nm) and by staining with a yellow solution containing $Ce(NH_4)_2(NO_3)_6$ (0.5 g) and $(NH_4)_6Mo_7O_{24}/4H_2O$ (24.0 g) in 6% H_2SO_4 (500 mL) or with 10% H_2SO_4 in ethanol followed by heat treatment. For column chromatography Silica Gel 60, 230–400 mesh, 40–63 μm (Merck) was used. ^1H NMR and ^{13}C NMR spectra were recorded on Bruker AMX-400 (400 MHz for ^1H, 100.6 MHz for ^{13}C) and on Bruker DRX-500 (500 MHz for ^1H, 125.8 MHz for ^{13}C) at 300 K. Chemical shifts were calibrated to solvent residual peaks ($CDCl_3$: δ=7.24 ppm for ^1H and δ=77.0 ppm for ^{13}C; methanol-d_4: δ=3.35 ppm for ^1H and δ=49.30 ppm for ^{13}C). The signals were assigned by ^1H–^1H-COSY, HSQC, HMBC and if necessary NOESY experiments. Hydrogen and carbon atoms are indexed as follows: the sugar residue is numbered as usual from 1 to 6 with the anomeric position being number 1, the atoms of the anomeric spacer moiety then receive numbers with index 'bu' for butyl and 'ar' for aromatic by consequent numbering starting from the glycosidic bond. Optical rotations were measured using a Krüss Optronic P8000 (589 nm) at 20 °C. MALDI-TOF-MS was performed on a BrukerBiflex III with dihydroxybenzoic acid or trihydroxyanthracene as matrices in positive reflector mode. FAB–HRMS was performed on a Thermo Finnigan MAT95 XL mass spectrometer.

4.2. General procedure for the deprotection of the benzaldehyde functionalized Le^x analogs

The metathesis products were dissolved in a mixture of THF, water, and TFA (90:9.9:0.1 v/v) to obtain a 0.2 M solution. After stirring for 1 h the reaction mixture was diluted with DCM (20 mL), and the reaction was stopped by addition of triethylamine (2 mL) followed by addition of water (20 mL). The organic layer was separated and dried over Na_2SO_4. The solvent was removed under reduced pressure and the crude product was used in the next transformation without further purification. For hydrogenolysis the aldehyde was dissolved in anhydrous EtOAc (10 mL) and put in a flame-dried flask containing palladium (10%) on charcoal and diphenylsulfite (0.01 equiv). The suspension was degassed, and after purging with hydrogen the mixture was stirred for 12 h. Then the suspension was filtered and thoroughly dried before the residue was redissolved in dry THF (5–10 mL) and cooled to 0 °C followed by addition of 5 equiv acetic acid. After warming to room temperature 1.2 equiv of 1 M TBAF solution in THF were added. The mixture was stirred over night. After TLC control the reaction was quenched by addition of brine. The aqueous phase was extracted with ethyl acetate (4×100 mL). The combined organic layers were concentrated and redissolved in methanolic sodium methoxide solution (20 mL, 0.1 M). The solution was stirred for 6 h at room temperature and the mixture was neutralized with Amberlite IR 120 (H^+) resin. After filtration and evaporation of the solvent the crude product was purified by flash chromatography using silica and dichloromethane/methanol (3:1).

*4.2.1. 4-(4-Formylphenoxy)-butyl 2-acetamido-2-deoxy-3-O-(α-L-fucopyranosyl)-4-O-(β-D-galactopyranosyl)-β-D-glucopyranoside (**1**).* Obtained from compound **52** (700 mg, 546 μmol) as a colorless solid (243 mg, 63%). R_f=0.25 (DCM/MeOH 2:1); mp 209 °C, $[\alpha]_D^{20}$ +15.1 (*c* 0.2, H_2O); ^1H NMR (500 MHz, D_2O) δ=9.80 (s, 1H, H_{ald}), 7.86 (d, $^3J_{Ar}$=8.7 Hz, 1H, H-1_{arom}), 7.12 (d, $^3J_{Ar}$=8.7 Hz, 1H, H-2_{arom}), 5.03 (d, 1H, $^3J_{1',2'}$=3.5 Hz, H-1′), 4.76 (m, 1H, H-5′), 4.40 (d, 1H, $^3J_{1,2}$=7.5 Hz, H-1), 4.38 (d, 1H, $^3J_{1'',2''}$=8.0 Hz, H-1″), 4.10 (t, $^3J_{3bu,4bu}$=6.6 Hz, 2H, H-4_{bu}), 4.00–3.98 (m, 1H, H-$1a_{bu}$), 3.94–3.92 (m, 1H, H-5), 3.90–3.75 (m, 5H, H-3, H-4, H-3″, H-6ab), 3.72 (m, 1H, H-2), 3.70–3.58 (m, 4H, H-6ab″, H-3′, H-4″), 3.57 (d, 1H, $^3J_{3',4'}$=3.5 Hz, H-4′), 3.53–3.50 (m, 2H, H-2′, H-2″), 1.95 (s, 3H, NHAc), 1.94–1.87 (m, 2H, H-3_{bu}), 1.85–1.75 (m, 2H, H-2_{bu}), 1.10 (d, 3H, $^3J_{5',6'}$=7.0 Hz, H-6′) ppm; ^{13}C NMR (126 MHz, D_2O) δ=192.3 (C_{ald}),173.9 (COHN), 133.0 (C_{arom}), 115.5 (C_{arom}), 103.9 (C-1), 103.2 (C-1″), 100.4 (C-1′), 77.4 (C-4), 76.7 (C-5), 76.6 (C-3), 75.2 (C-5″), 74.9 (C-4″), 73.7 (C-5′), 72.7 (C-4′), 72.0 (C-1_{bu}), 71.5 (C-3′), 71.2 (C-3″), 70.2 (C-4_{bu}), 70.0 (C-2′), 67.7 (C-2″), 62.8 (C-6″), 61.3 (C-6), 57.3 (C-2), 27.1 (C-3_{bu}), 26.0 (C-2_{bu}), 23.0 (C_{Ac}),16.6 (C-6′); HRMS (ESI): calcd for $C_{31}H_{47}NO_{17}Na^+$: 728.2742, found: 728.2830 $[M+Na]^+$.

*4.2.2. 4-(4-Formylphenoxy)-butyl 2-acetamido-2-deoxy-3-O-(α-L-fucopyranosyl)-4-O-(β-D-glucopyranosyl)-β-D-glucopyranoside (**2**).* Obtained from compound **53** (300 mg, 234 μmol) as a colorless solid (112 mg, 68%). R_f=0.29 (DCM/MeOH 2:1); mp 197 °C, $[\alpha]_D^{20}$ +25.4 (*c* 0.2, H_2O); ^1H NMR (500 MHz, D_2O) δ=9.79 (s, 1H, H_{ald}), 7.86 (d, $^3J_{Ar}$=8.8 Hz, 1H, H-1_{arom}), 7.12 (d, $^3J_{Ar}$=8.8 Hz, 1H, H-2_{arom}), 4.99 (d, 1H, $^3J_{1',2'}$=3.5 Hz, H-1′), 4.76 (m, 1H, H-5′), 4.44 (d, 1H, $^3J_{1'',2''}$=8.8 Hz, H-1″), 4.40 (d, 1H, $^3J_{1,2}$=7.6 Hz, H-1), 4.10 (t, $^3J_{3bu,4bu}$=6.6 Hz, 2H, H-4_{bu}), 4.00–3.98 (m, 1H, H-$1a_{bu}$), 3.94–3.92 (m, 1H, H-5), 3.90–3.75 (m, 6H, H-3, H-4, H-4′, H-3″, H-6ab), 3.72 (m, 1H, H-2), 3.70–3.58 (m, 4H, H-6ab″, H-3′, H-4″), 3.55–3.50 (m, 3H, H-2′, H-4′, H-2″), 1.95 (s, 3H, NHAc), 1.94–1.87 (m, 2H, H-3_{bu}), 1.85–1.75 (m, 2H, H-2_{bu}), 1.15 (d, 3H, $^3J_{5',6'}$=6.6 Hz, H-6′) ppm; ^{13}C NMR (126 MHz, D_2O) δ=192.3 (C_{ald}),173.9 (COHN), 133.0 (C_{arom}), 115.5 (C_{arom}), 103.5 (C-1′), 100.7 (C-1), 100.4 (C-1′), 77.4 (C-4), 76.7 (C-5), 76.6 (C-3), 75.2 (C-5″), 73.7 (C-5′), 72.7 (C-4′), 72.0 (C-1_{bu}), 71.29(C-3″), 71.5 (C-3′), 70.2 (C-4_{bu}), 70.1 (C-4″), 70.0 (C-2′), 67.7 (C-2″), 62.8 (C-6″), 61.3 (C-6), 57.2 (C-2), 27.1 (C-3_{bu}), 26.0 (C-2_{bu}), 23.0 (C_{Ac}),16.7 (C-6′); HRMS (ESI): calcd for $C_{31}H_{47}NO_{17}Na^+$: 728.2742, found: 728.2711 $[M+Na]^+$.

*4.2.3. 4-(4-Formylphenoxy)-butyl 2-acetamido-2-deoxy-3-O-(α-L-galactopyranosyl)-4-O-(β-D-galactopyranosyl)-β-D-glucopyranoside (**3**).* Obtained from compound **54** (445 mg, 332 μmol) as a colorless solid (168 mg, 70%). R_f=0.16 (DCM/MeOH 2:1); mp 244 °C, $[\alpha]_D^{20}$ −1.2 (*c* 0.1, H_2O); ^1H NMR (500 MHz, D_2O) δ=9.81 (s, 1H, H_{ald}), 7.84 (d, $^3J_{Ar}$=8.8 Hz, 1H, H-1_{arom}), 7.07 (d, $^3J_{Ar}$=8.8 Hz, 1H, H-2_{arom}), 4.99 (d, $^3J_{1',2'}$=3.8 Hz, 1H, H-1′), 4.59 (d, $^3J_{1,2}$=8.4 Hz, 1H, 1H), 4.48 (d, $^3J_{1'',2''}$=7.6 Hz, 1H, H-1″), 4.12 (t, $^3J_{3bu,4bu}$=6.7 Hz, 2H, H-4_{bu}), 4.00–3.92 (m, 3H, H-5, H-6a, H-$1a_{bu}$), 3.90–3.80 (m, 6H, H-4, H-3′, H-4″, H-6b, H-6a′), 3.79–3.75 (m, 4H, H-2, H-4′, 2×H-6ab″), 3.72–3.66 (m, 1H, H-6b′, H-$1b_{bu}$), 3.65–3.58 (m, 3H, H-3, H-3″, H-5″), 3.58–3.47 (m, 3H, H-5′, H-2′, H-2″), 2.02 (s, 3H, H_{Ac}), 1.96–1.87 (m, 2H, H-3_{bu}), 1.85–1.75 (m, 2H, H-2_{bu}) ppm;. ^{13}C NMR (126 MHz, D_2O) δ=192.9 (C_{ald}), 176.8 (CONH), 133.1 (C_{arom}), 116.0 (C_{arom}), 106.1 (C-1), 103.9 (C-1″) 101.3 (C-1′), 82.1 (C-4), 77.2 (C-5), 76.9 (C-3), 76.6 (C-5″), 76.5 (C-5′), 74.1 (C-4″), 73.6 (C-2), 72.9 (C-2″), 72.8 (C-2′), 72.5 (C-4′), 72.4 (C-3′), 71.7 (C-1_{bu}), 70.3 (C-4_{bu}), 70.0 (C-3″), 62.6 (C-6′), 62.3 (C-6″), 61.1 (C-6), 56.2 (C-2), 27.2 (C-3_{bu}), 26.9 (C-2_{bu}), 23.9 (C_{Ac}) ppm; HRMS (ESI): calcd for $C_{31}H_{47}NO_{17}Na^+$: 744.2961, found: 744.3010 $[M+Na]^+$.

*4.2.4. 4-(4-Formylphenoxy)-butyl 2-acetamido-2-deoxy-3-O-(α-L-rhamnopyranosyl)-4-O-(β-D-galactopyranosyl)-β-D-glucopyranoside (**4**).* Obtained from compound **56** (540 mg, 422 μmol) as a solid (209 mg, 70%). R_f=0.19 (DCM/MeOH 2:1); mp 187 °C; $[\alpha]_D^{20}$ +6.6 (*c* 0.2, H_2O); ^1H NMR (500 MHz, D_2O) δ=9.80 (s, 1H, H_{ald}), 7.86 (d, $^3J_{Ar}$=8.7 Hz, 1H, H-1_{arom}), 7.12 (d, $^3J_{Ar}$=8.7 Hz, 1H, H-2_{arom}), 5.23 (d, 1H, $^3J_{1',2'}$=1.8 Hz, H-1′), 4.76 (m, 1H, H-5′), 4.45 (d, 1H, $^3J_{1,2}$=8.0 Hz, H-1), 4.39 (dq, $^3J_{5',6'}$=7.0, $^3J_{4',5'}$=9.7 Hz, 1H, H-5′), 4.33 (d, 1H, $^3J_{1'',2''}$=8.1 Hz, H-1″), 4.10 (t, $^3J_{3bu,4bu}$=6.6 Hz, 2H, H-4_{bu}), 4.00–3.92 (m, 2H, H-5, H-$1a_{bu}$), 3.90–3.75 (m, 5H, H-3, H-4, H-3″, H-6ab), 3.74 (m, 1H, H-2), 3.70–3.58 (m, 4H, H-6ab″, H-3′, H-4″), 3.57 (d, 1H, $^3J_{3',4'}$=3.5 Hz, H-4′), 3.53–3.50 (m, 2H, H-2′, H-2″), 1.95 (s, 3H, NHAc), 1.94–1.87 (m, 2H, H-3_{bu}), 1.85–1.75 (m, 2H,

H-2$_{bu}$), 1.18 (d, 3H, $^3J_{5',6'}$=7.0 Hz, H-6′) ppm; ^{13}C NMR (126 MHz, D_2O) δ=192.3 (C_{ald}),173.9 (COHN), 133.0 (C_{arom}), 115.7 (C_{arom}), 103.1 (C-1), 102.9 (C-1″), 102.3 (C-1′), 76.4 (C-4), 76.0 (C-5), 76.6 (C-3), 75.6 (C-5′), 75.2 (C-5″), 74.9 (C-4″), 72.7 (C-4′), 72.5 (C-2′), 72.0 (C-1$_{bu}$), 71.5 (C-3′), 71.2 (C-3″), 70.2 (C-4$_{bu}$), 67.7 (C-2″), 62.8 (C-6″), 61.3 (C-6), 57.3 (C-2), 27.2 (C-3$_{bu}$), 26.6 (C-2$_{bu}$), 23.1 (C_{Ac}),20.1 (C-6′); HRMS (ESI): calcd for $C_{31}H_{47}NO_{17}Na^+$: 728.2742, found: 728.2738 $[M+Na]^+$.

