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Efficient synthesis of a series of novel fructose-based 3-acetyl-5-alkyl-2,3-dihydro-1,3,4-oxadiazole derivatives and studies of the reaction mechanism

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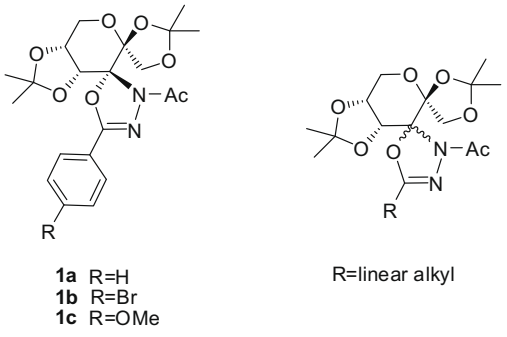
ABSTRACT

A series of novel alkyl substituted fructose-based oxadiazoles were synthesized and their cytotoxic activities toward tumor cells were investigated. We studied the reaction mechanism and the stereochemistry of the reaction. Tautomerization between isomers **2** and **3** was observed in solution. The tautomerization was accelerated by heating or in the presence of acetic acid. An intermediate **6** during the heterocyclization was isolated, and two different pathways for the heterocyclization were suggested. On the basis of these findings, an efficient method, with the assistance of microwave irradiation was developed for the synthesis of **4** and **5**. The yields were satisfactory and no by-products were found. We also proposed that the (*R*/*S*)-configurations of oxadiazoles were determined by the *E*/*Z* configurations of hydrazones.

1. Introduction

1,3,4-Oxadiazole derivatives have attracted significant attention in the field of drug discovery because of their wide array of pharmacological activities, including antibacterial, anti-fungal, analgesic, anti-inflammatory, anti-hypertension, and muscle relaxing activities.[1–7] Various modifications of the structure of 1,3,4-oxadiazole have been carried out.[8–10] As an important group of 1,3,4-oxadiazole derivatives, 3-acetyl-2,3-dihydro-1,3,4-oxadiazoles have also been well documented with biological activities such as anti-cancer and anti-bacterial activities.[11–13]

We have concentrated on the synthesis of carbohydrate-based heterocyclic derivatives because of their unique biological activities and metabolic properties. In previous works, we synthesized a series of fructose-based 1,3,4-oxadiazole derivatives **1** with antitumor activities (Scheme 1).[14–16] The configuration of **1** is (*R*) at C-3. The diastereomer of **1** with (*S*)-configuration at C-3 was not obtained due to the stereoselectivity of the heterocyclization reaction. A bioactivity assay showed that **1b** inhibited the transmembrane water absorption mediated by aquaporin-1 (AQP1) water channel (Y. Pan, X.J. Li, unpublished data). Molecular modeling confirmed that **1b** could bind to AQP1 and inhibit the AQP1 water channel (Fig. 1). Molecular docking modeling suggested that modification of the hydrophobic 5-aryl substitution of **1** could affect the affinity to aquaporin-1. Based on these findings, we designed and synthesized a series of 5-alkyl substituted fructose-based 1,3,4-oxadiazole derivatives (Scheme 1). Both diastereomers with (*R*)- and (*S*)-configurations at C-3 were obtained, and the possible mechanism of the stereoselective synthesis of these compounds was investigated.



Scheme 1. Structures of compound **1** and designed alkyl substituted derivatives.

Substituted 3-acetyl-2,3-dihydro-1,3,4-oxadiazoles are generally obtained from hydrazones in acetic anhydride or acetyl chloride under heating.[17–27] The reaction can be promoted by the addition of trifluoroacetic acid, sodium acetate, pyridine, or zinc chloride, and by an increase in the reaction temperature. However, the current synthesis procedures have the shortcomings of long reaction time, low yields, and significant formation of by-products.[13] Therefore, further investigation of the reaction mechanisms including the by-product formation mechanism was needed to improve the synthesis of this type of 1,3,4-oxadiazole derivatives.

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Figure 1. Molecular modeling of **1b** docked into the AQP1 water channel.

