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Synthesis of some 2-alkoxy glyco-[2,1-*d*]-2-oxazolines and evaluation of their glycosylation reactivity

Sergey S. Pertel [a,*], Leonid O. Kononov [b], Alexander I. Zinin [b], Vasily Ja. Chirva [a], Elena S. Kakayan [a]

[a] Department of Organic and Biological Chemistry, V.I. Vernadsky Taurida National University, Vernadsky ave. 4, 95007 Simferopol, Crimea, Ukraine
[b] N.D. Zelinsky Institute of Organic Chemistry of the Russian Academy of Sciences, Leninsky prosp., 47, 119991 Moscow, Russian Federation

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ABSTRACT

The synthesis of the title compounds using intramolecular nucleophilic substitution reactions in the molecules of the corresponding 2-alkoxycarbonylamino-2-deoxy glucosyl halides was studied. It was found that in contrast to the 2-alkyl (aryl) glyco-[2,1-*d*]-2-oxazolines, the synthesis of the target 2-alkoxy glyco-[2,1-*d*]-2-oxazolines was possible only in highly basic media. The synthesized 2-alkoxy oxazoline derivatives turned out to be active glycosyl donors and were used for stereoselective 1,2-*trans* glycosylation reactions catalyzed by weak protic acid under very mild conditions, thus preventing anomerization and other side reactions. As a result of this glycosylation, the glycoside and oligosaccharide derivatives containing urethane N-protecting groups were formed.

1. Introduction

Considering that 2-amino-2-deoxy sugars are abundant in naturally occurring oligosaccharides which play important biological roles,[1] the preparation of sugar derivatives with glycosaminide bonds is of great interest. However, the achievement of this goal is often complicated, because the glycosaminide synthesis, as a rule, is less effective than the preparation of other glycosides.[2]

Many glycosyl donors have been suggested for the synthesis of glycosaminides and those bearing 2-phthalimido group are probably the best in terms of reactivity, 1,2-*trans*-stereoselectivity and overall efficiency of glycosylation.[3,4] This group is compatible with a vast number of leaving groups. However, it is notoriously difficult or sometimes even impossible to remove the *N*-phthaloyl protecting group in the presence of some functional groups like esters, reactive halogens or multiple bonds since this process requires rather harsh conditions.[3,4] Therefore, introduction of new efficient glycosylation methods obviating these difficulties can be considered useful.

It is thought that the synthesis of 2-acylamino-2-deoxy sugar glycosides, which mostly occurs as nucleophilic substitution at the anomeric center of a glycosyl donor, is usually accompanied by participation of neighboring acylamino group. This participation leads to the intermediate oxazoline derivatives and favors formation of 1,2-*trans* glycoside bonds (Scheme 1).[3–6]

The effectiveness of a glycosylating agent is determined by reactivity of oxazolinium intermediate. Inasmuch as only poorly reactive 2-methyl glycooxazoline derivatives (R = CH_3) arise during activation of 2-acetamido-2-deoxy glycosyl donors, they are used rarely at the present time in spite of the fact that their use provides high stereoselectivity and considerable decrease in the number of synthetic steps.[3,6]

More reactive glycooxazolines possess electron withdrawing substituents at the second position of oxazoline cycle. In particular, the corresponding 2-trichloromethyl[7–11] (R = CCl_3) and trifluoromethyl[12,13] (R = CF_3) glycooxazolines were synthesized and shown to be able to glycosylate poorly reactive secondary carbohydrate hydroxyls.[9,14] It was assumed[3,6] that analogous oxazoline derivatives arose during glycosylation when highly reactive glycosyl donors, which bear urethane N-protecting groups, are used. Such glycosyl donors are valuable glycosylating agents due to their high reactivity.[3,4] In particular, a comparative study of glycosylation activity of widely used 2-phtalimido derivatives and their 2-(2,2,2-trichloroethoxycarbonylamino) (*N*-Troc) analogs showed that *N*-Troc derivatives were approximately 30 times more reactive.[15] The isolation of the corresponding oxazoline intermediates is of interest because this may confirm the expected glycosylation mechanism. On the other hand, the synthesized glycooxazolines, in the case of their sufficient stability, could be used as new promising glycosyl donors, which would be not only highly reactive but also stereoselective, similarly to the 2-alkyl (aryl) glyco-[2,1-*d*]-2-oxazolines. The use of isolated 2-alkoxy glyco-[2,1-*d*]-2-oxazolines as glycosylating agents, rather than their generation in situ,

* Corresponding author. Tel.: +380 652 608 379; fax: +380 652 637589.
E-mail addresses: orgchem@crimea.edu, sergepertel@yahoo.com (S.S. Pertel).

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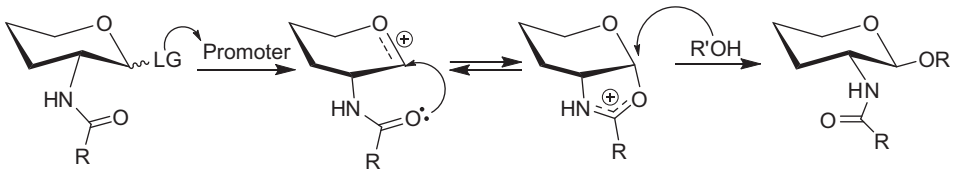


Scheme 1. Formation of the oxazolinium intermediate during the synthesis of glycosides of 2-acylamino-2-deoxy sugars.

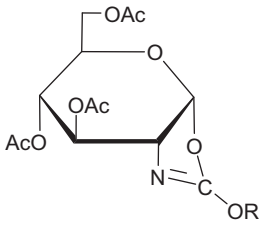
offers additional possibilities for controlling glycoside synthesis in terms of effectiveness, stereoselectivity, and minimization of side reactions. As a result of such glycosylation, glycosaminides with the corresponding urethane N-protecting groups could be obtained under new conditions that are different from those used to generate the oxazolines in situ.

Here we attempted to synthesize 2-alkoxy glycooxazolines using intramolecular nucleophilic substitution reactions in the molecules of the corresponding glycosyl halides containing urethane N-protecting groups and studied their ability to act as glycosyl donors.

2. Results and discussion

Since 2-alkoxy glycooxazolinium ions can easily eliminate alkyl carbenium ions with formation of oxazolidinone derivatives,[16–18] isolable 2-alkoxy glycooxazolines must contain alkyl substituents which are unable to form stable carbocations. The stability of carbocations can be considerably decreased when introducing electron withdrawing group into their structure. On the other hand, the presence of electron withdrawing fragments in alkyl substituents, as already mentioned, increases the glycosylating activity of 2-alkyl glycooxazolines. Therefore, taking into account availability of many well developed methods for introduction and removal of 2,2,2-trichloroethoxycarbonyl N-protecting groups,[19–25] 2-(2,2,2-trichloroethoxy) oxazolines, for example **1**, may be considered as the most promising synthetic targets. It is worth mentioning that a similar 2-(2,2,2-trichloroethoxy) glycooxazoline derivative with *galacto*-configuration was obtained, albeit in low yield, as a side product of the reaction of a 4,6-*O*-(di-*tert*-butylsilylene)-2-deoxy-2-(2,2,2-trichloroethoxycarbonylamino) glycosyl donor with 4-methylumbelliferone under Mitsunobu conditions.[26] For the comparative analysis of the properties of 2-alkoxy oxazolines, the preparation of oxazolines **2** and **3** with isobutyloxy and benzyloxy substituents was also attempted in this work (Fig. 1).

Several approaches for the preparation of 2-alkyl or 2-aryl glycooxazolines from N,O-acylated 2-amino-2-deoxy glycosyl halides are described in the literature.[3] All these approaches are based on formation of a good leaving group at the anomeric center of amino sugar derivative as a result of a catalyst action. In this work, we have studied the applicability of these methods for the synthesis of 2-alkoxy glyco-[2,1-*d*]-2-oxazolines using the known glycosyl bromides **4**,[17,27] **5**,[28] and **6**[29] as the starting compounds (Fig. 2).