*4.2.5. 4-(4-Formylphenoxy)-butyl 2-acetamido-2-deoxy-3-O-(β-L-fucopyranosyl)-4-O-(β-D-galactopyranosyl)-β-D-glucopyranoside (**5**).* Obtained from compound **57** (169 mg, 132 μmol) as a solid (63 mg, 68%). R_f=0.27 (DCM/MeOH 2:1); mp 198 °C, $[\alpha]_D^{20}$ +7.6 (*c* 0.1, H_2O); ^{1}H NMR (500 MHz, D_2O) δ=9.80 (s, 1H, H_{ald}), 7.86 (d, $^3J_{Ar}$=8.7 Hz, 1H, H-1$_{arom}$), 7.12 (d, $^3J_{Ar}$=8.7 Hz, 1H, H-2$_{arom}$), 4.56 (m, 1H, H-5′), 4.40 (d, 1H, $^3J_{1,2}$=7.5 Hz, H-1), 4.38 (d, 1H, $^3J_{1'',2''}$=8.0 Hz, H-1″), 4.33 (d, 1H, $^3J_{1',2'}$=7.5 Hz, H-1′), 4.12 (t, $^3J_{3bu,4bu}$=6.6 Hz, 2H, H-4$_{bu}$), 4.01–3.98 (m, 1H, H-1a$_{bu}$), 3.92–3.75 (m, 6H, H-3, H-4, H-5, H-3″, H-6ab), 3.72 (m, 1H, H-2), 3.70–3.58 (m, 4H, H-6ab″, H-3′, H-4″), 3.57 (d, 1H, $^3J_{3',4'}$=3.4 Hz, H-4′), 3.53–3.50 (m, 2H, H-2′, H-2″), 1.95 (s, 3H, NHAc), 1.94–1.87 (m, 2H, H-3$_{bu}$), 1.85–1.75 (m, 2H, H-2$_{bu}$), 1.27 (d, 3H, $^3J_{5',6'}$=6.3 Hz, H-6′) ppm; ^{13}C NMR (126 MHz, D_2O) δ=192.3 (C_{ald}),173.9 (COHN), 133.0 (C_{arom}), 115.5 (C_{arom}), 103.9 (C-1), 103.2 (C-1), 102.9 (C-1′), 77.4 (C-4), 76.7 (C-5), 76.6 (C-3), 75.2 (C-5″), 74.9 (C-4″), 73.7 (C-5′), 72.7 (C-4′), 72.0 (C-1$_{bu}$), 71.5 (C-3′), 71.2 (C-3″), 70.2 (C-4$_{bu}$), 70.0 (C-2′), 67.7 (C-2″), 62.8 (C-6″), 61.3 (C-6), 57.3 (C-2), 27.1 (C-3$_{bu}$), 26.0 (C-2$_{bu}$), 23.0 (C_{Ac}),16.6 (C-6′); HRMS (ESI): calcd for $C_{31}H_{47}NO_{17}Na^+$: 728.2742, found: 728.2830 $[M+Na]^+$.

*4.2.6. 4-(4-Formylphenoxy)-butyl 2-acetamido-2-deoxy-4-O-(α-L-fucopyranosyl)-3-O-(β-D-galactopyranosyl)-β-D-glucopyranoside (**6**).* Obtained from compound **58** (255 mg, 199 μmol) as a solid (109 mg, 78%). R_f=0.20 (DCM/MeOH 2:1); mp 201 °C, $[\alpha]_D^{20}$ −29.0 (*c* 0.2, H_2O); ^{1}H NMR (500 MHz, D_2O) δ=9.80 (s, 1H, H_{ald}), 7.86 (d, $^3J_{Ar}$=8.7 Hz, 1H, H-1$_{arom}$), 7.12 (d, $^3J_{Ar}$=8.7 Hz, 1H, H-2$_{arom}$), 5.05 (d, 1H, $^3J_{1',2'}$=3.5 Hz, H-1′), 4.65 (m, 1H, H-5′), 4.51 (d, 1H, $^3J_{1'',2''}$=8.9 Hz, H-1″), 4.39 (d, 1H, $^3J_{1,2}$=7.5 Hz, H-1), 4.10 (t, $^3J_{3bu,4bu}$=6.6 Hz, 2H, H-4$_{bu}$), 4.00–3.98 (m, 1H, H-1a$_{bu}$), 3.94–3.92 (m, 1H, H-5), 3.90–3.75 (m, 5H, H-3, H-4, H-3″, H-6ab), 3.73–3.69 (m, 1H, H-2, H-3′), 3.66–3.58 (m, 4H, H-6ab″, H-4′, H-4″), 3.53–3.50 (m, 2H, H-2′, H-2″), 1.93 (s, 3H, NHAc), 1.94–1.87 (m, 2H, H-3$_{bu}$), 1.80–1.70 (m, 2H, H-2$_{bu}$), 1.13 (d, 3H, $^3J_{5',6'}$=7.4 Hz, H-6′) ppm; ^{13}C NMR (126 MHz, D_2O) δ=192.1 (C_{ald}),173.5 (COHN), 133.0 (C_{arom}), 115.5 (C_{arom}), 103.9 (C-1), 103.2 (C-1″), 100.4 (C-1′), 76.9 (C-3), 76.7 (C-5), 76.0 (C-4), 75.2 (C-5″), 74.9 (C-4″), 73.7 (C-5′), 72.7 (C-4′), 72.0 (C-1$_{bu}$), 71.5 (C-3′), 71.2 (C-3″), 70.2 (C-4$_{bu}$), 70.0 (C-2′), 67.7 (C-2″), 62.8 (C-6″), 61.3 (C-6), 57.3 (C-2), 27.1 (C-3$_{bu}$), 26.0 (C-2$_{bu}$), 23.0 (C_{Ac}),16.6 (C-6′); HRMS (ESI): calcd for $C_{31}H_{47}NO_{17}Na^+$: 728.2742, found: 728.2744 $[M+Na]^+$.

*4.2.7. 4-(4-Formylphenoxy)-butyl 2-acetamido-2-deoxy-3-O-(α-D-fucopyranosyl)-4-O-(β-L-galactopyranosyl)-β-D-glucopyranoside (**7**).* Obtained from compound **59** (218 mg, 170 μmol) as a solid (87 mg, 73%). R_f=0.23 (DCM/MeOH 2:1); mp 160 °C, $[\alpha]_D^{20}$ −32.0 (*c* 0.2, H_2O); ^{1}H NMR (500 MHz, D_2O) δ=9.80 (s, 1H, H_{ald}), 7.86 (d, $^3J_{Ar}$=8.7 Hz, 1H, H-1$_{arom}$), 7.12 (d, $^3J_{Ar}$=8.7 Hz, 1H, H-2$_{arom}$), 5.05 (d, $^3J_{1',2'}$=4.0 Hz, H-1, H-1′), 4.79 (dd, 1H, H-5′), 4.49 (d, $^3J_{1,2}$=8.4 Hz, 1H, H-1), 4.40 (d, $^3J_{1'',2''}$=8.4 Hz, 1H, H-1″), 4.10 (t, $^3J_{3bu,4bu}$=6.6 Hz, 2H, H-4$_{bu}$), 3.91 (dd, $^3J_{1'',2''}$=8.4, $^3J_{2'',3''}$=10.8 Hz, 1H, H-2″), 3.89–3.85 (m, 5H, H-2, H-6a, H-3′, 4″, H-1a$_{bu}$), 3.82 (dd, $^3J_{3,4}$=9.0, $^3J_{4,5}$=9.0 Hz, H-4), 3.78 (dd, $^3J_{2,3}$=8.5, $^3J_{3,4}$=9.0 Hz, 1H, H-3), 3.76–3.74 (m, 2H, H-4′, H-1b$_{bu}$), 3.71 (dd, $^3J_{5'',6''}$=7.8, $^3J_{6a'',6b''}$=11.6 Hz, 1H, H-6a″), 3.68–3.64 (m, 4H, H-3, H-2′, H-6b, H-6b″), 3.52–3.50 (m, 1H, H-5″), 3.45 (ddd, $^3J_{5,6a}$=3.4, $^3J_{5,6b}$=6.8, $^3J_{4,5}$=9.0 Hz, 1H, H-5), 1.99 (s, 3H, NHAc), 1.94–1.87 (m, 2H, H-3$_{bu}$), 1.85–1.75 (m, 2H, H-2$_{bu}$), 1.20 (d, $^3J_{5',6'}$=6.6 Hz, 3H, H-6′) ppm. HRMS (ESI): calcd for $C_{31}H_{47}NO_{17}Na^+$: 728.2742, found: 728.2720 $[M+Na]^+$.

4.3. Synthesis of monosaccharide building blocks

The glycosyl acceptor **8**[52] and the glycosyl donors **9**,[94] **10**,[94] and **14**[95] were synthesized according to previously published procedures.

*4.3.1. 2,3,4,6-Tetra-O-acetyl-α-L-galactopyranosyl trichloroacetimidate (**11**).* Compound **20**[42] (1.50 g, 3.82 mmol) was dissolved in THF /water (9:1, 50 mL) and cooled with an ice bath followed by addition of NIS (1.03 g, 4.58 mmol) and TfOH (43 μL, 382 μmol). After 30 min the ice bath was removed. Complete conversion of the starting material was observed by TLC analysis after (petroleum/ethyl acetate, 1:1). The reaction mixture was neutralized by addition of $NaHCO_3$ (500 mg) and diluted with DCM (150 mL). The organic phase was washed with water (100 mL) and brine (100 mL). The solvent was removed under reduced pressure and the crude compound **21** was used in next steps without further purification. Compound **21** (1.33 g, 3.82 mmol), trichloroacetonitrile 5.00 mL (26.2 g, 5.01 mmol) were dissolved in anhydrous DCM containing activated molecular sieve and stirred for 30 min at room temperature. The mixture was cooled to 0 °C followed by addition of a catalytic amount of DBU (ca. 0.4 equiv). After 2 h the mixture was concentrated and the crude was purified by column chromatography on silica using petroleum/ethyl acetate (2:1+0.2% triethylamine). Compound **11** was obtained as a colorless solid (1.34 g, 71%). R_f=0.57 (PE/EA 2:1), mp 90 °C, $[\alpha]_D^{20}$ −113.6 (*c* 1.0, $CHCl_3$), for D enantiomer: $[\alpha]_D^{20}$ +115.0 (*c* 1.0, $CHCl_3$);[96] NMR data are according to compound **9**.[96]

*4.3.2. Thioethyl 2,3,4-tri-O-triethylsilyl-β-L-fucopyranoside (**12**).* Compound **24** (2.00 g, 5.98 mmol) was reacted with a catalytic amount sodium methoxide in anhydrous methanol for 12 h. After neutralization with Amberlite IR 120 H^+ the mixture was filtered. After concentration the filtrate crude compound **22** (1.19 g, 96%) was obtained and used without further purification in next step. To a solution of compound **25** (1.15 g, 5.13 mmol) and a catalytic amount of DMAP in anhydrous pyridine (15 mL) TESCl (5.85 mL, 33.1 mmol) was added at 0 °C and the mixture was stirred over night. After TLC analysis (petroleum/ethyl acetate, 3:1) the solvent was removed under reduced pressure and the residue was dissolved in DCM (100 mL). After washing with 1 M HCl (2×100 mL), saturated $NaHCO_3$ solution (100 mL), and brine (100 mL) the organic phase was concentrated. The crude was purified by column chromatography on silica using petroleum ether/ethyl acetate (4:1). Compound **12** was obtained as syrup (2.55 g, 84%). R_f=0.47 (PE/EE 3:1), $[\alpha]_D^{20}$ −28.3 (*c* 1.0, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ=4.18 (d, $^3J_{1,2}$=8.8 Hz, 1H, H-1), 3.81 (dd, $^3J_{1,2}$=8.8, $^3J_{2,3}$=8.7 Hz, 1H, H-2), 3.64 (d, $^3J_{3,4}$=2.2 Hz, 1H, H-4), 3.51 (q, $^3J_{5,6}$=6.3 Hz, 1H, H-5), 3.45 (dd, $^3J_{3,4}$=2.2, $^3J_{2,3}$=8.7 Hz, 1H, H-3), 2.77–2.56 (m, 2H, SCH_2CH$_3$), 1.26 (t, $^3J_{SEt}$=7.4 Hz, 3H, SCH$_2$CH_3), 1.20 (d, $^3J_{5,6}$=6.3 Hz, 3H, H-6), 1.06–0.90 (m, 27H, SiCH$_2$CH_3), 0.81–0.56 (m, 18H, SiCH_2CH$_3$) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) δ=86.5 (C-1), 78.0 (C-3), 74.8 (C-4), 74.6 (C-5), 71.2 (C-2), 24.4 (SCH_2CH$_3$), 17.5 (C-5), 14.8 (SCH$_2$CH_3), 7.3–6.8 (SiCH$_2$CH_3), 5.9–4.6 (SiCH_2CH$_3$) ppm; MALDI-TOF: *m*/*z* calcd for $C_{26}H_{58}SSi_3O_4$: 550.34, found: 573.7 $[M+Na]^+$.

*4.3.3. Thioethyl 2,3,4,6-tetra-O-triethylsilyl-β-L-galactopyranoside (**13**).* According to the synthesis of compound **12** the thioglycoside **20** (2.00 g, 5.09 mmol) was reacted with a catalytic amount sodium methoxide in anhydrous methanol. Then, the crude compound **22** (1.15 g, 5.09 mmol) and a catalytic amount

of DMAP in anhydrous pyridine (15 mL) were reacted with TESCl (6.00 mL, 34.0 mmol) to obtain compound **13** as a colorless syrup (2.76 g, 79%, only β). R_f=0.43 (PE/EE 3:1), $[\alpha]_D^{20}$ +8.2 (*c* 1.0, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ=4.23 (d, $^3J_{1,2}$=8.2 Hz, 1H, H-1), 3.86 (dd, $^3J_{1,2}$=8.2, $^3J_{2,3}$=8.8 Hz, 1H, H-2), 3.64 (d, $^3J_{3,4}$=2.9 Hz, 1H, H-4), 3.51 (ddd, $^3J_{4,5}$=0.9 Hz, $^3J_{5,6}$=5.9 Hz, 1H, H-5), 3.48 (m, 2H, H-6ab), 3.45 (dd, $^3J_{3,4}$=2.2, $^3J_{2,3}$=8.7 Hz, 1H, H-3), 2.77–2.56 (m, 2H, SCH_2CH_3), 1.26 (t, $^3J_{SEt}$=7.4 Hz, 3H, SCH_2CH_3), 1.10–0.85 (m, 36H, $SiCH_2CH_3$), 0.82–0.51 (m, 24H, $SiCH_2CH_3$) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) δ=86.5 (C-1), 78.0 (C-3), 74.8 (C-4), 74.6 (C-5), 71.2 (C-2), 24.4 (SCH_2CH_3), 17.5 (C-5), 14.8 (SCH_2CH_3), 7.3–6.8 ($SiCH_2CH_3$), 5.9–4.6 ($SiCH_2CH_3$) ppm; HRMS (ES): *m*/*z* calcd for $C_{32}H_{72}O_5SSi_4$: 703.4070 [M+Na]; found: 703.4222 [M+Na].

*4.3.4. Thioethyl 2,3,4-tri-O-triethylsilyl-β-D-fucopyranoside (**15**).* According to the synthesis of compound **12** the thioglycoside **30** (288 mg, 861 μmol) was reacted with a catalytic amount sodium methoxide in anhydrous methanol. Then, the crude compound **31** (180 mg, 864 μmol) and a catalytic amount of DMAP in anhydrous pyridine (5 mL) were reacted with TESCl (1.0 mL, 5.7 mmol) to obtain compound **15** as a colorless syrup (410 mg, 86%). R_f=0.48 (PE/EE 3:1), $[\alpha]_D^{20}$ +22.7 (*c* 1.0, $CHCl_3$); NMR data are according to compound **12**.