We also investigated the effect of microwave irradiation on the reaction. Microwave irradiation has been widely used for the distribution of heat energy in organic synthesis. Unlike conventional heating methods, microwave irradiation administer selective, instantaneous heat to materials allowing, in many cases, faster reaction rates, cleaner chemical transformations, and higher yields with a concomitant decrease in the formation of by-products.[28–30]

2. Results and discussion

1,2:4,5-Di-*O*-isopropylidene-β-D-*erythro*-2,3-hexodiulo-2,6-pyranose reacted with hydrazides in methanol catalyzed by acetic acid to afford a mixture of hydrazones **2** and **3** (around a 2:1 ratio, Scheme 2),[14] which are a pair of *Z*/*E* isomers. The *E*/*Z* configurations of **2** and **3** were confirmed by ^{1}H, ^{13}C, and NOESY spectra.[22] The NOESY spectra of **2** showed a correlation between H-4 and –NHCO–, indicating that **2** is in the *E* configuration. The NOESY spectra of **3** showed a correlation between H-2 and –NHCO–, indicating **3** is in the *Z* configuration. In addition, we succeeded in obtaining a single crystal of **2a** from 1:2 AcOEt-cyclohexane for X-ray diffraction analysis.[31] The 3D-structure of **2a** (Fig. 2) clearly indicated an *E* configuration, which verified the NOESY results.

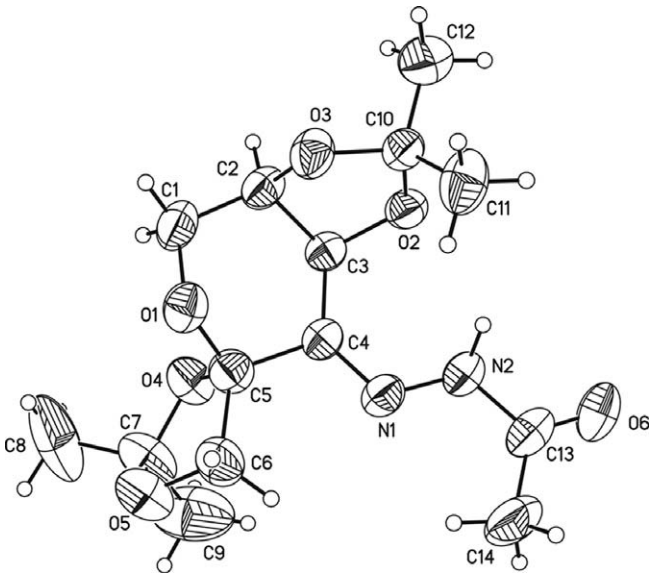
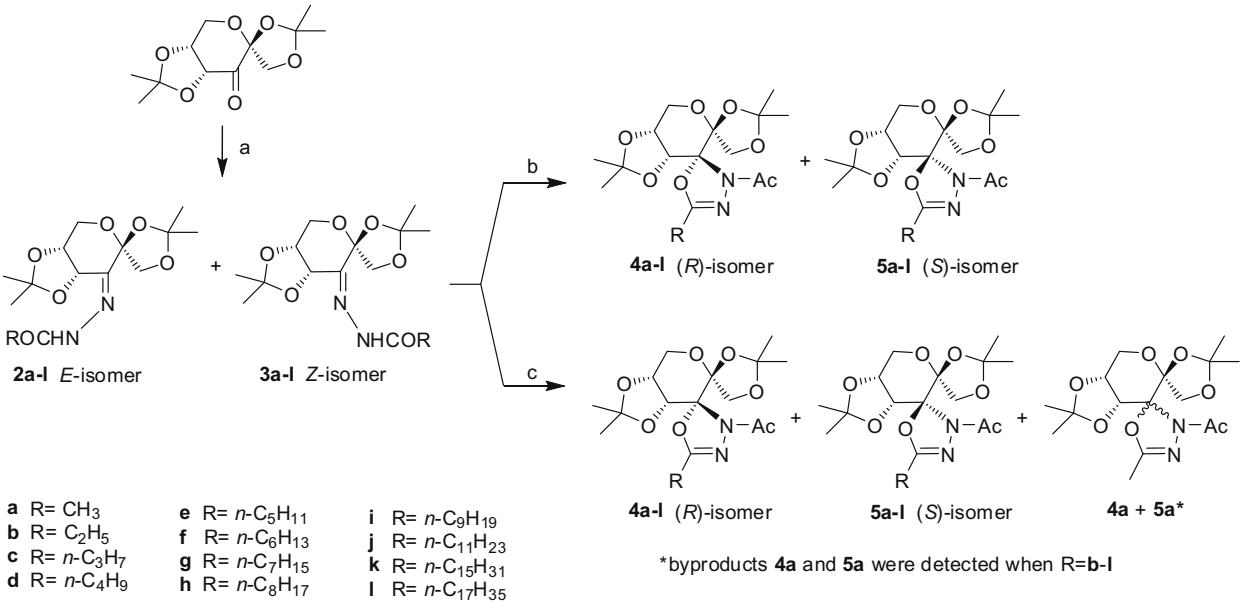