1 R = Cl_3CCH_2
2 R = $(CH_3)_2CHCH_2$
3 R = $PhCH_2$

Figure 1. Structures of the target compounds.

As it turned out, *N*-alkoxycarbonyl glycosyl halides **4**–**6** do not interact with weak bases in acetonitrile under the conditions of halide ion catalysis according to Lemieux[30] method, but quickly react with $AgClO_4$ or AgOTf in acetonitrile in the presence of pyridine under the conditions of Khorlin and Zurabyan[31–33] method. Nevertheless, 2-alkoxy glycooxazolines cannot be isolated from the reaction mixture even in the latter case. We believe that in the presence of silver salts the intramolecular nucleophilic substitution does occur, but highly reactive intermediate oxazolinium cations quickly undergo side reactions and do not form the target compounds. Therefore, for prevention of side reactions and isolation of target 2-alkoxy glyco-[2,1-*d*]-2-oxazolines it was necessary to deprotonate completely the intermediate oxazolinium derivatives in the reaction mixture. 2-Alkoxy oxazolines, being the isoelectronic analogs of guanidines, are expected to possess higher basicity than 2-alkyl oxazolines which are isoelectronic to amidines. Thus, for the deprotonation of 2-alkoxy oxazolinium cations bases stronger than pyridine are required.

For this reason, we attempted to prepare the target oxazoline derivatives by the reaction of glycosyl halides **4**–**6** with silver perchlorate or triflate in CH_2Cl_2–C_6H_6 mixture at −25 °C in the presence of the excess of Et_3N (Scheme 2). Indeed, under these conditions 2-(2,2,2-trichloroethoxycarbonylamino) and 2-(isobutyloxycarbonylamino) glycosyl bromides **5** and **6** cleanly gave CCl_4-soluble products which were isolated from the reaction mixtures in high yields. Their ESI mass spectra contain peaks of ions with *m*/*z* values that agree with the calculated ones for the corresponding oxazoline derivatives **1** and **2**. However, when 2-(benzyloxycarbonylamino) glycosyl bromide **4** was involved in this reaction, neither the target 2-(benzyloxy) glycooxazoline nor the known oxazolidinone **7**[16,34] could be identified in the reaction mixture.

Oxazolines **1** and **2** can be purified by chromatography on neutral alumina by elution with benzene–triethylamine or diethyl ether–triethylamine mixtures. It should be noted that purification of these compounds could not be accomplished using silica gel column chromatography, even if triethylamine was used as an additive in the eluent, because they are completely decomposed under these conditions.

The absorption band, corresponding to stretching vibrations of N–H bond (3200–3450 cm^{-1}) is absent in the IR spectra of the isolated derivatives **1** and **2**, while the absorption band of C=N bond (1665 cm^{-1}) is present. These spectra are analogous to the spectrum of the known oxazoline **8**.[30–33,35,36] ^1H NMR spectra of obtained products **1** and **2** correspond well to the proposed structures and are analogous to the spectrum of oxazoline **8** (Table 1). The values of coupling constants in these spectra correspond to the $^0S_2$ conformation of the pyranose ring in molecules of the prepared oxazoline derivatives **1** and **2**. Such conformation is also known[36,37] to be characteristic of 2-alkyl (aryl) glyco-[2,1-*d*]-2-oxazolines in solution, in particular, of 2-methyl oxazoline **8**.

Thus, the synthesized compounds were identified as 2-isobutoxy and 2-(2,2,2-trichloroethoxy) glycooxazolines **2** and **1**. The synthesized oxazolines **1** and **2** are quite stable compounds and in the absence of traces of moisture they can be stored in CCl_4

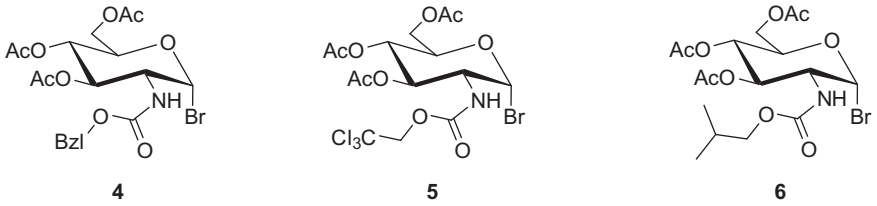
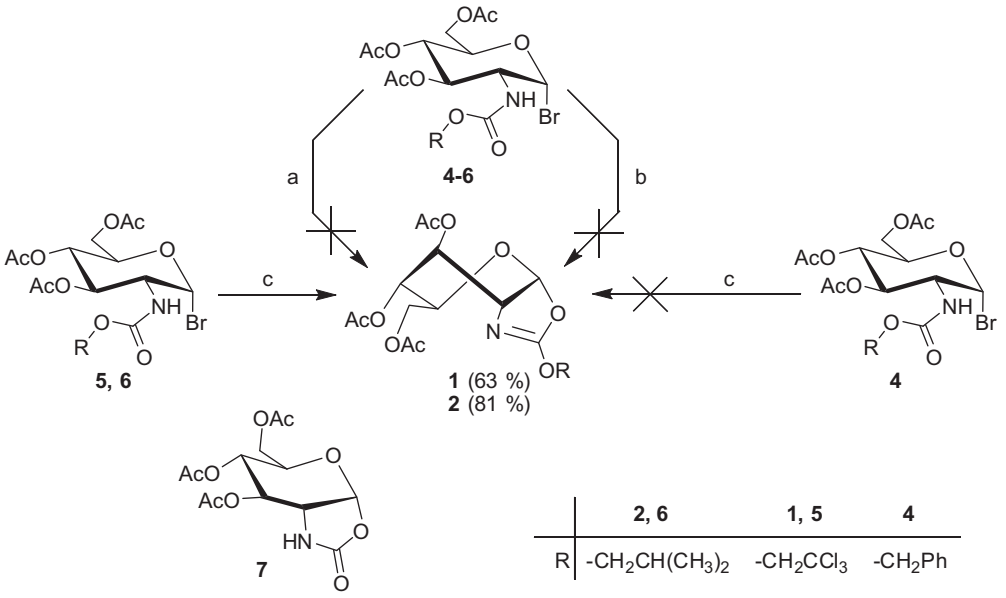


Figure 2. *N*-Alkoxycarbonyl glycosyl halides that were used for the synthesis of the target 2-alkoxy oxazolines.



Scheme 2. The synthesis of the target 2-alkoxy glyco-[2,1-*d*]-2-oxazolines. Reagents and conditions: (a) Et_4NBr, $NaHCO_3$, CH_3CN; (b) AgOTf, Py, CH_3CN; (c) $AgClO_4$, Et_3N, CH_2Cl_2–C_6H_6, −25 °C.

solutions at −15 °C for several months without considerable decomposition.