*4.3.5. 1,2;3,4-Di-isopropylidene-6-O-thiocarbonylimidazoyl-α-D-galactopyranose (**27**).* Under argon atmosphere 1,2;3,4-di-*O*-isopropylidene-α-D-galactopyranose (**26**) (5.30 g, 20.4 mmol) and 1,1′-thiocarbonyldiimidazol (TCDI, 8.71 g, 48.9 mmol) were dissolved in anhydrous THF (80 mL) and stirred for 40 h at room temperature. The solvent was removed under reduced pressure. The residue was dissolved in DCM (150 mL) and the organic phase was extracted three times with 0.1 M hydrochloric acid (15 mL), neutralized saturated sodium hydrogen carbonate solution (25 mL) and washed with water (50 mL). The organic layer was dried over sodium sulfate and concentrated under reduced pressure. The crude was purified by column chromatography on silica using petroleum ether/ethyl acetate (PE 100%→PE/EA 1:1). Compound **27** was obtained as colorless oil (4.50 g, 60%). R_f=0.60 (PE/EA 1:1), $[\alpha]_D^{20}$ −31.5 (*c* 1.0, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ=8.34 (s, 1H, H_{Im2}), 7.61 (s, 1H, H_{Im4}), 7.05 (s, 1H, H_{Im5}), 5.55 (d, $^3J_{1,2}$=5.0 Hz, 1H, H-1), 4.85 (m, 1H, H-6a), 4.73 (m, 1H, H-6b), 4.67 (dd, $^3J_{2,3}$=2.5, $^3J_{3,4}$=7.7 Hz, 1H, H-3), 4.37 (dd, $^3J_{2,3}$=2.5, $^3J_{1,2}$=5.0 Hz, 1H, H-2), 4.30–4.25 (m, 2H, H-4, H-5), 1.51 (s, 3H, CH_3), 1.47 (s, 3H, CH_3), 1.35 (s, 3H, CH_3), 1.34 (s, 3H, CH_3) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) δ=184.4 (C=S), 136.2 (C_{Im2}), 131.2 (C_{Im2}), 118.9 (C_{Im4}), 110.5 (C_{Isop}), 109.5 (C_{Isop}), 96.4 (C-1), 72.7 (C-6), 71.7 (C-3), 71.5 (C-2), 70.6 (C-4), 66.5 (C-5), 26.8 (CH_3), 26.6 (CH_3), 25.4 (CH_3), 24.1 (CH_3) ppm.

*4.3.6. 1,2;3,4-Di-O-isopropylidene-α-D-fucopyranose (**28**).* Under Schlenk conditions tributyltin hydride (4.0 mL, 15 mmol) in anhydrous and degassed toluene (80 mL) was heated to reflux in flame dried glassware. To this solution compound **27** (2.00 g, 5.60 mmol) in anhydrous and degassed toluene (20 mL) was added dropwise over a period of 60 min. The reaction mixture was stirred for 15 h under reflux. Then the solvent was removed under reduced pressure and the residue was extracted three times with hot acetonitrile (100 mL). The acetonitrile phase was two times washed with petroleum (150 mL) and subsequently concentrated. The crude was purified by column chromatography on silica using petroleum/ethyl acetate (PE 100%→PE/EA 2:1). Compound **28** was obtained as colorless oil with contamination (511 mg, ~30%, product/contamination ratio 4:1, determined by ^{1}H NMR). R_f=0.85 (PE/EE 2:1), clearly verified signals: ^{1}H NMR (400 MHz, $CDCl_3$) δ=5.52 (d, $^3J_{1,2}$=5.1 Hz, 1H, H-1), 3.91 (dq, $^3J_{5,6}$=0.8, $^3J_{5,6}$=6.6 Hz, 1H, H-5), 1.25 (d, $^3J_{5,6}$=6.6 Hz, 3H, H-6) ppm; MALDI-TOF: *m*/*z* calcd for $C_{12}H_{20}O_5$: 244.13, found: 267.12 $[M+Na]^+$.

*4.3.7. Thioethyl 2,3,4-tri-O-acetyl-β-D-fucopyranoside (**30**).* Compound **28** (500 mg, 2.05 mmol) was suspended in 0.2 M H_2SO_4 (100 mL, 20 mmol) and stirred for 12 h to 60 °C. TLC analysis indicated complete conversion of the starting material (PE/EA 1:1). After cooling to room temperature the reaction mixture was neutralized by addition of barium hydroxide (3.24 g, 21 mmol). The precipitated $BaSO_4$ was filtered and the filtrate was lyophilized. Compound **29** was obtained as a colorless solid (560 mg, quant, containing salts) and used without further purification and characterization in the next step. Compound **29** (560 mg) was acetylated using acetic anhydride and pyridine. The corresponding 1,2,3,4-tetra-*O*-acetyl-α/β-D-fucopyranose was obtained after column chromatography on silica using petroleum ether/ethyl acetate (1:1) as colorless syrup (416 mg, 61%, β/α-ratio: 2:1). R_f=0.58 (PE/EE 1:1), β: ^{1}H NMR (500 MHz, $CDCl_3$) δ=5.67 (d, $^3J_{1,2}$=8.31 Hz, 1H, H-1), 5.34–5.28 (m, 1H, H-2), 5.26 (dd, $^3J_{4,5}$=0.8, $^3J_{3,4}$=3.4 Hz, 1H, H-4), 5.06 (dd, $^3J_{3,4}$=3.4, $^3J_{2,3}$=10.4 Hz, 1H, H-3), 3.95 (dq, $^3J_{4,5}$=0.8, $^3J_{5,6}$=6.4 Hz, 1H, H-5), 2.18 (s, 3H, H_{Ac}), 2.10 (s, 3H, H_{Ac}), 2.03 (s, 3H, H_{Ac}), 1.98 (s, 3H, H_{Ac}), 1.22 (d, $^3J_{5,6}$=6.4 Hz, 3H, H-6) ppm. 1,2,3,4-Tetra-*O*-acetyl-α/β-D-fucopyranose (400 mg, 1.20 mmol), ethanethiol (130 μL, 2.41 mmol), and borontrifluoride etherate (380 μL 2.40 mmol) were reacted for 2 h in DCM (5 mL) at 0 °C and additional 18 h at room temperature. After aqueous work up the crude was purified by column chromatography on silica using petroleum ether/ethyl acetate (1:1). Compound **30** was obtained as a yellowish syrup (320 mg, 80%). R_f=0.37 (PE/EA 2:1); $[\alpha]_D^{20}$ +3.6 (*c* 1.0, $CHCl_3$); NMR data are according to compound **24**.[97]

4.4. Synthesis of disaccharide intermediates

*4.4.1. Allyl 2-acetamido-4-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-β-D-glucopyranoside (**32**), allyl 2-acetamido-3-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-β-D-glucopyranoside (**33**), and allyl 2-acetamido-3,4-di-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-β-D-glucopyranoside (**34**). Method A*: To a solution of acceptor **8** (200 mg, 400 μmol) and trichloroacetimidate **9** (295 mg, 600 μmol) in anhydrous DCM (10 mL) was added activated powdered molecular sieve (4 Å, 500 mg) under argon atmosphere. After stirring for 2 h at room temperature the mixture was cooled to −45 °C followed by addition of borontrifluoride etherate (50 μL, 57 mg, 0.40 mmol). After TLC analysis (EA) the reaction was quenched by addition of triethylamine (1 mL). The mixture was diluted with DCM (10 mL) and filtered over Celite followed by washing with 1 M HCl, saturated $NaHCO_3$ solution, and water. The organic layer was dried over Na_2SO_4 and concentrated. The desired product **32** (143 mg, 43%) was obtained after column chromatography on silica using DCM /methanol (30:1) besides compounds **33** (77 mg, 23%) and **34** (74 mg, 16%).

Method B: To a solution of acceptor **8** (200 mg, 400 μmol) and trichloroacetimidate **9** (295 mg, 600 μmol) in anhydrous DCM (6 mL) was added activated powdered molecular sieve (4 Å, 500 mg) under argon atmosphere. After stirring for 2 h at room temperature the mixture was cooled to −20 °C followed by dropwise addition of trimethylsilyl triflate (7.2 μL, 8.9 mg, 40 μmol). After TLC analysis (EA) the reaction was quenched by addition of triethylamine (1 mL). The mixture was diluted with DCM (10 mL) and filtered over Celite followed by washing with 1 M HCl, saturated $NaHCO_3$ solution, and water. The organic layer was dried over Na_2SO_4 and concentrated. The desired product **32** (186 mg, 56%) was obtained after column chromatography on silica using DCM /methanol (30:1) besides compounds **33** (63 mg, 19%) and **34**

(32 mg, 7%). For **32**: $[\alpha]_D^{20}$ −3.4 (*c* 1.0, $CHCl_3$), ^1H NMR (500 MHz, $CDCl_3$) δ=7.77–7.65 (m, 4H, H_{arom}), 7.49–7.32 (m, 6H, H_{arom}), 5.89 (ddd, $^3J_{1,2all}$=5.0, $^3J_{all\text{-}cis}$=10.7, $^3J_{all\text{-}trans}$=16.6 Hz, 1H, H-2$_{all}$, H-2$_{all}$), 5.70 (d, $^3J_{2,NH}$=7.1 Hz, 1H, H_{NAc}), 5.36 (d, $^3J_{3',4'}$=3.0 Hz, 1H, H-4′), 5.26 (dd, $^3J_{all\text{-}trans}$=16.6 Hz, 1H, H-3a$_{all}$), 5.22–5.15 (m, 2H, H-2′, H-3b$_{all}$), 4.97 (dd, $^3J_{3',4'}$=3.0, $^3J_{2',3'}$=10.4 Hz, 1H, H-3′), 4.77 (d, $^3J_{1,2}$=7.9 Hz, 1H, H-1), 4.70 (d, $^3J_{1',2'}$=8.1 Hz, 1H, H-1′), 4.32 (dd, $^2J_{1a,ball}$=12.9, $^3J_{1,2all}$=5.0 Hz, 1H, H-1a$_{all}$), 4.17–4.11 (m, 2H, H-6′ab), 4.09–3.98 (m, 2H, H-3, H-1b$_{all}$), 3.96–3.87 (m, 2H, H-6a, H-5′), 3.86–3.79 (m, 2H, H-4, H-6b), 3.55 (ddd, $^3J_{2,NH}$=7.1, $^3J_{1,2}$=7.9, $^3J_{2,3}$=10.3 Hz, 1H, H-2), 3.42 (m, 1H, H-5), 2.15 (s, 3H, H_{Ac}), 2.06 (s, 3H, H_{Ac}), 2.03 (s, 3H, H_{Ac}), 1.99 (s, 3H, H_{Ac}), 1.72 (s, 3H, H_{Ac}), 1.07 (s, 9H, SiC(CH$_3$)$_3$) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ=171.1–168.8 (*C*H$_3$CO), 136.3–133.3 (C_{arom}), 132.5 (C-2$_{all}$), 130.6–127.4 (C_{arom}), 117.4 (C-3$_{all}$), 100.9 (C-1′), 98.8 (C-1), 79.8 (C-4), 74.5 (C-5), 71.3 (C-3), 71.2 (C-5′), 70.7 (C-3′), 69.3 (C-1$_{all}$), 68.8 (C-2′), 66.8 (C-4′), 61.8 (C-6), 61.2 (C-6′), 56.7 (C-2), 26.8 (SiC(*C*H$_3$)), 23.7–19.9 (*C*H$_3$CO), 19.3 (SiC(CH$_3$)) ppm; MALDI-TOF: *m*/*z* calcd for $C_{41}H_{55}NO_{15}Si$: 829.33, found: 852.51 $[M+Na]^+$.

For **33**: $[\alpha]_D^{20}$ +17.1 (*c* 1.0, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$) δ=7.72–7.68 (m, 4H, H_{arom}), 7.43–7.32 (m, 6H, H_{arom}), 5.90 (dddd, $^3J_{2all,1aall}$=5.2, $^3J_{2all,1aall}$=5.8, $^3J_{2all,3all\text{-}cis}$=10.9, $^3J_{2all,3all\text{-}trans}$=17.3 Hz, 1H, H-2$_{all}$), 5.69 (d, $^3J_{2,NH}$=6.9 Hz, 1H, NH), 5.37 (d, $^3J_{3',4'}$=3.1 Hz, 1H, H-4′), 5.31–5.17 (m, 3H, H-2′, H-3a,b$_{all}$), 5.00 (dd, $^3J_{3',4'}$=3.1, $^3J_{2',3'}$=10.5 Hz, 1H, H-3′), 4.97 (d, $^3J_{1,2}$=8.3 Hz, 1H, H-1), 4.57 (d, $^3J_{1',2'}$=8.1 Hz, 1H, H-1′), 4.42 (dd, $^3J_{3,4}$=8.1, $^3J_{2,3}$=10.2 Hz, 1H, H-3), 4.34 (dd, $^2J_{1aball}$=12.8, $^3J_{2all,1aall}$=5.2 Hz, 1H, H-1a$_{all}$), 4.15–4.05 (m, 3H, H-6′ab H-1a$_{all}$), 4.05–3.95 (m, 2H, H-6a, H-5′), 3.87 (dd, $^2J_{6ab}$=11.1, $^3J_{5,6,b}$=5.6 Hz, 1H, H-6b), 3.77 (s, 1H, OH), 3.53–3.37 (m, 2H, H-4, H-5), 3.05 (ddd, $^3J_{2,NH}$=6.9, $^3J_{1,2}$=8.3, $^3J_{2,3}$=10.2 Hz, 1H, H-2), 2.15 (s, 3H, H_{ac}), 2.07 (s, 3H, H_{ac}), 2.01 (s, 3H, H_{ac}), 1.98 (s, 3H, H_{ac}), 1.98 (s, 3H, H_{ac}), 1.05 (s, 9H, SiC(CH$_3$)$_3$) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ=170.4–169.4 (*C*H$_3$CO), 136.3–134.2 (C_{arom}), 133.7 (C-2$_{all}$), 130.2–125.9 (C_{arom}), 117.7 (C-3$_{all}$), 101.4 (C-1′), 97.5 (C-1), 83.6 (C-3), 76.4 (C-5), 71.1 (C-5′), 70.9 (C-3′), 69.7 (C-1$_{all}$), 69.3 (C-4), 68.7 (C-2′), 68.4 (C-4′), 63.4 (C-6), 61.5 (C-6′), 57.7 (C-2), 26.8 (SiC(*C*H$_3$)), 24.0–20.3 (*C*H$_3$CO) 19.2 (SiC(CH$_3$)) ppm; MALDI-TOF: *m*/*z* calcd for $C_{41}H_{55}NO_{15}Si$: 829.33, found: 852.49 $[M+Na]^+$. For **34**: MALDI-TOF: *m*/*z* calcd for $C_{55}H_{73}NO_{24}Si$: 1159.43, found: 1182.40 $[M+Na]^+$.