Figure 2. The crystal structure ORTEP plot of **2a**.

When the pure isomer of **2** or **3** was dissolved in solution with MeOH or ethyl acetate for more than 24 h, a new spot was always



Scheme 2. Reagents and condition: (a) hydrazide, MeOH, AcOH, 82–95%; (b) Ac_2O, microwave irradiation, 160 °C, 30 min, 83–94%; (c) Ac_2O, 120 °C, oil bath heating, 12–48 h, 40–58% (81% for **4a** + **5a**).

observed on TLC. The newly generated compound was separated and characterized as the *E*/*Z* isomer of the reactant. Therefore, tautomerization between **2** and **3** was discovered in solution. Pure hydrazone **2d** or **3d** was used as the starting isomer to determine the rate of tautomerization and the final ratio of isomers under different conditions. The results showed that the isomer tautomerized in less than 5% in different solvents such as MeOH, DCM, and cyclohexane when left at room temperature for more than 24 h. However, an equilibrium of **2d** and **3d** (around 2:1 in ratio) in each solvent was achieved in 2 h at reflux, and the same ratio was achieved in less than 5 min in the presence of 0.1% AcOH. Our syntheses of **2** and **3** were catalyzed by AcOH, therefore the isomers **2** and **3** should have reached equilibrium, in a ratio around 2:1.

When a mixture of **2** and **3** was used as the starting material in acetic anhydride under heating conditions and nitrogen protection, two oxadiazole isomers **4** and **5** were isolated, which were a pair of diastereomers (around 2:1 in ratio, Scheme 2). These products were isomers with different configurations at the spiro carbon C-3 of the pyran ring. The major isomer **4** showed a smaller R_f value than **5**. The ^{1}H NMR spectra indicated that the chemical shift of the Ac-group of the major isomer **4** (δ 2.03–2.07 ppm) was lower than that of the minor isomer **5** (δ 2.26–2.28 ppm), while the chemical shift of $-CH_2$=N– of the major isomer **4** (δ 2.57–2.62 ppm) was higher than that of the minor isomer **5** (δ 2.33–2.39 ppm). These facts implied that all the major isomers **4a**–**4l** have the same configuration at C-3, and all the minor isomers **5a**–**5l** have the same opposite configuration. The C-3 configurations of **4** and **5** were assigned by NOESY spectra and crystal structure. In the NOESY spectra, the major isomer **4** showed a correlation between the CH_3 of NAc and H-6, suggesting that the C-3 was (*R*) configuration. The same correlation was not observed in the NOESY spectra of **5**, indicating that the C-3 was (*S*) configuration. The ^{1}H NMR and NOESY results were in agreement with the conclusion of Ashry et al.[22] Moreover, compound **4a** was crystallized from 1:4 AcOEt–cyclohexane for X-ray diffraction analysis.[31] The ORTEP plot (Fig. 3) clearly indicates that **4a** has an (*R*)-configuration at the spiro C-3, which is consistent with the NOESY results.