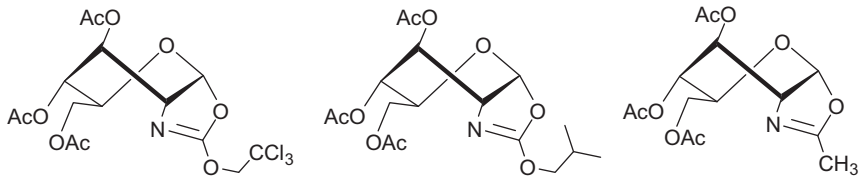
Having prepared glycooxazolines **1** and **2**, we attempted to determine whether synthesized 2-alkoxy oxazoline derivatives possess glycosylating properties, analogously to 2-alkyl (aryl) glyco-[2,1-*d*]-2-oxazolines, and to estimate effectiveness and stereoselectivity of such glycosylation, if it occurs. Because the 2-alkyl (aryl) glyco-[2,1-*d*]-2-oxazoline glycosyl donors interact with glycosyl acceptors under the conditions of acidic catalysis,[3] it should be expected that the glycosylation of alcohols with 2-alkoxy glyco-[2,1-*d*]-2-oxazolines also can be catalyzed by both protic and Lewis acids. Indeed, the synthesized oxazolines **1** and **2**, similarly to 2-alkyl (aryl) glyco-[2,1-*d*]-2-oxazolines, can quickly interact with alcohols at rt in the presence of protic acids (TfOH, $HClO_4$) to give the corresponding 1,2-*trans* glucosaminides with *N*-isobutyloxycarbonyl and *N*-Troc urethane N-protecting groups. However, under these conditions the yields of the products were low, even when the reactive acceptors, such as benzyl alcohol were used. Besides, an increase in concentration of acidic catalyst or time of reaction resulted in formation of considerable quantities of anomeric 1,2-*cis* glucosaminides (α-isomer **9α** was formed in 80% yield when 1 equiv of TfOH was used), apparently due to anomerization of initially formed 1,2-*trans* glycosides in highly acidic medium. Side reactions of reactive 2-alkoxy oxazolinium salts could be the cause of low yields of glycosylation products. Decreasing concentration of acidic catalyst should lead to minimization of side processes. On the other hand, owing to presumed high basicity of 2-alkoxy glycooxazolines, they should be protonated with quite weak acids. Indeed, glycosylation of alcohols with oxazolines **1** and **2** in dichloromethane was catalyzed effectively with *sym*-collidinium perchlorate; the concentration of the catalyst could be as low as 0.1 mg/mL for the catalyst to exhibit the catalytic effect (Scheme 3).

In this case the glycosylation was performed in practically neutral medium and, as could be expected, anomerization and other side reactions did not occur. Under these conditions the reaction of **1** or **2** with benzyl alcohol led exclusively to the 1,2-*trans* benzyl glycosides **9** and **10** in very good yields (85–95%). In this context it is interesting to note that the reaction of the related 2-(2,2,2-trichloroethoxy)-[3-*O*-(2,3,4,6-tetra-*O*-acetyl-β-D-galactopyranosyl)-4,6-*O*-(di-*tert*-butylsilylene)-1,2-dideoxy-α-D-*galacto*-pyrano]-[2,1-*d*]-2-oxazoline,[26] mentioned above, with 4-methylumbelliferone, although occurred under mild conditions too (no additional acidic catalyst was required), led to the formation of aryl glycoside with 1,2-*cis* configuration at the anomeric center probably due to anomerization promoted by the acidic phenol.

At the same time, in diethyl ether the 2-(2,2,2-trichloroethoxy) oxazoline **1** was more stereoselective than 2-isobutoxy oxazoline **2**. Because the yields of the benzyl glycosides **9** and **10** were both high and nearly equal, we chose the weakly nucleophilic 2,2,2-trichloroethanol **11** to estimate relative reactivity of glycooxazolines **1** and **2**. The corresponding 1,2-*trans*-(2,2,2-trichloroethyl) glycoside **14** could be obtained only when 2-(2,2,2-trichloroethoxy) oxazoline **1** was used as the glycosyl donor (Scheme 4), thus indicating the lower reactivity of 2-isobutoxy oxazoline **2**.

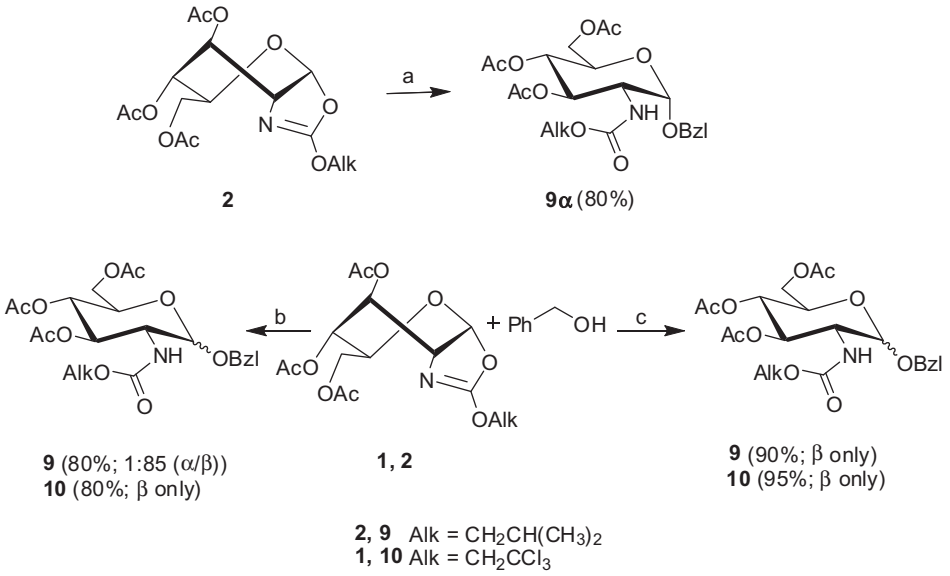
For evaluation of prospects of application of synthesized 2-alkoxy glyco-[2,1-*d*]-2-oxazolines to the formation of 1,2-*trans*

Table 1
^{1}H NMR data of synthesized 2-alkoxy oxazolines **1**, **2**, and 2-methyl oxazoline **8** (δ, ppm)



1 **2** **8**

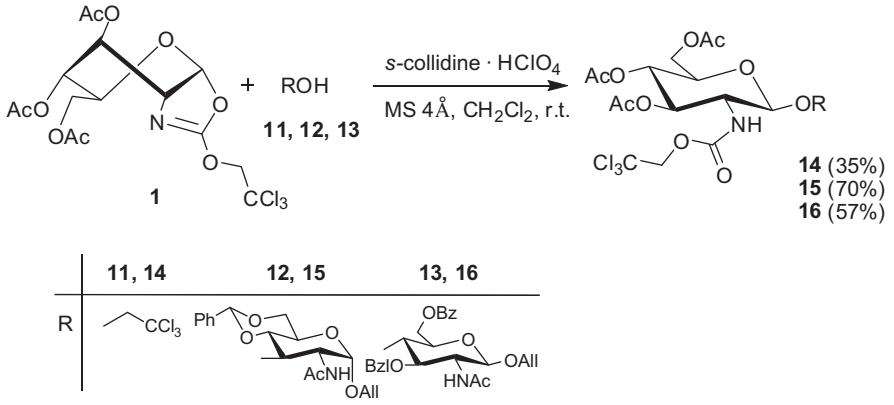
	Compound (solvent)		
	8 ($CDCl_3$)	**2** ($CDCl_3$)	**1** (C_6D_6)
H-1 ($J_{1,2}$ Hz)	5.98 d (7.5)	6.00 d (7.0)	5.62 d (7.0)
H-3 ($J_{3,2}$ Hz)	5.27 dd (2.5)	5.20 br t (2.7)	5.48 br t (2.7)
H-4 ($J_{4,3}$ Hz)	4.93 ddd (2.0)	4.93 ddd (2.4)	5.15 ddd (2.5)
H-6a ($J_{6a,6b}$ Hz)	4.20 dd (12.0) ($J_{6a,5}$ 4.0 Hz)	4.22 dd (12.5) ($J_{6a,5}$ 4.0 Hz)	4.19 dd (12.3) ($J_{6a,5}$ 3.6 Hz)
H-6b ($J_{6b,5}$ Hz)	4.17 dd (5.0)	4.19 dd (4.6)	4.12 dd (4.8)
H-2 ($J_{2,4}$ Hz)	4.14 ddd (1.3)	4.13 ddd (1.1)	3.82 ddd (1.1)
H-5 ($J_{5,4}$ Hz)	3.60 br dt (9.3)	3.80 br dt (9.0)	3.91 br dt (9.4)
CH_3CO	2.08 s, 2.11 s, 2.12 s	2.05 s, 2.08 s, 2.09 s	1.64 s, 1.62 s, 1.56 s
CH_3	2.10 br s	0.97 d (6H) ($J_{CH3,CH}$ 6.8 Hz)	–
$CHaCH(CH_3)_2$ ($J_{CHa,CH}$ Hz)	–	4.07 dd (6.6)	–
$CHbCH(CH_3)_2$ ($J_{CHa,CHb}$ Hz)	–	3.99 dd (10.1) ($J_{CHb,CH}$ 7.0 Hz)	–
$CHaCCl_3$ ($J_{CHa,CHb}$ Hz)	–	–	4.81 d (11.8)
$CHbCCl_3$	–	–	4.57 d
$CH(CH_3)_2$	–	2.13–2.00 m	–