*4.4.2. Allyl 2-acetamido-4-O-(2,3,4,6-tetra-O-acetyl-β-D-glucopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-β-D-glucopyranoside (**35**) and allyl 2-acetamido-3-O-(2,3,4,6-tetra-O-acetyl-β-D-glucopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-β-D-glucopyranoside (**36**).* According to the synthesis of compound **32** (method B) donor **10** (460 mg, 930 μmol) and acceptor **8** (310 mg, 620 μmol) were reacted with trimethylsilyl triflate (22 μL, 27 mg, 0.12 mmol) in anhydrous DCM (6 mL). The desired product **35** (128 mg, 25%) was obtained after column chromatography on silica using DCM /methanol (30:1) besides compound **36** (252 mg, 49%). For **35**: $[\alpha]_D^{20}$ +39.2 (*c* 1.0, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$) δ=7.81–7.74 (m, 4H, H_{arom}), 7.51–7.36 (m, 6H, H_{arom}), 5.98–5.82 (m, 2H, H-2$_{all}$, H_{NAc}), 5.29 (dd, $^3J_{all\text{-}trans}$=17.3, 1H, H-3a$_{all}$), 5.25–5.14 (m, 2H, H-3′, H-3a$_{all}$), 5.10 (dd, $^3J_{3',4'}$=9.6, $^3J_{4',5'}$=9.6 Hz, 1H, H-4′), 5.04 (dd, $^3J_{1',2'}$=8.1, $^3J_{2',3'}$=9.5 Hz, 1H, H-2′), 4.82 (d, $^3J_{1',2'}$=8.1 Hz, 1H, H-1′), 4.76 (d, $^3J_{1,2}$=8.1 Hz, 1H, H-1), 4.35 (dd, $^2J_{1a,ball}$=12.9, $^3J_{1,2all}$=5.0 Hz, 1H, H-1a$_{all}$), 4.29 (dd, $^2J_{6'ab}$=12.4, $^3J_{5',6'a}$=5.6 Hz, 1H, H-6′a), 4.22–4.04 (m, 1H, H-6′b), 4.01–3.90 (m, 3H, H-3, H-6a, H-1b$_{all}$), 3.89–3.81 (m, 2H, H-4, H-6b), 3.70 (m, 1H, H-5′), 3.61 (dd, $^3J_{1,2}$=8.1, $^3J_{2,NH}$=8.4, $^3J_{2,3}$=9.3 Hz, 1H, H-2), 3.41 (m, 1H, H-5), 2.13 (s, 3H, H_{Ac}), 2.06 (s, 3H, H_{Ac}), 2.05 (s, 3H, H_{Ac}), 2.05 (s, 3H, H_{Ac}), 2.03 (s, 1H, H_{Ac}), 1.10 (s, 9H, SiC(CH$_3$)$_3$) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ=170.4–169.4 (CH$_3$CO), 136.7–134.8 (C_{arom}), 134.1 (C-2$_{all}$), 130.4–127.0 (C_{arom}), 117.2 (C-3$_{all}$), 100.5 (C-1′), 98.9 (C-1), 79.9 (C-4), 74.7 (C-5), 72.7 (C-3′), 72.2 (C-5′), 71.7 (C-3), 71.3 (C-2′), 69.4 (C-1$_{all}$), 68.3 (C-4′), 61.6 (C-6), 61.3 (C-6′), 56.6 (C-2), 26.8 (SiC(CH$_3$)), 24.0–20.3 (CH$_3$CO) 19.2 (SiC(CH$_3$)) ppm; MALDI-TOF: *m*/*z* calcd for $C_{41}H_{55}NO_{15}Si$: 829.33, found: 852.43 $[M+Na]^+$. For **36**: $[\alpha]_D^{20}$ +19.7 (*c* 1.0, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$) δ=7.73–7.67 (m, 4H, H_{arom}), 7.45–7.31 (m, 6H, H_{arom}), 5.90 (dddd, $^3J_{1,2all}$=5.0, $^3J_{1,2all}$=5.8, $^3J_{all\text{-}cis}$=10.9, $^3J_{all\text{-}trans}$=17.3 Hz, 1H, H-2$_{all}$), 5.71 (d, $^3J_{2,NH}$=7.0 Hz, 1H, H_{NAc}), 5.27 (dd, $^3J_{all\text{-}trans}$=17.3 Hz, 1H, H-3a$_{all}$), 5.23–5.17 (m, 2H, H-3′ H-3b$_{all}$), 5.06–4.97 (m, 2H, H-2′, H-4′), 4.95 (d, $^3J_{1,2}$=8.3 Hz, 1H, H-1), 4.61 (d, $^3J_{1',2'}$=8.1 Hz, 1H, H-1′), 4.42 (dd, $^3J_{3,4}$=7.6, $^3J_{2,3}$=10.1 Hz, 1H, H-3), 4.33 (dd, $^2J_{1a,ball}$=12.8, $^3J_{1,2all}$=5.2 Hz, 1H, H-1a$_{all}$), 4.19–4.06 (m, 3H, H-6′ab, H-1b$_{all}$), 4.01 (dd, $^2J_{6ab}$=11.0, $^3J_{5',6a}$=1.3 Hz, 1H, H-6a), 3.87 (dd, $^2J_{6ab}$=11.0, $^3J_{5',6b}$=5.1 Hz, 1H, H-6b), 3.83–3.75 (m, 1H, H-5′), 3.68 (s, 1H, OH), 3.51–3.40 (m, 2H, H-4, H-5), 3.04 (ddd, $^3J_{2,NH}$=7.0, $^3J_{1,2}$=8.3, $^3J_{2,3}$=10.1 Hz, 1H, H-2), 2.05 (s, 3H, H_{Ac}), 2.04 (s, 3H, H_{Ac}), 2.02 (s, 1H, H_{Ac}), 2.01 (s, 3H, H_{Ac}), 2.00 (s, 1H, H_{Ac}), 1.04 (s, 9H, SiC(CH$_3$)$_3$) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ=170.4–169.4 (CH$_3$CO), 136.6–134.9 (C_{arom}), 133.9 (C-2$_{all}$), 130.2–126.9 (C_{arom}), 117.9 (C-3$_{all}$), 100.8 (C-1′), 97.8 (C-1), 83.4 (C-3), 76.2 (C-5), 72.8 (C-3′), 71.8 (C-5′), 71.4 (C-2′), 69.9 (C-1$_{all}$), 69.6 (C-4), 68.4 (C-4′), 63.6 (C-6), 62.0 (C-6′), 58.0 (C-2), 26.8 (SiC(CH$_3$)), 24.0–20.3 (CH$_3$CO) 19.2 (SiC(CH$_3$)) ppm; MALDI-TOF: *m*/*z* calcd for $C_{41}H_{55}NO_{15}Si$: 829.33, found: 852.51 $[M+Na]^+$.

*4.4.3. Allyl 2-acetamido-4-O-(2,3,4,6-tetra-O-acetyl-β-L-galactopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-β-D-glucopyranoside (**37**) and allyl 2-acetamido-3-O-(2,3,4,6-tetra-O-acetyl-β-L-galactopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-β-D-glucopyranoside (**38**).* According to the synthesis of compound **32** (method B) donor **14** (625 mg, 1.27 mmol) and acceptor **8** (475 mg, 1.06 mmol) were reacted with trimethylsilyl triflate (7.2 μL, 8.9 mg, 40 μmol) in anhydrous DCM (5 mL). The desired product **37** (394 mg, 45%) was obtained after column chromatography on silica using DCM/methanol (30:1) beside the compound **38** (169 mg, 20%). For **37**: $[\alpha]_D^{20}$ −25.5 (*c* 1.0, $CHCl_3$), ^1H NMR (500 MHz, $CDCl_3$) δ=7.78–7.66 (m, 4H, H_{arom}), 7.47–7.32 (m, 6H, H_{arom}), 5.89 (dddd, $^3J_{1,2all}$=5.1, $^3J_{1,2all}$=5.6, $^3J_{all\text{-}cis}$=11.1, $^3J_{all\text{-}trans}$=17.0 Hz, 1H, H-2$_{all}$), 5.70 (d, $^3J_{NH,2}$=7.1 Hz, 1H, NHAc), 5.35 (dd, $^3J_{3',4'}$=3.1 Hz, 1H, H-4′), 5.23 (dd, $^3J_{1,2all}$=5.1, $^3J_{all\text{-}trans}$=17.0 Hz, 1H, H-3a$_{all}$), 5.21–5.16 (m, 2H, H-2′, H-3a$_{all}$), 4.89 (dd, $^3J_{3',4'}$=3.1, $^3J_{2',3'}$=10.5 Hz, 1H, H-3′), 4.80 (d, $^3J_{1,2}$=7.8 Hz, 1H, H-1), 4.75 (d, $^3J_{1',2'}$=7.8 Hz, 1H, H-1′), 4.31 (dd, $^2J_{1a,ball}$=12.9, $^3J_{1,2all}$=5.1 Hz, 1H, H-1a$_{all}$), 4.17–4.10 (m, 2H, H-6′a,b), 4.09–3.98 (m, 2H, H-4, H-1b$_{all}$), 3.96–3.78 (m, 4H, H-3, H-6ab, H-5′), 3.54 (ddd, $^3J_{1,2}$=7.8, $^3J_{2,NH}$=8.3, $^3J_{2,3}$=9.9 Hz, 1H, H-2), 3.42 (ddd, $^3J_{4,5}$=10.1, $^3J_{5,6a}$=5.3, $^3J_{5,6b}$=6.2 Hz, 1H, H-5), 2.15 (s, 3H, H_{Ac}), 2.06 (s, 3H, H_{Ac}), 2.03 (s, 3H, H_{Ac}), 1.99 (s, 3H, H_{Ac}), 1.72 (s, 3H, H_{Ac}), 1.07 (s, 9H, SiC(CH$_3$)$_3$) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ=170.4–169.4 (CH$_3$CO), 136.6–134.8 (C_{arom}), 134.2 (C-2$_{all}$), 130.4–127.0 (C_{arom}), 117.2 (C-3$_{all}$), 101.9 (C-1′), 99.0 (C-1), 80.1 (C-4), 75.7 (C-5), 72.6 (C-3′), 72.2 (C-5′), 72.1 (C-3), 71.4 (C-2′), 69.9 (C-1$_{all}$), 69.3 (C-4′), 62.0 (C-6′), 61.9 (C-6), 55.9 (C-2), 26.6 (SiC(*C*H$_3$)), 24.0–20.3 (*C*H$_3$CO) 19.2 (SiC(CH$_3$)) ppm; MALDI-TOF: *m*/*z* calcd for $C_{41}H_{55}NO_{15}Si$: 829.33, found: 852.40 $[M+Na]^+$.

For **38**: MALDI-TOF: *m*/*z* calcd for $C_{41}H_{55}NO_{15}Si$: 829.33, found: 852.54 $[M+Na]^+$.

4.5. Synthesis of allylic Le^x trisaccharide analogs

*4.5.1. Allyl 2-acetamido-4-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-3-O-(2,3,4-tri-O-acetyl-α-L-fucopyranosyl)-β-D-glucopyranoside (**40**). Method A*: Acceptor **32** (300 mg, 361 μmol) and donor **12** (298 mg, 541 μmol) were dissolved in anhydrous DCM/DMF (5 mL/5 mL) and stirred for 1 h with activated powdered molecular sieve (4 Å, 1 g) under argon atmosphere. Then, TBAB (198 mg, 614 mmol) and copper(II) bromide (137 mg, 614 mmol) were added. After 24 h the solvents were removed under reduced pressure. The residue redissolved in DCM

and filtered over Celite. The filtrate was concentrated and the crude was reacted for 3 h in aqueous THF with a catalytic amount of acetic acid. After acetylation of the crude with acetic anhydride and pyridine the anomeric trisaccharide mixture was purified by column chromatography on silica with petroleum/ethyl acetate. The anomeric mixture of compound **40** and **42** was obtained as a colorless solid (270 mg, 68%, α/β-ratio: 1:1.1, determinate by ^{1}H NMR). Column chromatography provided the pure α anomer **40** as a colorless solid (95 mg).

Method B: Under argon atmosphere NIS (53 mg/0.23 mmol) was added to a solution of acceptor **32** (150 mg, 180 μmol) and donor **12** (118 mg, 216 μmol) in anhydrous DCM (3 mL) containing activated molecular sieve (4 Å, 200 mg). After cooling to −20 °C trifluoromethanesulfonic acid (3 μL, 0.04 mmol) was added. After 1 h the reaction was quenched by addition of triethylamine. TLC analysis showed no conversion to the product.

Method C: A solution of donor **12** (299 mg, 541 μmol) and DMTST (186 mg, 722 μmol) in anhydrous DCM (2.5 mL) containing activated molecular sieve (4 Å, 200 mg) was stirred for 30 min at 0 °C under argon atmosphere. Then, a solution of acceptor **32** (300 mg, 361 μmol) in anhydrous DCM (750 μL) was added. After warming to room temperature the reaction mixture was stirred for 1 h followed by quenching with triethylamine. The mixture was filtered over Celite and diluted with DCM (20 mL) followed by washing with 1 M HCl, saturated $NaHCO_3$ solution, and water. The organic layer was dried over Na_2SO_4 and concentrated. The residue was reacted for 3 h in aqueous THF with a catalytic amount of acetic acid. After acetylation of the crude with acetic anhydride and pyridine the anomeric trisaccharide mixture was purified by column chromatography on silica with petroleum/ethyl acetate. The anomeric mixture of compound **40** and **42** was obtained as a colorless solid (155 mg, 39%, α/β-ratio: 4.3:1, determined by ^{1}H NMR). Column chromatography provided the pure α anomer **40** as a colorless solid (103 mg).

Method D: A solution of donor **12** (240 mg, 433 μmol) and 2,6-di-*tert*-butyl-4-methylpyridine (300 mg, 361 μmol) in anhydrous DCM (2 mL) containing activated molecular sieve (4 Å, 200 mg) was stirred for 30 min at −40 °C under argon atmosphere followed by addition of a 1 M solution of dimethyldisulfide and Tf_2O in anhydrous DCM (450 μL, 450 μmol). After additional stirring for 30 min at −40 °C a solution of acceptor **32** (300 mg, 361 μmol) in anhydrous DCM (750 μL) was added. After 1 h the reaction was quenched by addition of triethylamine. The mixture was filtered over Celite and diluted with DCM (20 mL) followed by washing with 1 M HCl, saturated $NaHCO_3$ solution, and water. The organic layer was dried over Na_2SO_4 and concentrated. The residue was reacted for 3 h in aqueous THF with a catalytic amount of acetic acid. After acetylation of the crude with acetic anhydride and pyridine the anomeric trisaccharide mixture was purified by column chromatography on silica with petroleum/ethyl acetate. The anomeric mixture of compound **40** and **42** was obtained as a colorless solid (266 mg, 67%, α/β-ratio: 8.3:1, determined by ^{1}H NMR). Column chromatography provided the pure α anomer **40** as a colorless solid (187 mg).