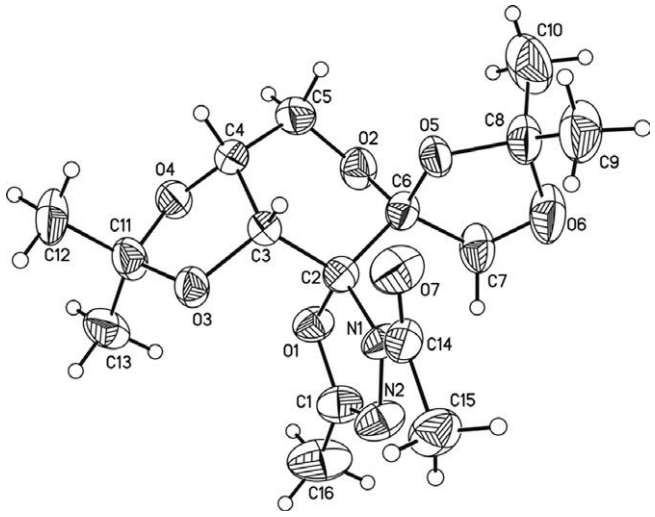


Figure 3. The crystal structure ORTEP plot for **4a**.

The yield of **4a** and **5a** was high when reacted at 120 °C for 12 h. However, **4b**–**l** and **5b**–**l** were produced only in 40% yield under the same conditions, and a considerable amount of by-products **4a** and **5a** was generated. The amount of by-product increased significantly with prolonged reaction time. Efforts were made to optimize the reaction conditions. However, the reaction solution turned dark after the addition of TFA, pyridine, or $ZnCl_2$, and the final yield decreased. The amount of by-products also increased with an increase in the reaction temperature. Thus, we reasoned that a better understanding of the reaction mechanism was needed for further improvement of this synthetic method.

2.1. Mechanism of the heterocyclization

During the cyclization of **2** and **3**, a new spot on TLC with high R_f value was observed after about 2 h, and the spot disappeared after a certain period of time. This spot could be an intermediate or a by-product of the heterocyclization reaction, which could provide clues of the reaction mechanism. To isolate and identify this intermediate, the reactions were quenched in which the substitute R was methyl **a**, butyl **d,** and undecyl **k** after 5 h. The intermediates were isolated by column chromatography to obtain compounds **6a**, **6d** and **6k**, respectively. These compounds **6a**, **6d** and **6k** turned out to be the respective *N*-acetyl substitutes of the hydrazones after characterization (Scheme 3). Even though only three intermediates were isolated and identified, similar intermediates **6a**–**l** should be formed in all the reactions with different substitutions under the same conditions.

The transformation of hydrazone **6** to oxadiazoles **4** and **5** likely undergoes the same process as the cyclization of hydrazones **2** and **3** to form oxadiazoles. However, because there are two acyl substitutions in hydrazone **6**, any one of the two acyl groups could participate in the cyclization. When the RCO– group participates in the cyclization, oxadiazoles **4** and **5** are formed. However, when the CH_3CO– group participates in the cyclization, by-products **4a** and **5a** are formed (Scheme 3). We found that compounds **6a**, **6d,** and **6k** were not stable, but their degradation products at room temperature or at 100 °C were not **4** and **5**, indicating that acetic anhydride or acetyl chloride was required for the cyclization reaction.

The heterocyclization of hydrazones **2** and **3** could undergo direct cyclization or indirect cyclization through the di-acylated intermediate **6**, as shown in Scheme 3. In the direct cyclization mechanism, compounds **2** and **3** react directly with acetic anhydride through path A. Because intermediate **6** was formed later in the reaction and products **4** and **5** were already detected before the formation of **6**, direct cyclization should be the dominant pathway.