Scheme 3. Estimation of effectiveness and stereoselectivity of glycosylation using 2-alkoxy glyco-[2,1-*d*]-2-oxazoline glycosyl donors. Reagents and conditions: (a) TfOH, MS 4 Å, CH_2Cl_2, rt; (b) *s*-collidine·$HClO_4$, MS 4 Å, Et_2O, rt; (c) *s*-collidine ·$HClO_4$, MS 4 Å, CH_2Cl_2, rt.

glucosaminide bond in oligosaccharides we used carbohydrate glycosyl acceptors. The reactivities of sugar hydroxyls are known to differ considerably and to depend on their nature (primary or secondary hydroxyl), orientation (axial or equatorial), position in the cycle and neighborhood in general.[38,39] One of the least reactive hydroxyl groups of sugars is the hydroxyl group at C-4 of glucopyranose cycle in the molecules of *N*-acetyl-D-glucosamine (GlcNAc) derivatives.[40–42] It is believed[42] that the lack of reactivity of these alcohols arises from combination of steric hindrance of pyranose 4-OH group and ability of acetamido function to participate in strong intra- and/or intermolecular hydrogen bonding.

Thus, for estimation of reactivity of 2-alkoxy glycooxazolines **1** and **2** we used 4-OH glycosyl acceptor **13**,[11] and also carbohydrate alcohol **12**, which was shown[43] to be poor 3-OH glycosyl acceptor in reactions with some glycosyl donors, for example, it could not be glycosylated with 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranosyl bromide[43] (see Scheme 4). As it turned out, 1,2-*trans* glycosylation of these sugar alcohols could be performed by 2-(2,2,2-trichloroethoxy) oxazoline **1** in the presence of catalytic amounts of *sym*-collidinium perchlorate. As a result, the corresponding *N*-Troc protected disaccharide derivatives with 1,2-*trans* glycosidic linkages **15** and **16** were formed in good yields, which confirms effectiveness of this approach to 1,2-*trans* glycosaminide synthesis.



Scheme 4. Glycosylation of poorly reactive glycosyl acceptors using 2-(2,2,2-trichloroethoxy) glycooxazoline **1** as the glycosyl donor.

Thus, 2-alkoxy glyco-[2,1-*d*]-2-oxazolines, especially oxazoline **1**, in contrast to the corresponding 2-alkyl (aryl) glyco-[2,1-*d*]-2-oxazolines, proved to be effective glycosylating agents and may be considered as new valuable glycosyl donors for oligosaccharide synthesis due to their high stereoselectivity and the ability to perform glycosylation in practically neutral media.

3. Conclusions

In summary, we have developed an approach to the synthesis of 2-isobutoxy and 2-(2,2,2-trichloroethoxy) glyco-[2,1-*d*]-2-oxazolines **2** and **1**. The oxazolines **1** and **2** were shown to be reactive and 1,2-*trans* stereoselective glycosyl donors, which could be used for the synthesis of *N*-alkoxycarbonyl protected glycosaminide and oligosaccharide derivatives under very mild conditions as compared to many other methods of glycosaminide synthesis. While new nitrogen protecting groups compatible with glycosylation conditions and capable of nucleophilic participation continue to emerge, the 2-alkoxy glyco-[2,1-*d*]-2-oxazolines described here are not just participating group equivalents. Due to their exceptional reactivity, the new glycosyl donors can be activated under conditions that usually leave other types of glycosyl donors intact. This opens prospects for orthogonal glycosylations, which will be the subject of our further research.

4. Experimental

4.1. General methods

Reagents of reagent grade were purchased from standard vendors (Aldrich and Fluka) and used without additional purification unless otherwise indicated. THF and diethyl ether were boiled under reflux over metallic sodium followed by distillation. CH_2Cl_2, CCl_4, triethylamine, and benzene were distilled over phosphorus pentoxide. Molecular sieves (4 Å) were activated under vacuum at 320 °C for 3 h. *sym*-Collidinium perchlorate was prepared according to the known method,[44] and stored over P_2O_5. All reactions were monitored by TLC, which was performed on silica gel STH-1A-coated aluminum foil (Sorbpolimer, Russian Federation). Visualization of spots of carbohydrate derivatives was effected by exposure of TLC plates to chlorosulfonic acid vapor for 5 min at room temperature followed by heating to ~200 °C. Column chromatography was carried out on Silica Gel 60 (Fluka 220–448 mesh) and on neutral aluminum oxide type 507 C (Fluka 0.05–0.15 mm). ^{1}H NMR spectra were recorded on a Varian Mercury 400 spectrometer (400.49 MHz) or on a Bruker AM300 spectrometer (300.13 MHz). ^{13}C NMR spectra were recorded on a Bruker AM300 spectrometer (75.48 MHz) or on a Bruker AVANCE 600 spectrometer (150.90 MHz). The chemical shifts were referred either to the signal of internal Me_4Si (δ_H 0.0) or to the residual signals of protonated solvent. Assignments of the signals in the NMR spectra were performed using 2D-spectroscopy (COSY, HSQC, HMQC) and DEPT-135 experiments. Optical rotation was measured with a Carl-Zeiss Polamat-S polarimeter. Melting points were determined in capillaries and were uncorrected. IR spectra were recorded on a Carl-Zeiss Specord IR-75 spectrometer in the 400–4000 cm^{-1} range for solutions in CCl_4. Mass spectra (electrospray ionization, ESI) were recorded on a Bruker micrOTOF II mass spectrometer for 2×10^{-5} M solutions in MeCN.

4.2. General procedure for the reaction of *N*-alkoxycarbonyl glycosyl halides (3–6) with silver salts in the presence of triethylamine

Glycosyl halide (0.7 mmol) was dissolved in dichloromethane (4 mL) and the solution obtained was concentrated to half its volume. Powdered molecular sieves (4 Å, 200 mg) were added to the solution and the mixture was cooled to −35 °C. A solution of AgOTf or $AgClO_4$ (obtained by dissolution of AgOTf (234 mg, 1.3 equiv) or of $AgClO_4$ (189 mg, 1.3 equiv) in benzene (6 mL) and concentration of the solution to half its volume) and triethylamine (127 μL, 1.3 equiv) were added to the cooled mixture. After 30 min, when TLC showed the reaction completion, the mixture was filtered and the precipitate was washed with anhydrous CCl_4 (2 × 2 mL). The filtrate and washings were collected and concentrated to dryness in vacuo. The products were isolated by chromatography of the dry residue on a column of neutral alumina using benzene–triethylamine (100:2, v/v) or diethyl ether–triethylamine (100:2, v/v) mixtures as the eluents.