Method E: A solution of donor **12** (240 mg, 433 μmol) and MeOTf (50 μg, 433 μmol) in anhydrous DCM (2.5 mL) containing activated molecular sieve (4 Å, 200 mg) was stirred for 30 min at −40 °C under argon atmosphere followed by addition of a solution of acceptor **32** (300 mg, 361 μmol) in anhydrous DCM (750 μL) was added. After 1 h the reaction was quenched by addition of triethylamine. The mixture was filtered over Celite and diluted with DCM (20 mL) followed by washing with 1 M HCl, saturated $NaHCO_3$ solution, and water. The organic layer was dried over Na_2SO_4 and concentrated. The residue was reacted for 3 h in aqueous THF with a catalytic amount of acetic acid. After acetylation of the crude with acetic anhydride and pyridine the anomeric trisaccharide mixture was purified by column chromatography on silica with petroleum /ethyl acetate. The anomeric mixture of compound **40** and **42** was obtained as a colorless solid (84 mg, 21%, α/β-ratio: 4.3:1, determined by ^{1}H NMR). R_f=0.45 (EE); mp 176 °C; $[\alpha]_D^{20}$ +74.5 (*c* 1.0, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ=7.80–7.62 (m, 4H, H_{arom}), 7.51–7.34 (m, 6H, H_{arom}), 5.92–5.82 (m, 1H, H-3$_{all}$), 5.81 (d, $^3J_{2,HNAc}$=8.9 Hz, 1H, H_{NAc}), 5.43 (d, $^3J_{1',2'}$=3.2 Hz, 1H, H-1′), 5.32 (d, $^3J_{3'',4''}$=3.2 Hz, 1H, H-4″), 5.29–5.20 (m, 1H, H-3a$_{all}$), 5.19–4.99 (m, 5H, H-2′, H-4′, H-5′, H-2″, H-3b$_{all}$), 4.99–4.90 (m, $^3J_{3'',4''}$=3.2, $^3J_{2'',3''}$=10.1 Hz 2H, H-3′, H-3″), 4.69 (d, $^3J_{1'',2''}$=8.1 Hz, 1H, H-1″), 4.57 (d, $^3J_{1,2}$=6.2 Hz, 1H, H-1), 4.34–4.25 (dd, $^2J_{1aball}$=11.2, $^3J_{1all,2all}$=5.1 Hz, 1H, H-1a$_{all}$), 4.22–4.16 (m, 2H, H-4, H-6a″), 4.11–4.01 (m, 2H, H-6b″, H-1a$_{all}$), 4.00–3.92 (m, 4H, H-2, H-3, H-6ab), 3.73 (dd, $^3J_{5'',6a''}$=6.4, $^3J_{5'',6b''}$=6.4Hz, 1H, H-5″), 3.33 (ddd, $^3J_{5,6a}$=6.7, $^3J_{5,6b}$=6.7, $^3J_{4,5}$=10.5 Hz, 1H, H-5), 2.14 (s, 3H, H_{Ac}), 2.11 (s, 3H, H_{Ac}), 2.08 (s, 3H, H_{Ac}), 2.06 (s, 3H, H_{Ac}), 2.03 (s, 3H, H_{Ac}), 2.02 (s, 3H, H_{Ac}), 2.00 (s, 3H, H_{Ac}), 1.87 (s, 3H, H_{Ac}), 1.31 (d, $^3J_{5',6'}$=6.5 Hz, 3H, H-6′), 1.08 (s, 9H, SiC(CH$_3$)$_3$) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ=170.4–169.4 (CH_3CO), 136.5–134.5 (C_{arom}), 133.5 (C-2$_{all}$), 130.5–126.9 (C_{arom}), 116.8 (C-3$_{all}$), 105.7 (C-1′), 99.7 (C-1″), 99.0 (C-1) 83.6 (C-4), 80.9 (C-4′), 76.8 (C-3′), 75.6 (C-3), 74.9 (C-5), 70.7 (C-3″), 70.6 (C-5″), 70.3 (C-2′), 69.9 (C-1$_{all}$), 69.1 (C-2″), 68.9 (C-5′), 66.5 (C-4″), 61.4 (C-6), 60.8 (C-6″), 52.8 (C-2), 26.7 (SiC(CH$_3$)), 24.0–20.3 (CH_3CO), 19.1 (SiC(CH$_3$)), 15.8 (C-6′) ppm; HRMS (ESI): *m*/*z* calcd for $C_{53}H_{71}NO_{22}SiNa^+$: 1124.4135, found: 1124.4153 $[M+Na]^+$.

*4.5.2. Allyl 2-acetamido-4-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-3-O-(2,3,4-tri-O-acetyl-β-L-fucopyranosyl)-β-D-glucopyranoside (**42**).* Compound **42** was obtained as a side product of glycosylation to compound **40** (233 mg, 45%). $C_{53}H_{71}NO_{22}Si$ (1102.21 g/mol); R_f=0.42 (EA); mp 170 °C; $[\alpha]_D^{20}$ +10.5 (*c* 1.0, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ=7.81–7.59 (m, 4H, H_{arom}), 7.51–7.29 (m, 6H, H_{arom}), 6.12 (s, 1H, H_{NAc}), 5.97–5.79 (m, 1H, H-2$_{all}$), 5.33 (d, $^3J_{3'',4''}$=3.1 Hz, 1H, H-4″), 5.29–5.24 (m, 1H, H-3a$_{all}$), 5.20 (d, $^3J_{3',4'}$=3.2 Hz, 1H, H-4′), 5.17–5.08 (m, 2H, H-2′, H-2b$_{all}$), 5.03 (dd, $^3J_{1'',2''}$=7.9, $^3J_{2'',3''}$=10.5 Hz, 1H, H-2″), 4.99 (dd, $^3J_{3',4'}$=3.2, $^3J_{2',3'}$=10.5, 3.44 Hz, 1H, H-3′), 4.95 (d, $^3J_{1',2'}$=8.1 Hz, 1H, H-1′), 4.91 (dd, $^3J_{3'',4''}$=3.1, $^3J_{2'',3''}$=10.5 Hz, 1H, H-3″), 4.83 (d, $^3J_{1,2}$=6.6 Hz, 1H, H-1), 4.59 (d, $^3J_{1'',2''}$=7.9 Hz, 1H, H-1″), 4.34–4.22 (m, 2H, H-3, H-1a$_{all}$), 4.13–4.08 (m, 2H, H-6″), 4.06–4.00 (m, 2H, H-4, H-1b$_{all}$), 3.94–3.89 (m, 2H, H-6), 3.82 (q, $^3J_{5',6'}$=6.1 Hz, 1H, H-5′), 3.64 (dd, $^3J_{1,2}$=6.6, $^3J_{2,3}$=6.6 Hz, 1H, H-2), 3.57 (dd, $^3J_{5'',6a''}$=6.7, $^3J_{5'',6a''}$=6.7 Hz, 1H, H-5″), 3.40–3.28 (m, 1H, H-5), 2.17 (s, 3H, H_{Ac}), 2.16 (s, 3H, H_{Ac}), 2.04 (s, 6H, 2×H_{Ac}), 2.03 (s, 3H, H_{Ac}), 2.00 (s, 3H, H_{Ac}), 1.96 (s, 3H, H_{Ac}), 1.91 (s, 3H, H_{Ac}), 1.22 (d, $^3J_{5',6'}$=6.1 Hz, 3H, H-6′), 1.08 (s, 9H, SiC(CH$_3$)$_3$) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ=170.4–169.4 (CH_3CO), 136.5–134.5 (C_{arom}), 133.8 (C-2$_{all}$), 130.3–126.9 (C_{arom}), 116.8 (C-3$_{all}$), 99.4 (C-1′), 98.8 (C-1″), 98.6 (C-1), 75.3 (C-5), 74.6 (C-3), 74.1 (C-4), 71.2 (C-3′), 70.7 (C-5″), 70.4 (C-4′), 70.3 (C-3″), 69.2 (C-5′), 69.1 (C-2′), 68.9 (C-2″), 68.8 (C-1$_{all}$), 66.5 (C-4″), 62.6 (C-6), 60.5 (C-6″), 54.4 (C-2), 29.4 (C-6′), 26.8 (SiC(*C*H$_3$)), 23.4–20.1 (*C*H$_3$CO), 19.2 (Si*C*(CH$_3$)) ppm; HRMS (ESI): *m*/*z* calcd for $C_{53}H_{71}NO_{22}SiNa^+$: 1124.4135, found: 1124.4146 $[M+Na]^+$.

*4.5.3. Allyl 2-acetamido-4-O-(2,3,4,6-tetra-O-acetyl-β-D-glucopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-3-O-(2,3,4-tri-O-acetyl-α-L-fucopyranosyl)-β-D-glucopyranoside (**44**).* According to the synthesis of compound **40** (method D) donor **12** (318 mg, 578 μmol) and acceptor **35** (400 mg, 482 μmol) were reacted with a 1 M DCM solution (578 μL, 578 μmol) of dimethyldisulfide and Tf_2O in anhydrous DCM (8 mL). The anomeric mixture was obtained as colorless solid (335 mg, 63%, α/β-ratio: 9.5:1, determined by ^{1}H NMR). Column chromatography provided the pure α anomer **44** as a colorless solid (240 mg, 72%). R_f=0.45 (EA); mp 170 °C; $[\alpha]_D^{20}$ +34.9 (*c*

1.0, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$) δ=7.79–7.60 (m, 4H, H_{arom}), 7.52–7.34 (m, 6H, H_{arom}), 5.88 (ddd, $^3J_{2,3all}$=5.2, $^3J_{cis}$=10.7, $^3J_{trans}$=17.5 Hz), 5.81 (d, $^3J_{2,\ HNAc}$=8.9 Hz, 1H, H_{NAc}), 5.40 (d, $^3J_{1',2'}$=3.0 Hz, 1H, H-1′), 5.29–5.20 (m, 1H, H-3a$_{all}$), 5.19–4.99 (m, 6H, H-2′, H-4′, H-5′, H-2″, H-4″, H-3b$_{all}$), 4.98–4.90 (m, 2H, H-3′, H-3″), 4.62 (d, $^3J_{1'',2''}$=8.0 Hz, 1H, H-1″), 4.58 (d, $^3J_{1,2}$=7.9 Hz, 1H, H-1), 4.29 (dd, $^2J_{1aball}$=10.9, $^3J_{1all,2all}$=5.0 Hz, 1H, H-1a$_{all}$), 4.21–4.16 (m, 2H, H-4, H-6a″), 4.11–4.07 (m, 1H, H-1b$_{all}$), 4.00–3.92 (m, 5H, H-2, H-3, H-6ab, H-6b″), 3.53 (ddd, $^3J_{4,5}$=9.9, $^3J_{5,6a}$=4.3, $^3J_{5,6b}$=2.1 Hz, 1H, H-5), 2.16 (s, 3H, H_{Ac}), 2.13 (s, 3H, H_{Ac}), 2.08 (s, 3H, H_{Ac}), 2.06 (s, 3H, H_{Ac}), 2.04 (s, 3H, H_{Ac}), 2.01 (s, 3H, H_{Ac}), 2.00 (s, 3H, H_{Ac}), 1.85 (s, 3H, H_{Ac}), 1.32 (d, $^3J_{5',6'}$=6.5 Hz, 3H, H-6′), 1.08 (s, 9H, SiC(CH$_3$)$_3$) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ=170.4–169.4 (CH$_3$*C*O), 136.5–134.5 (C$_{arom}$), 133.5 (C-2$_{all}$), 130.5–126.9 (C$_{arom}$), 116.8 (C-3$_{all}$), 103.3 (C-1′), 100.4 (C-1) 99.5 (C-1″), 83.6 (C-4), 75.6 (C-3), 75.1 (C-3′), 74.9 (C-5), 70.6 (C-5″), 70.3 (C-2′), 69.9 (C-1$_{all}$), 69.5 (C-3″), 69.1 (C-2″), 68.4 (C-5′), 67.7 (C-4′), 66.5 (C-4″), 61.8 (C-6′), 61.2 (C-6), 51.9 (C-2), 26.9 (SiC(*C*H$_3$)), 24.0–20.3 (*C*H$_3$CO), 19.0 (SiC(CH$_3$)), 15.7 (C-6′) ppm; HRMS (ESI): *m*/*z* calcd for $C_{53}H_{71}NO_{22}SiNa^+$: 1124.4135, found: 1124.4178 $[M+Na]^+$.

*4.5.4. Allyl 2-acetamido-4-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-3-O-(2,3,4,6-tetra-O-acetyl-α-L-galactopyranosyl)-β-D-glucopyranoside (**46**).* According to the synthesis of compound **40** (method D) donor **13** (735 mg, 1.08 mmol) and acceptor **32** (750 mg, 904 μmol) were reacted with a 1 M DCM solution (1.08 μL, 1.08 mmol) of dimethyldisulfide and Tf_2O in anhydrous DCM (8 mL). The anomeric mixture was obtained as colorless solid (556 mg, 53%, α/β-ratio: 8.7:1, determined by ^1H NMR). Column chromatography provided the pure α anomer **46** as a colorless solid (491 mg, 88%). R_f=0.36 (EA); mp 185 °C; $[\alpha]_D^{20}$ +55.8 (*c* 1.0, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$) δ=7.74–7.67 (m, 4H, H_{arom}), 7.48–7.30 (m, 8H, H_{arom}), 6.84 (d, $^3J_{Ar}$=8.0 Hz, 2H, H-2$_{arom}$), 6.00 (d, $^3J_{2,HNAc}$=7.8 Hz, 1H, H_{NAc}), 5.97–5.79 (m, 2H, H-2$_{bu,}$ H-3$_{bu}$), 5.36 (d, $^3J_{3',4'}$=3.0 Hz, 1H, H-4′), 5.34–5.31 (m, 2H, H-4″, H$_{acetal}$), 5.15 (dd, $^3J_{1',2'}$=3.6, $^3J_{2',3'}$=9.4 Hz, 1H, H-2′), 5.06–4.99 (m, 2H, H-3′, H-2″), 4.95–4.91 (m, 2H, H-1′, H-3″), 4.80 (d, $^3J_{1,2}$=7.8 Hz, 1H, H-1), 4.60 (d, $^3J_{1'',2''}$=8.0 Hz, 1H, H-1″), 4.51–4.47 (m, 2H, H-4$_{bu}$), 4.39–4.16 (m, 4H, H-3, H-6′ab, H-1a$_{bu}$), 4.11–3.99 (m, 3H, H-4, H-6″ab, H-1b$_{bu}$), 3.97–3.89 (m, 3H, H-6ab, H-5′), 3.62 (ddd, $^3J_{1,2}$=7.8, $^3J_{2,3}$=7.2 Hz $^3J_{2,HNAc}$=7.8 Hz, 1H, H-2), 3.55 (dd, $^3J_{5'',6a''}$=6.6, $^3J_{5'',6a''}$=6.9 Hz, 1H, H-5″), 3.39–3.31 (m, 1H H-5), 3.28 (s, 6H, OCH$_3$), 2.17 (s, 3H, H_{Ac}), 2.16 (s, 3H, H_{Ac}), 2.10 (s, 3H, H_{Ac}), 2.08 (s, 3H, H_{Ac}), 2.06 (s, 3H, H_{Ac}), 2.03 (s, 3H, H_{Ac}), 2.00 (s, 3H, H_{Ac}), 1.99 (s, 3H, H_{Ac}), 1.95 (s, 3H, H_{Ac}), 1.07 (s, 9H, SiC(CH$_3$)$_3$) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ=170.9–168.5 (CH$_3$*C*O), 136.0–127.4 (C$_{arom}$), 114.1 (C-2$_{bu}$), 113.4 (C-3$_{bu}$), 103.0 (C$_{aectal}$), 100.2 (C-1′), 98.9 (C-1), 98.7 (C-1″), 75.5 (C-5), 74.3 (C-4), 74.2 (C-3), 71.1 (C-5′), 70.7 (C-3′), 70.7 (C-5″), 70.4 (C-3″), 69.4 (C-1$_{all}$), 69.1 (C-2″), 69.0 (C-2′), 68.8 (C-4$_{bu}$), 68.7 (C-4′), 67.9 (C-1$_{bu}$), 67.4 (C-4″), 62.5 (C-6), 61.3 (C-6′), 60.9 (C-6″), 54.9 (C-2), 52.5 (O*C*H$_3$), 26.6 (SiC(*C*H$_3$)), 23.1–20.1 (*C*H$_3$CO), 19.1 (Si*C*(CH$_3$)) ppm; HRMS (ESI): *m*/*z* calcd for $C_{55}H_{73}NO_{24}SiNa^+$: 1182.4189, found: 1124.4213 $[M+Na]^+$.

*4.5.5. Allyl 2-acetamido-4-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-3-O-(2,3,4-tri-O-acetyl-α-L-rhamnopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-β-D-glucopyranoside (**47**).* According to the synthesis of compound **32** (method B) donor **14** (315 mg, 722 μmol) and acceptor **32** (500 mg, 602 μmol) were reacted with trimethylsilyl triflate (11 μL, 13 mg, 60 μmol) in anhydrous DCM (5 mL). Compound **47** was obtained as colorless solid (278 mg, 42%). R_f=0.39 (EA); mp 163 °C; $[\alpha]_D^{20}$ −13.6 (*c* 1.0, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$) δ=7.75–7.69 (m, 4H, H_{arom}), 7.47–7.34 (m, 6H, H_{arom}), 6.20 (s, 1H, H_{NHAc}), 5.86 (ddd, $^3J_{1,2all}$=5.6, $^3J_{cis}$=10.7, $^3J_{trans}$=22.2 Hz, 1H, H-2$_{allyl}$), 5.32 (d, $^3J_{3'',4''}$=3.5 Hz, 1H, H-4″), 5.27–5.19 (m, 3H, H-2′, H-3′, H-3a$_{allyl}$), 5.15 (dd, $^4J_{1,3ball}$=0.8, $^3J_{cis}$=10.7 Hz, 1H, H-3b$_{allyl}$), 5.11–5.04 (m, 2H, H-4′ H-2″), 4.94 (dd, $^3J_{3'',4''}$=3.5, $^3J_{2'',3''}$=10.5 Hz, 1H, H-3″), 4.92 (bs, 1H, H-1′), 4.84 (d, $^3J_{1,2}$=6.2 Hz, 1H, H-1), 4.76 (d, $^3J_{1,2}$=8.1 Hz, 1H, H-1″), 4.48 (qd, $^3J_{5',6'}$=6.1, $^3J_{4',5'}$=9.9 Hz, 1H, H-5′), 4.31–4.20 (m, 3H, H-3, H-6a, H-1a$_{all}$), 4.13–4.07 (dd, $^2J_{6ab}$=11.6, $^3J_{5,6b}$=6.8 Hz, 1H, H-6b), 4.06–3.94 (m, 4H, H-4, H-6″ab, H-1b$_{all}$), 3.75 (dd, $^3J_{5,6a}$=6.8, $^3J_{5,6b}$=6.8 Hz, 1H, H-5), 3.53–3.42 (m, 1H, H-2), 3.33–3.25 (m, 1H, H-5″), 2.12 (s, 3H, H_{Ac}), 2.09 (s, 3H, H_{Ac}), 2.02 (s, 6H, 2×H_{Ac}), 1.97 (s, 9H, 3×H_{Ac}), 1.87 (s, 3H, H_{Ac}), 1.25 (d, $^3J_{5',6'}$=6.1 Hz, 3H, H-6′), 1.10 (s, 9H, SiC(CH$_3$)$_3$) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) δ=172.1–168.8 (CH$_3$*C*O), 136.8–134.3 (C$_{arom}$), 133.8 (C-2$_{all}$), 130.6–127.4 (C$_{arom}$), 117.3 (C-3$_{all}$), 99.4 (C-1″), 97.6 (C-1), 97.4 (C-1′), 75.5 (C-3), 74.7 (C-5), 74.0 (C-4), 71.2 (C-4), 71.1 (C-4′), 70.7 (C-5″), 70.6 (C-3″), 70.1 (C-3′), 69.3 (C-1$_{all}$), 68.9 (C-2′), 68.7 (C-2″), 67.0 (C-4″), 66.3 (C-5′), 62.1 (C-6″), 60.8 (C-6), 55.7, (C-2), 29.6 (C-6′), 27.1 (SiC(*C*H$_3$)), 23.7–19.9 (*C*H$_3$CO), 19.3 (SiC(CH$_3$)) ppm; HRMS (ESI): *m*/*z* calcd for $C_{53}H_{71}NO_{22}SiNa^+$: 1124.4135, found: 1124.4209 $[M+Na]^+$.

*4.5.6. Allyl 2-acetamido-3-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-4-O-(2,3,4-tri-O-acetyl-α-L-fucopyranosyl)-β-D-glucopyranoside (**49**).* According to the synthesis of compound **40** (method D) donor **12** (238 mg, 433 μmol) and acceptor **33** (300 mg, 361 μmol) were reacted with a 1 M DCM solution (433 μL, 433 μmol) of dimethyldisulfide and Tf_2O in anhydrous DCM (2.5 mL). The anomeric mixture was obtained as colorless solid (556 mg, 53%, α/β-ratio: 8.7:1, determined by ^1H NMR). Column chromatography provided the pure α anomer **49** as a colorless solid (491 mg, 86%). R_f=0.43 (EA); mp 162 °C; $[\alpha]_D^{20}$ −5.4 (*c* 1.0, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$) δ=7.79–7.60 (m, 4H, H_{arom}), 7.51–7.33 (m, 6H, H_{arom}), 5.92–5.82 (m, 1H, H-1$_{all}$), 5.75 (d, $^3J_{2,\ HNAc}$=8.6 Hz, 1H, H_{NAc}), 5.37 (d, $^3J_{3'',4''}$=3.4 Hz, 1H, H-4″), 5.31 (d, $^3J_{3',4'}$=3.3 Hz, 1H, H-4′), 5.29–5.20 (m, 3H, H-1″, H-3″, H-3a$_{all}$), 5.10 (d, $^3J_{1,2}$=8.0 Hz, 1H, H-1), 4.97 (m, 2H, H-5″, H-3b$_{all}$), 4.95 (dd, $^3J_{1',2'}$=8.1, $^3J_{2',3'}$=10.4 Hz, 1H, H-2′), 4.91 (dd, $^3J_{1'',2''}$=3.8, $^3J_{2'',3''}$=10.4 Hz, 1H, H-2″), 4.76 (dd, $^3J_{3,4}$=9.4, $^3J_{2,3}$=10.0 Hz, 1H, H-3), 4.71 (dd, $^3J_{3',4'}$=3.3, $^3J_{2',3'}$=10.4 Hz, 1H, H-3′), 4.49 (d, $^3J_{1',2'}$=8.1, 1H, H-1′) 4.40 (dd, $^2J_{6'ab}$=11.6, $^3J_{5',6a'}$=6.5 Hz, 1H, H-6a′), 4.34 (dd, $^2J_{6'ab}$=11.6, $^3J_{5',6b'}$=6.7 Hz, 1H, H-6b′), 4.30 (dd, $^2J_{1aball}$=11.3, $^3J_{1all,2all}$=5.0 Hz, 1H, H-1a$_{all}$), 4.09 (ddd, $^3J_{1,2}$=8.0, $^3J_{2,\ HNAc}$=8.6, $^3J_{2,3}$=10.0 Hz 1H, H-2), 4.05 (dd, $^2J_{1aball}$=11.3, $^3J_{1all,2all}$=5.1 Hz, 1H, H-1b$_{all}$) 4.00 (dd, $^3J_{3,4}$=9.4, $^3J_{4,5}$=9.4 Hz, 1H, H-4), 3.92 (dd, $^2J_{6ab}$=11.8, $^3J_{5,6a}$=2.9 Hz, 1H, H-6a), 3.65–3.60 (m, 2H, H-6b, H-5′), 3.56–3.50 (m, 1H, H-5), 2.13 (s, 3H, H_{Ac}), 2.10 (s, 3H, H_{Ac}), 2.07 (s, 3H, H_{Ac}), 2.05 (s, 3H, H_{Ac}), 2.03 (s, 3H, H_{Ac}), 2.01 (s, 3H, H_{Ac}), 1.99 (s, 3H, H_{Ac}), 1.87 (s, 3H, H_{Ac}), 1.21 (d, $^3J_{5'',6''}$=6.5 Hz, 3H, H-6″), 1.08 (s, 9H, SiC(CH$_3$)$_3$) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ=171.5–169.4 (CH$_3$*C*O), 136.2–134.5 (C$_{arom}$), 133.1 (C-2$_{all}$), 130.5–126.9 (C$_{arom}$), 116.8 (C-3$_{all}$), 100.5 (C-1″), 97.1 (C-1′), 95.9 (C-1), 75.6 (C-4), 74.0 (C-5) 73.5 (C-3), 72.8 (C-3″), 72.2 (C-4′), 71.2 (C-5′), 70.9 (C-2″), 69.9 (C-1$_{all}$), 68.6 (C-5″), 67.4 (C-2′), 66.7 (C-3′), 64.3 (C-4″), 62.3 (C-6), 60.9 (C-6′), 59.2 (C-2), 26.7 (SiC(*C*H$_3$)), 24.0–20.3 (*C*H$_3$CO), 19.1 (SiC(CH$_3$)), 15.8 (C-6″) ppm; HRMS (ESI): *m*/*z* calcd for $C_{53}H_{71}NO_{22}SiNa^+$: 1124.4135, found: 1124.4146 $[M+Na]^+$.

*4.5.7. Allyl 2-acetamido-4-O-(2,3,4,6-tetra-O-acetyl-β-L-galactopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-3-O-(2,3,4-tri-O-acetyl-α-D-fucopyranosyl)-β-D-glucopyranoside (**51**).* According to the synthesis of compound **40** (method D) donor **15** (358 mg, 650 μmol) and acceptor **37** (450 mg, 542 μmol) were reacted with a 1 M DCM solution (650 μL, 650 μmol) of dimethyldisulfide and Tf_2O in anhydrous DCM (3.5 mL). The anomeric mixture was obtained as colorless solid (352 mg, 59%, α/β-ratio: 6.9:1, determined by ^1H NMR). Column chromatography provided the pure α anomer **51** as a colorless solid (265 mg, 75%). R_f=0.39 (EA); mp 166 °C; $[\alpha]_D^{20}$ +30.4 (*c* 1.0, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$) δ=7.78–7.66 (m, 4H, H_{arom}), 7.45–7.32 (m, 6H, H_{arom}), 5.90 (dddd, $^3J_{1,2all}$=5.0,

$^3J_{1,2all}$=5.6, $^3J_{all\text{-}cis}$=11.1, $^3J_{all\text{-}trans}$=17.6 Hz, 1H, H-2$_{all}$), 5.75 (d, $^3J_{NH,2}$=8.1 Hz, 1H, NHAc), 5.40 (d, $^3J_{1',2'}$=3.0 Hz, 1H, H-1′) 5.35 (dd, $^3J_{3',4'}$=3.3 Hz, 1H, H-4″), 5.22–4.99 (m, 6H, H-2′, H-4′, H-5′, H-2″, H-3a$_{all}$, H-3b$_{all}$), 4.95–4.88 (m, 2H, H-3′, H-3″), 4.80 (d, $^3J_{1,2}$=7.8 Hz, 1H, H-1), 4.75 (d, $^3J_{1'',2''}$=7.8 Hz, 1H, H-1″), 4.31 (dd, $^2J_{1a,ball}$=12.9, $^3J_{1,2all}$=5.1 Hz, 1H, H-1a$_{all}$), 4.17–4.10 (m, 2H, H-6″a,b), 4.09–3.98 (m, 2H, H-4, H-1b$_{all}$), 3.96–3.78 (m, 4H, H-3, H-6ab, H-5″), 3.54 (ddd, $^3J_{1,2}$=7.8, $^3J_{2,NH}$=8.1, $^3J_{2,3}$=9.9 Hz, 1H, H-2), 3.43 (ddd, $^3J_{4,5}$=9.9, $^3J_{5,6a}$=5.3, $^3J_{5,6b}$=6.2 Hz, 1H, H-5), 2.16 (s, 3H, H$_{Ac}$), 2.15 (s, 3H, H$_{Ac}$), 2.10 (s, 3H, H$_{Ac}$), 2.08 (s, 3H, H$_{Ac}$), 2.06 (s, 3H, H$_{Ac}$), 2.03 (s, 3H, H$_{Ac}$), 1.99 (s, 3H, H$_{Ac}$), 1.72 (s, 3H, H$_{Ac}$), 1.28 (d, $^3J_{5',6'}$=6.5 Hz, 3H, H-6′), 1.07 (s, 9H, SiC(CH$_3$)$_3$) ppm; ^{13}C NMR (126 MHz, CDCl$_3$) δ=170.4–169.4 (CH$_3$CO), 136.6–134.8 (C$_{arom}$), 134.2 (C-2$_{all}$), 130.4–127.0 (C$_{arom}$), 117.2 (C-3$_{all}$), 104.6 (C-1′), 101.8 (C-1″), 100.1 (C-1), 81.0 (C-4′), 79.7 (C-4), 76.8 (C-3′), 76.3 (C-3), 75.7 (C-5), 72.6 (C-3′), 72.2 (C-5″), 71.4 (C-2″), 70.3 (C-2′), 69.9 (C-1$_{all}$), 69.3 (C-4″), 68.8 (C-5′) 61.9 (C-6), 61.2 (C-6″), 55.9 (C-2), 26.6 (SiC(*C*H$_3$)), 24.0–20.3 (*C*H$_3$CO), 19.2 (Si*C*(CH$_3$)), 15.8 (C-6′) ppm; HRMS (ESI): *m*/*z* calcd for $C_{53}H_{71}NO_{22}SiNa^+$: 1124.4135, found: 1124.4118 [M+Na]$^+$.

4.6. General procedure synthesis of benzaldehyde functionalized Le^x trisaccharide analogs by cross metathesis

The allyl glycosides (1 mmol) and 9- to 10-fold excess of *para*-allyloxybenzalhyde dimethylacetal (**16**) (9–10 mmol) were dissolved in dry and degassed dichloromethane (49 mL) and put in a flame-dried flask containing activated molecular sieve (4 Å) using standard Schlenk techniques. Grubbs–Hoveyda second generation catalyst **17** (0.10 mmol), dissolved in dry and degassed dichloromethane (1 mL), was added via syringe or as a solid to attain a 0.02 M solution. The reaction mixture was refluxed for 6 h. Conversion of the starting material was detected by TLC. The solution was concentrated under reduced pressure, and the crude product was directly purified by column chromatography using silica and a petroleum ether/ethyl acetate gradient (2:1→100% ethyl acetate).