4.3. 2-Isobutoxy-(3,4,6-tri-*O*-acetyl-1,2-dideoxy-α-D-glucopyrano)-[2,1-*d*]-2-oxazoline (2)

Compound **2** was obtained from **6**[29] in 81% yield as a colorless syrup. Analytical data for **2**: $[\alpha]_{546}^{20}$ +11.8 (*c* 2.3, CCl_4); IR (CCl_4): *ν* 2962 and 2872 (CH_3), 1745 and 1240 (ester), and 1665 cm^{-1} (C═N); ^{1}H NMR (300.13 MHz, $CDCl_3$): *δ* 6.00 (d, 1H, $J_{1,2}$ 7.0 Hz, H-1), 5.20 (br t, 1H, $J_{3,2}$ 2.7 Hz, H-3), 4.93 (ddd, 1H, $J_{4,3}$ 2.4 Hz, H-4), 4.22 (dd, 1H, $J_{6a,6b}$ 12.5 Hz, $J_{6a,5}$ 4 Hz, H-6a), 4.19 (dd, 1H, $J_{6b,5}$ 4.6 Hz, H-6b), 4.13 (ddd, 1H, $J_{2,4}$ 1.1 Hz, H-2), 4.07 (dd, 1H, $J_{CHa,CH}$ 6.6 Hz, *CHa*CH(CH_3)$_2$), 3.99 (dd, 1H, $J_{CHb,CHa}$ 10.1 Hz, $J_{CHb,CH}$ 7.0 Hz, C*Hb*CH(CH_3)$_2$), 3.80 (br dt, 1H, $J_{5,4}$ 9.0 Hz, H-5), 2.13– 2.00 (m, 1H, $CH_2CH(CH_3)_2$), 2.09, 2.08, 2.05 (3s, 9H, 3OAc), 0.97 (d, 6H, $J_{CH3,CH}$ 6.8 Hz, 2CH_3); ^{13}C NMR (75.48 MHz, $CDCl_3$): *δ* 170.7,

169.6, 169.3 (CH_3CO), 163.2 (NCO), 100.3 (C-1), 77.4 ($CH_2CH(CH_3)_2$), 71.0 (C-3), 68.0 (C-4), 67.9 (C-5), 63.4 (C-6), 62.9 (C-2), 27.9 ($CH(CH_3)_2$), 21.0, 20.9, 20.8 (CH_3CO), 19.0 (CH_3CH), 18.9 (CH_3CH); HRMS (ESI): *m*/*z* Calcd for $[C_{17}H_{25}NO_9]Na^+$: 410.1427. Found: 410.1426.

4.4. 2-(2,2,2-Trichloroethoxy)-(3,4,6-tri-*O*-acetyl-1,2-dideoxy-α-D-glucopyrano)-[2,1-*d*]-2-oxazoline (1)

Compound **1** was obtained from **5**[28] in 63% yield as a colorless syrup. Analytical data for **1**: $[\alpha]_{546}^{25}$ +20.1 (*c* 1.38, CCl_4); IR (CCl_4): *v* 1745 and 1230 (ester), and 1665 cm^{-1} (C=N); ^1H NMR (300.13 MHz, C_6D_6): δ 5.62 (d, 1H, $J_{1,2}$ 7.0 Hz, H-1), 5.48 (br t, 1H, $J_{3,2}$ 2.7 Hz, H-3), 5.15 (ddd, 1H, $J_{4,3}$ 2.5 Hz, H-4), 4.81 (d, 1H, $J_{CHa,CHb}$ 11.8 Hz, C*Ha*CCl_3), 4.57 (d, 1H, C*Hb*CCl_3), 4.19 (dd, 1H, $J_{6a,6b}$ 12.3 Hz, $J_{6a,5}$ 3.6 Hz, H-6a), 4.12 (dd, 1H, $J_{6b,5}$ 4.8 Hz, H-6b), 3.91 (br dt, 1H, $J_{5,4}$ 9.4 Hz, H-5), 3.82 (ddd, 1H, $J_{2,4}$ 1.1 Hz, H-2), 1.64, 1.62, 1.56 (3s, 9H, 3OAc); ^{13}C NMR (75.48 MHz, C_6D_6): δ 169.9, 169.2, 168.8 (CH_3CO), 162.6 (NCO), 102.0 (C-1), 94.7 (CH_2CCl_3), 79.5 (CH_2CCl_3), 71.5 (C-3), 68.6 (2C, C-5, C-4), 63.3 (C-2), 63.2 (C-6), 20.3 (CH_3CO), 20.2 (2C, CH_3CO); HRMS (ESI): *m*/*z* Calcd for $[C_{15}H_{18}Cl_3NO_9]K^+$: 499.9684. Found: 499.9593.

4.5. Benzyl 3,4,6-tri-*O*-acetyl-2-deoxy-2-(isobutyloxycarbonylamino)-α-D-glucopyranoside (9a)

2-Isobutoxy-(3,4,6-tri-*O*-acetyl-1,2-dideoxy-α-D-glucopyrano)-[2,1-*d*]-2-oxazoline **2** (100 mg, 0.258 mmol) and benzyl alcohol (41.9 μL, 1.5 equiv) were dissolved in CH_2Cl_2 (8 mL) and the solution was concentrated to half its volume. Powdered molecular sieves (4 Å, 200 mg) and trifluoromethanesulfonic acid (22 μL, 1 equiv) were added to the mixture. After 24 h, when TLC showed the reaction completion, the reaction mixture was neutralized by addition of triethylamine (39 μL, 1.3 equiv). Then the solution was concentrated in vacuo and the dry residue was chromatographed on a column of silica gel using $CHCl_3$ → $CHCl_3$–EtOH, 100:0.5 (v/v) solvent systems followed by crystallization from hexane to give **9a** as white crystals (102 mg, 80%): mp 73.5–74 °C; $[\alpha]_{546}^{21}$ +108.6 (*c* 0.8, $CHCl_3$); ^1H NMR (300.13 MHz, $CDCl_3$): δ 7.42-7.28 (m, 5H, Ar-H), 5.24 (br t, 1H, $J_{3,2}$ 10.4 Hz, $J_{3,4}$ 9.6 Hz, H-3), 5.10 (br t, $J_{4,5}$ 9.7 Hz, 1H, H-4), 4.97 (d, 1H, $J_{1,2}$ 3.6 Hz, H-1), 4.92 (d, 1H, $J_{NH,2}$ 10.0 Hz, NH), 4.73 (d, 1H, $J_{PhCHa,PhCHb}$ 11.8 Hz, PhC*Ha*), 4.56 (d, 1H, PhC*Hb*), 4.25 (dd, 1H, $J_{6a,5}$ 4.0 Hz, $J_{6a,6b}$ 12.0 Hz, H-6a), 4.05 (br dt, 1H, H-2), 4.04 (dd, 1H, H-6b), 3.98 (ddd, 1H, $J_{5,6b}$ 2.3 Hz, H-5), 3.86 (dd, 1H, $J_{CHa,CH}$ 6.7 Hz, C*Ha*$CH(CH_3)_2$), 3.76 (dd, 1H, $J_{CHb,CHa}$ 10.4 Hz, $J_{CHb,CH}$ 6.8 Hz, C*Hb*$CH(CH_3)_2$), 2.10, 2.01, 2.00 (3s, 9H, 3OAc), 1.87 (br n, 1H, $J_{CH,CH3}$ 6.7 Hz, $CH_2CH(CH_3)_2$), 0.90 (d, 6H, $2CH_3$); ^{13}C NMR (75.48 MHz, $CDCl_3$): δ 171.1, 170.8, 169.5 (CH_3CO), 156.3 (NHCO), 136.6 (C aromatic), 128.8 (2C, CH aromatic), 128.5 (CH aromatic), 128.3 (2C, CH aromatic), 97.0 (C-1), 71.5 (2C, C-3, $CH_2CH(CH_3)_2$), 70.3 ($PhCH_2$), 68.5 (C-5), 68.1 (C-4), 62.1 (C-6), 53.8 (C-2), 28.1 (CH_3CH), 20.9, 20.8, 20.7 (CH_3CO), 19.1 (2C, CH_3CH); HRMS (ESI): *m*/*z* Calcd for $[C_{24}H_{33}NO_{10}]Na^+$: 518.2002. Found: 518.1997.