*4.6.1. (E)-4-(4-Dimethoxymethylphenoxy)-but-2-enyl 2-acetamido-4-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-3-O-(2,3,4-tri-O-acetyl-α-L-fucopyranosyl)-β-D-glucopyranoside (**52**).* Obtained from reaction of allyl glycoside **40** (743 mg, 674 μmol) with compound **16** (1.40 g, 6.74 mmol) and Grubbs–Hoveyda second generation catalyst (43 mg, 68 μmol) as a colorless solid (700 mg, 546 μmol, 81%). R_f=0.45 (EE); mp 166 °C; $[\alpha]_D^{20}$ +48.7 (*c* 1.0, CHCl$_3$); ^{1}H NMR (500 MHz, CDCl$_3$): δ=7.80–7.62 (m, 4H, H$_{arom}$), 7.51–7.30 (m, 8H, H$_{arom}$), 6.86 (d, $^3J_{Ar}$=8.4 Hz, 2H, H-2$_{arom}$), 5.96–5.79 (m, 3H, H$_{NAc}$, H-2$_{bu}$, H-3$_{bu}$), 5.41 (d, $^3J_{1',2'}$=3.3 Hz, 1H, H-1′), 5.33 (d, $^3J_{3'',4''}$=3.3 Hz, 1H, H-4″), 5.22 (d, $^3J_{3',4'}$=3.9 Hz, 1H, H-4′), 5.16–5.00 (m, 3H, H-2′, H-5′, H-2″), 4.99–4.92 (m, 2H, H-3′, H-3″), 4.70 (d, $^3J_{1'',2''}$=7.9 Hz, 1H, H-1″), 4.61 (d, $^3J_{1,2}$=7.8 Hz, 1H, H-1), 4.51–4.48 (m, 2H, H-4$_{bu}$), 4.38–4.30 (m, 1H, H-1a$_{bu}$), 4.22–4.16 (m, 2H, H-4, H-6a″), 4.15–4.00 (m, 2H, H-6b″, H-1b$_{bu}$), 4.00–3.92 (m, 4H, H-2, H-3, H-6ab), 3.73 (dd, $^3J_{5'',6a''}$=6.4, $^3J_{5'',6b''}$=6.4 Hz, 1H, H-5″), 3.33 (ddd, $^3J_{5,6a}$=6.7, $^3J_{5,6b}$=6.7, $^3J_{4,5}$=10.5 Hz, 1H, H-5), 3.25 (s, 6H, OCH$_3$), 2.14 (s, 3H, H$_{Ac}$), 2.11 (s, 3H, H$_{Ac}$), 2.08 (s, 3H, H$_{Ac}$), 2.06 (s, 3H, H$_{Ac}$), 2.03 (s, 3H, H$_{Ac}$), 2.02 (s, 3H, H$_{Ac}$), 2.00 (s, 3H, H$_{Ac}$), 1.87 (s, 3H, H$_{Ac}$), 1.31 (d, $^3J_{5',6'}$=6.5 Hz, 3H, H-6′), 1.08 (s, 9H, SiC(CH$_3$)$_3$) ppm; ^{13}C NMR (126 MHz, CDCl$_3$)=170.4–169.4 (CH$_3$*C*O), 136.5–134.5 (C$_{arom}$), 130.5–126.9 (C$_{arom}$), 114.6 (C-2$_{bu}$), 114.1 (C-3$_{bu}$), 105.0 (C-1′), 102.9 (C$_{aectal}$), 99.9 (C-1″), 98.9 (C-1) 80.8 (C-4), 79.5 (C-4′), 76.8 (C-3′), 75.6 (C-3), 74.0 (C-5), 71.1 (C-3″), 70.6 (C-5″), 70.0 (C-2′), 69.1 (C-2″), 68.9 (C-5′), 68.8 (C-4$_{bu}$), 68.2 (C-1$_{bu}$), 66.5 (C-4″), 61.4 (C-6), 60.8 (C-6″), 52.8 (C-2), 52.4 (OCH$_3$), 26.7 (SiC(*C*H$_3$)), 24.0–20.3 (*C*H$_3$CO), 19.1 (Si*C*(CH$_3$)), 15.8 (C-6′) ppm; HRMS (ESI): calcd for $C_{63}H_{83}NO_{25}SiNa^+$: 1304.4916, found: 1304.4902 [M+Na]$^+$.

*4.6.2. (E)-4-(4-Dimethoxymethylphenoxy)-but-2-enyl 2-acetamido-4-O-(2,3,4,6-tetra-O-acetyl-β-D-glucopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-3-O-(2,3,4-tri-O-acetyl-α-L-fucopyranosyl)-β-D-glucopyranoside (**53**).* Obtained from reaction of allyl glycoside **44** (296 mg, 269 μmol) with compound **16** (530 mg, 2.56 mmol) and Grubbs–Hoveyda second generation catalyst (17 mg, 27 μmol) as a colorless solid (300 mg, 234 μmol, 87%). R_f=0.44 (EE); mp 160 °C; $[\alpha]_D^{20}$ +23.8 (*c* 1.0, CHCl$_3$); ^{1}H NMR (500 MHz, CDCl$_3$): δ=7.79–7.60 (m, 4H, H$_{arom}$), 7.52–7.34 (m, 6H, H$_{arom}$), 7.32 (d, $^3J_{Ar}$=8.5 Hz, 2H, H-1$_{arom}$), 6.85 (d, $^3J_{Ar}$=8.5 Hz, 2H, H-2$_{arom}$), 5.96–5.81 (m, 2H, H-2$_{bu}$, H-3$_{bu}$), 5.78 (d, $^3J_{2,\ HNAc}$=8.2 Hz, 1H, H$_{NAc}$), 5.39 (d, $^3J_{1',2'}$=3.1 Hz, 1H, H-1′), 5.30 (s, 1H, H$_{acetal}$), 5.19–4.99 (m, 5H, H-2′, H-4′, H-5′, H-2″, H-4″), 4.95 (dd, $^3J_{3',4'}$=3.5, $^3J_{2',3'}$=9.3 Hz, 1H, H-3′), 4.89 (dd, $^3J_{2'',3''}$=9.5, $^3J_{3'',4''}$=9.5 Hz, 1H, H-3″), 4.60 (d, $^3J_{1'',2''}$=8.9 Hz, 1H, H-1″), 4.57 (d, $^3J_{1,2}$=8.0 Hz, 1H, H-1), 4.51–4.46 (m, 2H, H-4$_{bu}$), 4.37–4.32 (m, 1H, H-1a$_{bu}$), 4.21–4.16 (m, 2H, H-4, H-6a″), 4.05–3.92 (m, 5H, H-2, H-3, H-6ab, H-6b″, H-1b$_{bu}$), 3.54 (ddd, $^3J_{4,5}$=9.8 $^3J_{5,6a}$=6.3, $^3J_{5,6b}$=2.1 Hz, 1H, H-5), 3.25 (s, 6H, OCH$_3$), 2.15 (s, 3H, H$_{Ac}$), 2.13 (s, 3H, H$_{Ac}$), 2.10 (s, 3H, H$_{Ac}$), 2.08 (s, 3H, H$_{Ac}$), 2.04 (s, 3H, H$_{Ac}$), 2.01 (s, 3H, H$_{Ac}$), 2.00 (s, 3H, H$_{Ac}$), 1.85 (s, 3H, H$_{Ac}$), 1.32 (d, $^3J_{5',6'}$=6.5 Hz, 3H, H-6′), 1.08 (s, 9H, SiC(CH$_3$)$_3$) ppm; ^{13}C NMR (126 MHz, CDCl$_3$): δ=171.3–169.0 (CH$_3$*C*O), 136.5–126.9 (C$_{arom}$), 114.2 (C-2$_{bu}$), 114.1 (C-3$_{bu}$), 103.2 (C-1′), 102.3 (C$_{aectal}$), 99.7 (C-1) 99.5 (C-1″), 82.0 (C-4), 80.0 (C-3), 75.0 (C-3′), 74.5 (C-5), 70.6 (C-5″), 70.3 (C-2′), 69.0 (C-3″), 69.0 (C-2″), 68.8 (C-4$_{bu}$), 68.4 (C-5′), 67.9 (C-1$_{bu}$), 67.7 (C-4′), 66.5 (C-4″), 61.8 (C-6′), 61.2 (C-6), 52.5 (O*C*H$_3$), 51.9 (C-2), 26.9 (SiC(*C*H$_3$)), 24.0–20.3 (*C*H$_3$CO), 19.0 (Si*C*(CH$_3$)), 15.7 (C-6′) ppm; HRMS (ESI): calcd for $C_{63}H_{83}NO_{25}SiNa^+$: 1304.4916, found: 1304.4889 [M+Na]$^+$.

*4.6.3. (E)-4-(4-Dimethoxymethylphenoxy)-but-2-enyl 2-acetamido-4-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-3-O-(2,3,4,6-tetra-O-acetyl-α-L-galactopyranosyl)-β-D-glucopyranoside (**54**).* Obtained from reaction of allyl glycoside **46** (452 mg, 390 μmol) with compound **16** (810 mg, 3.90 mmol) and Grubbs–Hoveyda second generation catalyst (24 mg, 39 μmol) as a colorless solid (445 mg, 332 μmol, 85%). R_f=0.36 (EE); mp 171 °C; $[\alpha]_D^{20}$ +41.5 (*c* 1.0, CHCl$_3$); ^{1}H NMR (500 MHz, CDCl$_3$): δ=7.74–7.67 (m, 4H, H$_{arom}$), 7.48–7.30 (m, 8H, H$_{arom}$), 6.84 (d, $^3J_{Ar}$=8.0 Hz, 2H, H-2$_{arom}$), 6.00 (d, $^3J_{2,HNAc}$=7.8 Hz, 1H, H$_{NAc}$), 5.97–5.79 (m, 2H, H-2$_{bu}$, H-3$_{bu}$), 5.36 (d, $^3J_{3',4'}$=3.0 Hz, 1H, H-4′), 5.34–5.31 (m, 2H, H-4″, H$_{acetal}$), 5.15 (dd, $^3J_{1',2'}$=3.6, $^3J_{2',3'}$=9.4 Hz, 1H, H-2′), 5.06–4.99 (m, 2H, H-3′, H-2″), 4.95–4.91 (m, 2H, H-1′, H-3″), 4.80 (d, $^3J_{1,2}$=7.8 Hz, 1H, H-1), 4.60 (d, $^3J_{1'',2''}$=8.0 Hz, 1H, H-1″), 4.51–4.47 (m, 2H, H-4$_{bu}$), 4.39–4.16 (m, 4H, H-3, H-6′ab, H-1a$_{bu}$), 4.11–3.99 (m, 3H, H-4, H-6″ab, H-1b$_{bu}$), 3.97–3.89 (m, 3H, H-6ab, H-5′), 3.62 (ddd, $^3J_{1,2}$=7.8, $^3J_{2,3}$=7.2 Hz $^3J_{2,HNAc}$=7.8 Hz, 1H, H-2), 3.55 (dd, $^3J_{5'',6a''}$=6.6, $^3J_{5'',6a''}$=6.9 Hz, 1H, H-5″), 3.39–3.31 (m, 1H H-5), 3.28 (s, 6H, OCH$_3$), 2.17 (s, 3H, H$_{Ac}$), 2.16 (s, 3H, H$_{Ac}$), 2.10 (s, 3H, H$_{Ac}$), 2.08 (s, 3H, H$_{Ac}$), 2.06 (s, 3H, H$_{Ac}$), 2.03 (s, 3H, H$_{Ac}$), 2.00 (s, 3H, H$_{Ac}$), 1.99 (s, 3H, H$_{Ac}$), 1.95 (s, 3H, H$_{Ac}$), 1.07 (s, 9H, SiC(CH$_3$)$_3$) ppm; ^{13}C NMR (126 MHz, CDCl$_3$): δ=170.9–168.5 (CH$_3$CO), 136.0–127.4 (C$_{arom}$), 114.1 (C-2$_{bu}$), 113.4 (C-3$_{bu}$), 103.0 (C$_{aectal}$), 100.2 (C-1′), 98.9 (C-1), 98.7 (C-1″), 75.5 (C-5), 74.3 (C-4), 74.2 (C-3), 71.1 (C-5′), 70.7 (C-3′), 70.7 (C-5″), 70.4 (C-3″), 69.4 (C-1$_{all}$), 69.1 (C-2″), 69.0 (C-2′), 68.8 (C-4$_{bu}$), 68.7 (C-4′), 67.9 (C-1$_{bu}$), 67.4 (C-4″), 62.5 (C-6), 61.3 (C-6′), 60.9 (C-6″), 54.9 (C-2), 52.5 (OCH$_3$), 26.6 (SiC(CH$_3$)), 23.1–20.1 (CH$_3$CO), 19.1 (SiC(CH$_3$)) ppm; HRMS (ESI): calcd for $C_{65}H_{85}NO_{27}SiNa^+$: 1362.4976, found: 1362.4943 [M+Na]$^+$.

4.6.4. (E)-4-(4-Dimethoxymethylphenoxy)-but-2-enyl 2-acetamido-4-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-3-O-(2,3,4-tri-O-

*acetyl-α-L-rhamnopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-β-D-glucopyranoside (**55**).* Obtained from reaction of allyl glycoside **47** (553 mg, 502 μmol) with compound **16** (1.04 g, 5.00 mmol) and Grubbs–Hoveyda second generation catalyst (31 mg, 50 μmol) as a colorless solid (540 mg, 422 μmol, 84%). R_f=0.35 (EE); mp 166 °C; $[\alpha]_D^{20}$ +5.7 (*c* 0.25, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ=7.81–7.70 (m, 4H, H_{arom}), 7.48–7.35 (m, 6H, H_{arom}), 7.31 (d, $^3J_{Ar}$=8.1 Hz, 2H, H-1_{arom}), 6.84 (d, $^3J_{Ar}$=8.1 Hz, 2H, H-2_{arom}), 6.15 (s, 1H, H_{NHAc}), 5.97–5.82 (m, 2H, H-2_{bu}, H-3_{bu}), 5.33 (s, 1H, H_{acetal}), 5.31 (d, $^3J_{3'',4''}$=3.4 Hz, 1H, H-4″), 5.25 (dd, $^3J_{2',3'}$=3.5, $^3J_{3',4'}$=9.9 Hz, 1H, H-3′) 5.19 (dd, $^3J_{1',2'}$=1.8, $^3J_{2',3'}$=3.5 Hz, 1H, H-2′), 5.12 (dd, $^3J_{3',4'}$=9.9, $^3J_{4',5'}$=9.9 Hz, 1H, H-4′), 5.06 (dd, $^3J_{1',2'}$=1.8, $^3J_{2'',3''}$=10.5 Hz, 1H, H-2″), 4.93 (dd, $^3J_{3'',4''}$=3.4, $^3J_{2'',3''}$=10.5 Hz, 1H, H-3″), 4.90 (d, $^3J_{1',2'}$=1.8 Hz, 1H, H-1′), 4.84 (d, $^3J_{1,2}$=7.4 Hz, 1H, H-1), 4.80 (d, $^3J_{1,2}$=8.1 Hz, 1H, H-1″), 4.50–4.48 (m, 2H, H-4_{bu}), 4.46 (qd, $^3J_{5',6'}$=6.1, $^3J_{4',5'}$=9.9 Hz, 1H, H-5′), 4.35–4.20 (m, 3H, H-3, H-6a, $1a_{bu}$), 4.13–4.07 (m, 2H, H-6b, H-$1b_{bu}$), 4.06–3.94 (m, 3H, H-4, H-6″ab), 3.79 (dd, $^3J_{5,6a}$=6.8, $^3J_{5,6b}$=6.8 Hz, 1H, H-5), 3.53–3.42 (m, 1H, H-2), 3.33–3.25 (m, 7H, H-5″, OCH_3), 2.15 (s, 3H, H_{Ac}), 2.10 (s, 3H, H_{Ac}), 2.02 (s, 6H, 2×H_{Ac}), 1.98 (s, 9H, 3×H_{Ac}), 1.92 (s, 3H, H_{Ac}), 1.25 (d, $^3J_{5',6'}$=6.1 Hz, 3H, H-6′), 1.07 (s, 9H, $SiC(CH_3)_3$) ppm; ^{13}C NMR (101 MHz, $CDCl_3$): δ=172.1–168.8 (CH_3CO), 136.8–127.4 (C_{arom}), 115.0 (C-2_{bu}), 114.1 (C-3_{bu}), 101.9 (C_{aectal}), 99.4 (C-1″), 98.1 (C-1′), 97.7 (C-1), 75.7 (C-3), 75.0 (C-5), 74.4 (C-4), 71.1 (C-4′), 70.7 (C-5″), 70.6 (C-3″), 70.1 (C-3′), 69.3 (C-1_{all}), 68.9 (C-2′), 68.7 (C-2″), 68.0 (C-4_{bu}), 67.6 (C-1_{bu}), 67.0 (C-4″), 66.3 (C-5′), 62.1 (C-6″), 61.5 (C-6), 54.9 (C-2), 53.1 (OCH_3), 29.6 (C-6′), 27.1 ($SiC(CH_3)$), 23.7–19.9 (CH_3CO), 19.3 ($SiC(CH_3)$) ppm; HRMS (ESI): calcd for $C_{63}H_{83}NO_{25}SiNa^+$: 1304.4916, found: 1304.4910 $[M+Na]^+$.

*4.6.5. (E)-4-(4-Dimethoxymethylphenoxy)-but-2-enyl 2-acetamido-4-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-3-O-(2,3,4-tri-O-acetyl-β-L-fucopyranosyl)-β-D-glucopyranoside (**56**).* Obtained from reaction of allyl glycoside **42** (185 mg, 168 μmol) with compound **16** (315 mg, 1.51 mmol) and Grubbs–Hoveyda second generation catalyst (11 mg, 17 μmol) as a colorless solid (169 mg, 132 μmol, 79%). R_f=0.42 (EE); mp 179 °C; $[\alpha]_D^{20}$ +2.6 (*c* 0.25, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ=7.80–7.57 (m, 4H, H_{arom}), 7.55–7.29 (m, 8H, H_{arom}), 6.85 (d, $^3J_{Ar}$=8.0 Hz, 2H, H-2_{arom}), 6.10 (s, 1H, H_{NAc}), 5.93–5.79 (m, 2H, H-2_{bu}, H-3_{bu}), 5.35–5.31 (m, 2H, H-4″, H_{acetal}), 5.21 (d, $^3J_{3',4'}$=3.3 Hz, 1H, H-4′), 5.08 (dd, $^3J_{1'',2''}$=8.0, $^3J_{2'',3''}$=10.5 Hz, 1H, H-2″), 5.00 (dd, $^3J_{3',4'}$=3.3, $^3J_{2',3'}$=10.5, 3.44 Hz, 1H, H-3′), 4.95 (d, $^3J_{1',2'}$=8.1 Hz, 1H, H-1′), 4.91 (dd, $^3J_{3'',4''}$=3.1, $^3J_{2'',3''}$=10.5 Hz, 1H, H-3″), 4.88 (d, $^3J_{1,2}$=7.8 Hz, 1H, H-1), 4.62 (d, $^3J_{1'',2''}$=8.0 Hz, 1H, H-1″), 4.50–4.47 (m, 2H, H-4_{bu}), 4.38–4.26 (m, 2H, H-3, H-$1a_{bu}$), 4.13–4.08 (m, 2H, H-6″), 4.10–4.00 (m, 2H, H-4, H-$1b_{bu}$), 3.94–3.89 (m, 2H, H-6), 3.82 (q, $^3J_{5',6'}$=6.1 Hz, 1H, H-5′), 3.65 (dd, $^3J_{1,2}$=8.0, $^3J_{2,3}$=9.5 Hz, 1H, H-2), 3.57 (dd, $^3J_{5'',6a''}$=6.7, $^3J_{5'',6a''}$=6.7 Hz, 1H, H-5″), 3.40–3.30 (m, 1H, H-5), 3.28 (s, 6H, OCH_3), 2.17 (s, 3H, H_{Ac}), 2.13 (s, 3H, H_{Ac}), 2.04 (s, 6H, 2×H_{Ac}), 2.03 (s, 3H, H_{Ac}), 2.00 (s, 3H, H_{Ac}), 1.95 (s, 3H, H_{Ac}), 1.91 (s, 3H, H_{Ac}), 1.22 (d, $^3J_{5',6'}$=6.1 Hz, 3H, H-6′), 1.09 (s, 9H, $SiC(CH_3)_3$) ppm; ^{13}C NMR (126 MHz, $CDCl_3$): δ=171.4–168.4 (CH_3CO), 136.5–126.8 (C_{arom}), 114.1 (C-2_{bu}), 113.8 (C-3_{bu}), 102.5 (C_{aectal}), 100.1 (C-1′), 99.2 (C-1), 98.9 (C-1″), 75.2 (C-5), 74.6 (C-3), 74.2 (C-4), 71.2 (C-3′), 70.7 (C-5″), 70.4 (C-4′), 70.3 (C-3″), 69.6 (C-2′), 69.2 (C-5′), 69.0 (C-2″), 68.8 (C-4_{bu}), 67.5 (C-1_{bu}), 66.5 (C-4″), 62.6 (C-6), 60.5 (C-6″), 54.4 (C-2), 52.5 (OCH_3), 29.4 (C-6′), 26.7 ($SiC(CH_3)$), 23.4–20.1 (CH_3CO), 19.1 ($SiC(CH_3)$) ppm; HRMS (ESI): calcd for $C_{63}H_{83}NO_{25}SiNa^+$: 1304.4916, found: 1304.4936 $[M+Na]^+$.

*4.6.6. (E)-4-(4-Dimethoxymethylphenoxy)-but-2-enyl 2-acetamido-3-O-(2,3,4,6-tetra-O-acetyl-β-D-galactopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-4-O-(2,3,4-tri-O-acetyl-α-L-fucopyranosyl)-β-D-glucopyranoside (**57**).* Obtained from reaction of allyl glycoside **49** (296 mg, 268 μmol) with compound **16** (500 mg, 2.41 mmol) and Grubbs–Hoveyda second generation catalyst (17 mg, 27 μmol) as a colorless solid (255 mg, 199 μmol, 74%). R_f=0.42 (EE); mp 173 °C; $[\alpha]_D^{20}$ −6.9 (*c* 0.5, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ=7.80–7.61 (m, 4H, H_{arom}), 7.55–7.34 (m, 6H, H_{arom}), 7.30 (d, $^3J_{Ar}$=8.4 Hz, 2H, H-1_{arom}), 6.85 (d, $^3J_{Ar}$=8.4 Hz, 2H, H-2_{arom}), 5.96–5.82 (m, 2H, H-2_{bu}, H-3_{bu}), 5.70 (d, $^3J_{2,\ HNAc}$=8.5 Hz, 1H, H_{NAc}), 5.38 (d, $^3J_{3'',4''}$=3.5 Hz, 1H, H-4″), 5.33–5.30 (m, 2H, H-4′, H_{acetal}), 5.27 (dd, $^3J_{3'',4''}$=3.5 $^3J_{2'',3''}$=10.0 Hz, 1H, H-3″) 5.20 (d, $^3J_{1'',2''}$=3.7 Hz, 1H, H-1″), 5.09 (d, $^3J_{1,2}$=8.0 Hz, 1H, H-1), 4.95 (q, $^3J_{5'',6''}$=6.6 Hz, 1H, H-5″), 4.93 (dd, $^3J_{1',2'}$=8.1, $^3J_{2',3'}$=10.4 Hz, 1H, H-2′), 4.91 (dd, $^3J_{1'',2''}$=3.7, $^3J_{2'',3''}$=10.0 Hz, 1H, H-2″), 4.76 (dd, $^3J_{3,4}$=9.4, $^3J_{2,3}$=10.0 Hz, 1H, H-3), 4.71 (dd, $^3J_{3',4'}$=3.3, $^3J_{2',3'}$=10.4 Hz, 1H, H-3′), 4.49 (d, $^3J_{1',2'}$=8.1, 1H, H-1′) 4.42 (dd, $^2J_{6'ab}$=12.0, $^3J_{5',6a'}$=6.5 Hz, 1H, H-6a′), 4.38–4.32 (m, 2H, H-6b′, H-$1a_{bu}$), 4.12–4.05 (m, 2H, H-2, H-$1b_{bu}$), 4.00 (dd, $^3J_{3,4}$=9.4, $^3J_{4,5}$=9.4 Hz, 1H, H-4), 3.93 (dd, $^2J_{6ab}$=11.9, $^3J_{5,6a}$=2.9 Hz, 1H, H-6a), 3.65–3.60 (m, 2H, H-6b, H-5′), 3.56–3.50 (m, 1H, H-5), 3.28 (s, 6H, OCH_3), 2.15 (s, 3H, H_{Ac}), 2.11 (s, 3H, H_{Ac}), 2.08 (s, 3H, H_{Ac}), 2.05 (s, 3H, H_{Ac}), 2.02 (s, 3H, H_{Ac}), 1.99 (s, 3H, H_{Ac}), 1.95 (s, 3H, H_{Ac}), 1.87 (s, 3H, H_{Ac}), 1.22 (d, $^3J_{5'',6''}$=6.6 Hz, 3H, H-6″), 1.10 (s, 9H, $SiC(CH_3)_3$) ppm; ^{13}C NMR (126 MHz, $CDCl_3$): δ=170.9–169.4 (CH_3CO), 136.3–127.0 (C_{arom}), 114.8 (C-2_{bu}), 114.3 (C-3_{bu}), 102.6 (C_{aectal}), 101.2 (C-1″), 97.1 (C-1′), 96.5 (C-1), 76.7 (C-3), 74.5 (C-5) 74.0 (C-4), 72.8 (C-3″), 72.2 (C-4′), 71.2 (C-5′), 70.9 (C-2″), 69.0 (C-1_{bu}), 68.8 (C-4_{bu}), 68.6 (C-5″), 67.4 (C-2′), 66.7 (C-3′), 64.3 (C-4″), 62.3 (C-6), 60.8 (C-6′), 59.2 (C-2), 52.1 (OCH_3), 26.7 ($SiC(CH_3)$), 24.0–20.3 (CH_3CO), 19.1 ($SiC(CH_3)$), 15.8 (C-6″) ppm; HRMS (ESI): calcd for $C_{63}H_{83}NO_{25}SiNa^+$: 1304.4916, found: 1304.4974 $[M+Na]^+$.

*4.6.7. (E)-4-(4-Dimethoxymethylphenoxy)-but-2-enyl 2-acetamido-4-O-(2,3,4,6-tetra-O-acetyl-β-L-galactopyranosyl)-6-O-tert-butyldiphenylsilyl-2-deoxy-3-O-(2,3,4-tri-O-acetyl-α-D-fucopyranosyl)-β-D-glucopyranoside (**58**).* Obtained from reaction of allyl glycoside **51** (340 mg, 310 μmol) with compound **16** (583 mg, 2.80 mmol) and Grubbs–Hoveyda second generation catalyst (19 mg, 31 μmol) as a colorless solid (218 mg, 170 μmol, 55%). R_f=0.41 (EE); mp 175 °C; $[\alpha]_D^{20}$ +22.3 (*c* 0.5, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$): δ=7.78–7.65 (m, 4H, H_{arom}), 7.45–7.31 (m, 8H, H_{arom}), 6.91 (d, $^3J_{Ar}$=8.3 Hz, 2H, H-2_{arom}), 5.96–5.80 (m, 2H, H-2_{bu}, H-3_{bu}), 5.73 (d, $^3J_{NH,2}$=8.2 Hz, 1H, NHAc), 5.40 (d, $^3J_{1',2'}$=3.0 Hz, 1H, H-1′), 5.36 (dd, $^3J_{4',5'}$=0.5, $^3J_{3',4'}$=3.3 Hz, 1H, H-4″), 5.29 (s, 1H, H_{acetal}), 5.22–4.99 (m, 4H, H-2′, H-4′, H-5′, H-2″), 4.95–4.88 (m, 2H, H-3′, H-3″), 4.81 (d, $^3J_{1,2}$=8.5 Hz, 1H, H-1), 4.75 (d, $^3J_{1'',2''}$=7.8 Hz, 1H, H-1″), 4.51–4.47 (m, 2H, H-4_{bu}) 4.38–4.35 (m, 1H, H-$1a_{bu}$), 4.17–4.05 (m, 3H, H-6″a,b, H-$1b_{bu}$), 4.02 (dd, $^3J_{4,5}$=9.3, $^3J_{3,4}$=9.9 Hz, 1H, H-4), 3.96–3.78 (m, 4H, H-3, H-6ab, H-5″), 3.55 (ddd, $^3J_{2,NH}$=8.2, $^3J_{1,2}$=8.5, $^3J_{2,3}$=9.9 Hz, 1H, H-2), 3.44 (ddd, $^3J_{5,6a}$=5.3, $^3J_{5,6b}$=6.2, $^3J_{4,5}$=9.3 Hz, 1H, H-5), 3.27 (s, 6H, OCH_3), 2.16 (s, 3H, H_{Ac}), 2.15 (s, 3H, H_{Ac}), 2.10 (s, 3H, H_{Ac}), 2.08 (s, 3H, H_{Ac}), 2.06 (s, 3H, H_{Ac}), 2.03 (s, 3H, H_{Ac}), 1.99 (s, 3H, H_{Ac}), 1.72 (s, 3H, H_{Ac}), 1.28 (d, $^3J_{5',6'}$=6.5 Hz, 3H, H-6′), 1.07 (s, 9H, $SiC(CH_3)_3$) ppm; ^{13}C NMR (126 MHz, $CDCl_3$): δ=171.0–168.2 (CH_3CO), 136.6–127.0 (C_{arom}), 114.4 (C-2_{bu}), 114.3 (C-3_{bu}), 103.2 (C-1′), 102.7 (C_{aectal}), 101.9 (C-1″), 99.5 (C-1), 79.9 (C-4′), 79.3 (C-4), 76.8 (C-3′), 76.3 (C-3), 75.7 (C-5), 72.6 (C-3′), 72.2 (C-5″), 71.4 (C-2″), 70.3 (C-2′), 69.9 (C-1_{all}), 69.3 (C-4″), 69.0 (C-4_{bu}), 68.8 (C-5′), 68.8 (C-4_{bu}), 68.0 (C-1_{bu}), 62.5 (C-6), 62.0 (C-6″), 54.8 (C-2), 52.5 (OCH_3), 26.6 ($SiC(CH_3)$), 24.0–20.3 (CH_3CO), 19.2 ($SiC(CH_3)$), 16.0 (C-6′) ppm; HRMS (ESI): calcd for $C_{63}H_{83}NO_{25}SiNa^+$: 1304.4916, found: 1304.4941 $[M+Na]^+$.

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