4.6. Benzyl 3,4,6-tri-*O*-acetyl-2-deoxy-2-(isobutyloxycarbonylamino)-β-D-glucopyranoside (9b)

4.6.1. Method A

2-Isobutoxy-(3,4,6-tri-*O*-acetyl-1,2-dideoxy-α-D-glucopyrano)-[2,1-*d*]-2-oxazoline **2** (100 mg, 0.258 mmol) and benzyl alcohol (41.9 μL, 1.5 equiv) were dissolved in CH_2Cl_2 (8 mL) and the solution was concentrated to half its volume. Powdered molecular sieves (4 Å, 200 mg) and 0.005 M solution of *sym*-collidinium perchlorate in CH_2Cl_2 (18 μL) were added to the mixture. After approximately 12 h, when TLC showed the reaction completion, the mixture was filtered and the precipitate was washed with CH_2Cl_2 (3 × 2 mL). The filtrate and washings were collected and concentrated to dryness in vacuo. The dry residue was chromatographed on a column of silica gel using $CHCl_3$ → $CHCl_3$–EtOH, 100:0.5 (v/v) solvent systems followed by crystallization from diethyl ether–hexane mixture to give **9b** as white crystals (108 mg, 84%): mp 147.5–148 °C; $[\alpha]_{546}^{23}$ −26.2 (*c* 2.5, $CHCl_3$); ^1H NMR (400.40 MHz, DMSO-d_6): δ 7.33-7.22 (m, 5H, Ar-H), 7.17 (d, 1H, $J_{NH,2}$ 9.1 Hz, NH), 5.09 (br t, 1H, $J_{3,2}$ 9.9 Hz, H-3), 4.85 (br t, 1H, $J_{4,3}$ 9.8 Hz, $J_{4,5}$ 9.8 Hz, H-4), 4.81 (d, 1H, $J_{PhCHa,PhCHb}$ 12.2 Hz, PhC*Ha*), 4.69 (d, 1H, $J_{1,2}$ 8.4 Hz, H-1), 4.57 (d, 1H, PhC*Hb*), 4.21 (dd, 1H, $J_{6a,5}$ 4.7 Hz, $J_{6a,6b}$ 12.2 Hz, H-6a), 4.04 (dd, 1H, $J_{6b,5}$ 1.9 Hz, H-6b), 3.75 (dd, 1H, $J_{CHa,CH}$ 6.8 Hz, C*Ha*$CH(CH_3)_2$), 3.75–3.65 (m, 1H, H-5), 3.70 (dd, 1H, $J_{CHb,CHa}$ 10.7 Hz, $J_{CHb,CH}$ 6.6 Hz, C*Hb*$CH(CH_3)_2$), 3.53 (br q, 1H, H-2), 2.04, 1.97, 1.93 (3s, 9H, 3OAc), 1.84 (br n, 1H, $CH_2CH(CH_3)_2$), 0.89 (d, 6H, $J_{CH3,CH}$ 6.7 Hz, $2CH_3$); ^{13}C NMR (75.48 MHz, $CDCl_3$): δ 170,8, 170.7, 169.6 (CH_3CO), 156.2 (NHCO), 136.9 (C aromatic), 128.6 (2C, CH aromatic), 128.1 (CH aromatic), 128.0 (2C, CH aromatic), 99.9 (C-1), 72.4 (C-3), 72.0 (C-5), 71.5 ($CH_2CH(CH_3)_2$), 70.9 ($PhCH_2$), 68.9 (C-4), 62.3 (C-6), 56.2 (C-2), 28.1 (CH_3CH), 20.9, 20.8, 20.7 (CH_3CO), 19.1, 19.0 (CH_3CH); HRMS (ESI): *m*/*z* Calcd for $[C_{24}H_{33}NO_{10}]Na^+$: 518.2002. Found: 518.2006.

4.6.2. Method B

2-Isobutoxy-(3,4,6-tri-*O*-acetyl-1,2-dideoxy-α-D-glucopyrano)-[2,1-*d*]-2-oxazoline **5** (100 mg, 0.258 mmol) and benzyl alcohol (41.9 μL, 1.5 equiv) were dissolved in anhydrous diethyl ether (8 mL) and the solution was concentrated to half its volume. Powdered molecular sieves (4 Å, 200 mg) and 0.005 M solution of *sym*-collidinium perchlorate in CH_2Cl_2 (18 μL) were added to the mixture. After approximately 16 h, when TLC showed the reaction completion, the mixture was filtered and the precipitate was washed with CH_2Cl_2 (3 × 2 mL). The filtrate and washings were collected and concentrated to dryness in vacuo. The dry residue was chromatographed on a column of silica gel using $CHCl_3$ → $CHCl_3$–EtOH, 100:0.5 (v/v) solvent systems to afford **9β** (102 mg, 80%) and **9α** (1.2 mg, 0.9%).

4.7. Benzyl 3,4,6-tri-*O*-acetyl-2-deoxy-2-(2,2,2-trichloroethoxycarbonylamino)-β-D-glucopyranoside (10)

4.7.1. Method A

2-(2,2,2-Trichloroethoxy)-(3,4,6-tri-*O*-acetyl-1,2-dideoxy-α-D-glucopyrano)-[2,1-*d*]-2-oxazoline **1** (100 mg, 0.216 mmol) and benzyl alcohol (34.9 μL, 1.5 equiv) were dissolved in CH_2Cl_2 (8 mL) and the solution was concentrated to half its volume. Powdered molecular sieves (4 Å, 200 mg) and 0.005 M solution of *sym*-collidinium perchlorate in CH_2Cl_2 (18 μL) were added to the mixture. After approximately 12 h, when TLC showed the reaction completion, the mixture was filtered and the precipitate was washed with CH_2Cl_2 (3 × 2 mL). The filtrate and washings were collected and concentrated to dryness in vacuo. The dry residue was chromatographed on a column of silica gel using $CHCl_3$ → $CHCl_3$–EtOH, 100:0.5 (v/v) solvent systems followed by crystallization from hexane to give **10** as white crystals (116 mg, 94%): mp 122–123 °C; $[\alpha]_{546}^{17}$ −23.9 (*c* 2.8, $CHCl_3$); ^1H NMR (300.13 MHz, $CDCl_3$): δ 7.42–7.27 (m, 5H, Ar-H), 5.23 (dd, 1H, $J_{3,2}$ 9.4 Hz, $J_{3,4}$ 10.6 Hz, H-3), 5.10 (br d, 1H, $J_{NH,2}$ 9.9 Hz, NH), 5.08 (t, 1H, $J_{4,5}$ 9.7 Hz, H-4), 4.92 (d, 1H, $J_{PhCHa,PhCHb}$ 12.1 Hz, PhC*Ha*), 4.71 (br s, 2H, CH_2CCl_3), 4.63 (d, 1H, PhC*Hb*), 4.60 (d, 1H, $J_{1,2}$ 8.9 Hz, H-1), 4.30 (dd, 1H, $J_{6a,5}$ 4.8 Hz, H-6a), 4.18 (dd, 1H, $J_{6b,6a}$ 12.2 Hz, $J_{6b,5}$ 2.4 Hz, H-6b), 3.71 (br q, 1H, H-2), 3.67 (ddd, 1H, $J_{5,4}$ 10.5 Hz, H-5), 2.10, 2.01, 2.00 (3s, 9H, 3OAc); ^{13}C NMR (75.48 MHz, $CDCl_3$): δ

170.8, 170.7, 169.6 (CH_3CO), 154.1 (NHCO), 136.7 (C aromatic), 128.7 (2C, CH aromatic), 128.3 (CH aromatic), 128.1(2C, CH aromatic), 99.4 (C-1), 95.6 (CH_2CCl_3), 74.7 (CH_2CCl_3), 72.1 (C-3), 72.0 (C-5), 70.9 ($PhCH_2$), 68.9 (C-4), 62.2 (C-6), 56.4 (C-2), 20.9, 20.8, 20.7 (CH_3CO); HRMS (ESI): *m*/*z* Calcd for $[C_{22}H_{26}Cl_3NO_{10}]Na^+$: 592.0520. Found: 592.0515.

4.7.2. Method B

2-(2,2,2-Trichloroethoxy)-(3,4,6-tri-*O*-acetyl-1,2-dideoxy-α-D-glucopyrano)-[2,1-*d*]-2-oxazoline **6** (100 mg, 0.216 mmol) and benzyl alcohol (34.9 μL, 1.5 equiv) were dissolved in anhydrous diethyl ether (8 mL) and the solution was concentrated to half its volume. Powdered molecular sieves (4 Å, 200 mg) and 0.005 M solution of *sym*-collidinium perchlorate in CH_2Cl_2 (18 μL) were added to the mixture. After approximately 14 h, when TLC showed the reaction completion, the mixture was filtered and the precipitate was washed with CH_2Cl_2 (3 × 2 mL). The filtrate and washings were collected and concentrated to dryness in vacuo. The dry residue was chromatographed on a column of silica gel using $CHCl_3$ → $CHCl_3$–EtOH, 100:0.5 (v/v) solvent systems to afford **10** (99 mg, 80%).

4.8. 2,2,2-Trichloroethyl 3,4,6-tri-*O*-acetyl-2-deoxy-2-(2,2,2-trichloroethoxycarbonylamino)-β-D-glucopyranoside (14)

2-(2,2,2-Trichloroethoxy)-(3,4,6-tri-*O*-acetyl-1,2-dideoxy-α-D-glucopyrano)-[2,1-*d*]-2-oxazoline **1** (100 mg, 0.216 mmol) and 2,2,2-trichloroethanol **11** (41.7 μL, 2 equiv) were dissolved in CH_2Cl_2 (8 mL) and the solution was concentrated to half its volume. Powdered molecular sieves (4 Å, 200 mg) and 0.1 M solution of *sym*-collidinium perchlorate in CH_2Cl_2 (108 μL) were added to the mixture. After approximately 24 h, when TLC showed the reaction completion, the mixture was filtered and the precipitate was washed with CH_2Cl_2 (3 × 2 mL). The filtrate and washings were collected and concentrated to dryness in vacuo. The dry residue was chromatographed on a column of silica gel using $CHCl_3$ → $CHCl_3$–EtOH, 100:0.5 (v/v) solvent systems followed by crystallization from diethyl ether to give **14** as white crystals (46 mg, 35%): mp 123–124 °C; $[\alpha]_{546}^{21}$ −11.5 (*c* 0.43, CH_3OH); ^1H NMR (300.13 MHz, $CDCl_3$) δ 5.37 (dd, 1H, $J_{3,2}$ 10.7 Hz, $J_{3,4}$ 9.7 Hz, H-3), 5.26 (br d, 1H, $J_{NH,2}$ 9.3 Hz, NH), 5.11 (t, 1H, $J_{4,5}$ 9.7 Hz, H-4), 5.00 (d, 1H, $J_{1,2}$ 8.3 Hz, H-1), 4.77 (d, 1H, $J_{CHa,CHb}$ 11.9 Hz, C*Ha*CCl_3), 4.67 (d, 1H, C*Hb*CCl_3), 4.47 (d, 1H, $J_{CHa,CHb}$ 11.9 Hz, OC*Ha*CCl_3), 4.31 (dd, 1H, $J_{6a,5}$ 4.6 Hz, $J_{6a,6b}$ 12.4 Hz, H-6a), 4.19 (dd, 1H, $J_{6b,5}$ 2.5 Hz, H-6b), 4.18 (d, 1H, OC*Hb*CCl_3), 3.76 (br dt, 1H, H-2), 3.78–3.72 (m, 1H, H-5), 2.11, 2.05, 2.04 (3s, 9H, 3OAc); HRMS (ESI): *m*/*z* Calcd for $[C_{17}H_{21}Cl_6NO_{10}]Na^+$: 631.9194. Found: 631.9190.

4.9. Allyl [3,4,6-tri-*O*-acetyl-2-deoxy-2-(2,2,2-trichloroethoxycarbonylamino)-β-D-glucopyranosyl]-(1→3)-2-acetamido-4,6-*O*-benzylidene-2-deoxy-β-D-glucopyranoside (15)

Allyl 2-acetamido-4,6-*O*-benzylidene-2-deoxy-α-D-glucopyranoside **12**[43] (50 mg, 0.143 mmol) and 2-(2,2,2-trichloroethoxy)-(3,4,6-tri-*O*-acetyl-1,2-dideoxy-α-D-glucopyrano)-[2,1-*d*]-2-oxazoline **1** (100 mg, 0.216 mmol) were dissolved in CH_2Cl_2 (8 mL) and the solution was concentrated to half its volume. Powdered molecular sieves (4 Å, 200 mg) and 0.005 M solution of *sym*-collidinium perchlorate in CH_2Cl_2 (18 μL) were added to the mixture. After 24 h some more 0.005 M solution of *sym*-collidinium perchlorate in CH_2Cl_2 (180 μL) was added to the reaction mixture. After approximately 48 h, when TLC showed the reaction completion, the mixture was filtered and the precipitate was washed with CH_2Cl_2 (3 × 2 mL). The filtrate and washings were collected and concentrated to dryness in vacuo. The dry residue was chromatographed on a column of silica gel using $CHCl_3$ → $CHCl_3$–EtOH, 100:1 (v/v) solvent systems followed by crystallization from chloroform–diethyl ether mixture to give **15** as white crystals (81 mg, 70%). In addition to the target compound **15**, the unreacted allyl glycoside **12** (15 mg) was isolated from the reaction mixture. Taking into account the unreacted **12** the yield of **15** was 99%: mp 208–210 °C; $[\alpha]_{546}^{25}$ +34 (*c* 1.0, CH_3OH); ^1H NMR (300.13 MHz, $CDCl_3$): δ 7.61–7.47 (m, 2H, Ar-H), 7.44–7.32 (m, 3H, Ar-H), 6.25 (d, 1H, $J_{NH,2}$ 7.5 Hz, *NH*Ac), 5.91 (broad decet, 1H, $J_{CH,OCHb}$ 6.0 Hz, J_{cis} 10.4 Hz, J_{trans} 16.7 Hz, OCH_2–*CH*=CH_2), 5.61 (t, 1H, $J_{3,4}$ 9.9 Hz, H^B-3) 5.54 (s, 1H, PhCH), 5.33(ddt, 1H, $J_{CHa,CHb}$ 2.9 Hz, $J_{1',3'}$ 1.5 Hz, OCH_2–CH=CHa), 5.24 (ddt, 1H, $J_{1',3'}$ 1.3 Hz, OCH_2–CH=CHb), 5.23 (br d, 1H, $J_{1,2}$ 8.7 Hz, H^B-1) 5.16 (br d, 1H, $J_{NH,2}$ 6.8 Hz, *NH*Troc) 5.00 (d, 1H, $J_{1,2}$ 3.4 Hz, H^A-1), 4.98 (t, 1H, $J_{4,5}$ 9.7 Hz, H^B-4), 4.67 (d, 1H, $J_{CHa,CHb}$ 12.1 Hz, C*Ha*CCl_3), 4.61 (d, 1H, C*Hb*CCl_3), 4.45 (br d, 1H, $J_{6a,6b}$ 11.9 Hz, H^B-6a), 4.28 (dd, 1H, $J_{6a,6b}$ 9.8 Hz, $J_{6a,5}$ 4.2 Hz, H^A-6a), 4.18 (dddd, 1H, $J_{OCHa,CH}$ 5.4 Hz, O*CHa*CH=CH_2), 4.14 (br dt, 1H, H^A-2), 4.02 (dddd, 1H, $J_{CHb,CHa}$ 12.8 Hz, O*CHb*CH=CH_2), 4.01 (t, 1H, $J_{3,2}$ 9.5 Hz, H^A-3), 3.97 (dd, 1H, $J_{6b,5}$ 2.9 Hz, H^B-6b), 3.85 (br dt, 1H, $J_{5,4}$ 9.1 Hz, H^A-5), 3.76 (br t, 1H, $J_{6b,5}$ 9.9 Hz, H^A-6b), 3.67 (t, 1H, $J_{4,3}$ 9.2 Hz, H^A-4), 3.66 (br dd, 1H, H^B-5), 3.09 (ddd, 1H, $J_{2,3}$ 10.0 Hz H^B-2), 2.07, 2.03, 2.00, 1.82 (4s, 12H, 3OAc+NAc); ^{13}C NMR (75.48 MHz, $CDCl_3$): δ 171.0, 170.6, 169.9 (CH_3CO), 169.8, 153.7, (NHCO), 136.8 (C aromatic), 133.7 (*C*H=CH_2), 129.8 (CH aromatic), 128.8 (2C, CH aromatic), 126.5 (2C, CH aromatic), 118.3 (CH=CH_2), 102.5 (Ph*C*H), 97.6 (C^A-1), 97.0 (C^B-1), 95.6 (CH_2CCl_3), 80.9 (C^A-4), 74.4 (CH_2CCl_3), 72.2 (C^B-5), 71.1 (C^A-3), 70.5 (C^B-3), 69.1 (C^A-6), 69.0 (OCH_2–CH=CH_2), 68.3 (C^B-4), 63.4 (C^A-5), 61.2 (C^B-6), 55.8 (C^B-2), 53.0 (C^A-2), 23.1, 20.9, 20.8, 20.5 (CH_3CO); HRMS (ESI): *m*/*z* Calcd for $[C_{33}H_{41}Cl_3N_2O_{15}]Na^+$: 833.1470. Found: 833.1465.

4.10. Allyl [3,4,6-tri-*O*-acetyl-2-deoxy-2-(2,2,2-trichloroethoxycarbonylamino)-β-D-glucopyranosyl]-(1→4)-2-acetamido-6-*O*-benzoyl-3-*O*-benzyl-2-deoxy-β-D-glucopyranoside (16)

Allyl 2-acetamido-6-*O*-benzoyl-3-*O*-benzyl-2-deoxy-β-D-glucopyranoside **13**[11] (50 mg, 0.111 mmol) and 2-(2,2,2-trichloroethoxy)-(3,4,6-tri-*O*-acetyl-1,2-dideoxy-α-D-glucopyrano)-[2,1-*d*]-2-oxazoline **1** (103 mg, 2 equiv) were dissolved in CH_2Cl_2 (8 mL) and the solution was concentrated to half its volume. Powdered molecular sieves (4 Å, 200 mg) and 0.005 M solution of *sym*-collidinium perchlorate in CH_2Cl_2 (18 μL) were added to the mixture. After 24 h some more 0.005 M solution of *sym*-collidinium perchlorate in CH_2Cl_2 (180 μL) was added to the reaction mixture. After approximately 48 h, when TLC showed the reaction completion, the mixture was filtered and the precipitate was washed with CH_2Cl_2 (3 × 2 mL). The filtrate and washings were collected and concentrated to dryness in vacuo. The dry residue was chromatographed on a column of silica gel using $CHCl_3$ → $CHCl_3$–EtOH, 100:1 (v/v) solvent systems followed by crystallization from chloroform–carbon tetrachloride mixture to give **16** as white crystals (58 mg, 57%). In addition to the target compound **16**, the unreacted allyl glycoside **13** (10 mg) was isolated from the reaction mixture. Taking into account the unreacted **13** the yield of **16** was 72%: mp 193–195 °C (decomp.); $[\alpha]_{546}^{23}$ −1 (*c* 2.0, CH_3OH); ^1H NMR (400.45 MHz, $CDCl_3$): δ 8.06 (dd, 2H, *J* 8.4 Hz, *J* 1.3 Hz, Ar-H), 7.61 (tt, 1H, *J* 7.4 Hz, Ar-H), 7.48 (br t, 2H, *J* 7.9 Hz, Ar-H), 7.34–7.28 (m, 5H, Ar-H), 6.16 (br d, 1H, $J_{NH,2}$ 8.3 Hz, *NH*Ac), 5.87 (br o, 1H, J_{cis} 10.7 Hz, J_{trans} 17.0 Hz, OCH_2–*CH*=CH_2), 5.56 (d, 1H, $J_{NH,2}$ 9.3 Hz, *NH*Troc), 5.26 (br dq, 1H, $J_{CHa,CHb}$ 2.9 Hz, $J_{1',3'}$ 1.5 Hz, OCH_2–CH=CHa), 5.16 (br dq, 1H, $J_{1',3'}$ 1.4 Hz, OCH_2–CH=CHb), 5.09 (dd, 1H, $J_{3,4}$ 9.6 Hz, H^B-3), 5.07 (dd, 1H, $J_{4,5}$ 9.6 Hz, H^B-4) 4.76 (s, 2H, $PhCH_2$), 4.73 (dd, 1H, $J_{6a,5}$ 5.0 Hz, H^A-6a), 4.72 (d, 1H, $J_{1,2}$ 9.0 Hz, H^A-1), 4.69 (d, 1H, C*Ha*CCl_3), 4.68 (d, 1H, $J_{CHb,CHa}$ 12.0 Hz, C*Hb*CCl_3),

4.62 (dd, 1H, $J_{6b,6a}$ 11.5 Hz, $J_{6b,5}$ 3.8 Hz, H^A-6b), 4.54 (d, 1H, $J_{1,2}$ 8.2 Hz, H^B-1), 4.35 (br dd, 1H, $J_{CHa,CHb}$ 13.0 Hz, $J_{CHa,CH}$ 5.0 Hz, O*CHa*CH=CH_2), 4.22 (dd, 1H, $J_{6a,6b}$ 12.4 Hz, $J_{6a,5}$ 4.4 Hz, H^B-6a), 4.04 (br ddt, 1H, $J_{CHb,CH}$ 6.1 Hz, O*CHb*CH=CH_2), 4.01-3.87 (m, 5H, H^B-6b, H^A-5, H^A-3, H^A-4, H^A-2), 3.78 (br q, 1H, $J_{2,3}$ 9.5 Hz, H^B-2), 3.47 (br dt, 1H, H^B-5), 2.03, 2.00, 1.99, 1.94, (4s, 12H, 3OAc+NAc); ^{13}C NMR (150.90 MHz, $CDCl_3$): δ 171.0, 170.6, 170.4 (CH_3CO), 169.4 (NHCO), 166.5 (PhCO), 154.8 (NHCO), 138.5 (C aromatic), 133.9 (*C*H=CH_2), 133.5 (CH aromatic), 129.9 (C aromatic), 129.8 (2C, CH aromatic), 128.7 (2C, CH aromatic), 128.5 (2C, CH aromatic), 127.8 (CH aromatic), 127.7 (2C, CH aromatic), 117.5 (CH=*C*H_2), 100.9 (C^B-1), 99.2 (C^A-1), 95.4 (CH_2CCl_3), 77.0 (C^A-4), 75.6 (C^A-3), 74.8 (CH_2CCl_3), 73.0 (2C, Ph*C*H_2+C^A-5), 72.1 (C^B-5), 71.9 (C^B-3), 69.7 (O*C*H_2–CH=CH_2), 68.3 (C^B-4), 64.4 (C^B-6), 61.8 (C^A-6), 56.7 (C^B-2), 51.9 (C^A-2), 23.4, 20.8, 20.7, 20.6 (CH_3CO); HRMS (ESI): *m*/*z* Calcd for $[C_{40}H_{47}Cl_3N_2O_{16}]Na^+$: 939.1883. Found: 939.1878.

Supplementary data

Supplementary data (NMR and mass spectra for new compounds) associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.carres.2012.03.026.

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