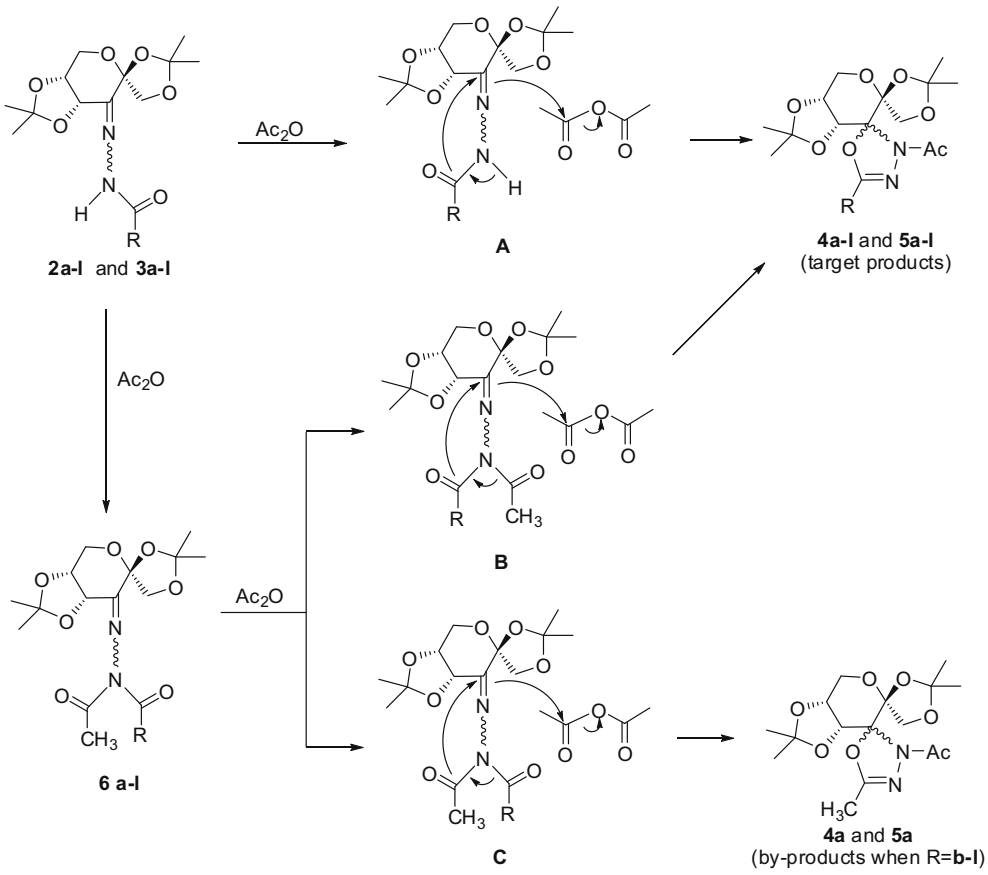
Since the generation of by-products **4a** and **5a** is through the formation of intermediate **6**, inhibition of the formation of **6** could avoid the generation of by-product. Because intermediate **6** was formed only after prolonged heating, ways to accelerate the reaction should be able to limit by-product formation. Microwave irradiation is one of the most promising ways to accelerate the reaction.

2.2. Efficient synthesis of 4 and 5 under microwave irradiation

We performed experiments to prepare **4b** and **5b** with microwave irradiation and optimized the reaction conditions (Table 1). Under the optimized conditions, target products were prepared in up to 92% yield at 160 °C for 30 min. Because of the short reaction time, as expected, no traces of by-products were detected. Using the optimal conditions, oxadiazole derivatives **4a**–**4l** and **5a**–**5l** were prepared efficiently. Results under microwave irradiation and oil bath heating are summarized in Table 2. Under the microwave irradiation, the isolated yields were obviously improved and no by-products were detected. However, the ratio of the isomers **4** and **5** was around 2:1 under both heating and microwave conditions.

2.3. The stereochemistry of the oxadiazole synthesis

In order to improve the stereospecific synthesis of diastereomers **4** and **5** to obtain a higher proportion of one isomer, we inves-



Scheme 3. Mechanism for the formation of target products and by-products.

Table 1
Optimization of the microwave irradiation conditions to prepare **4b** + **5b**

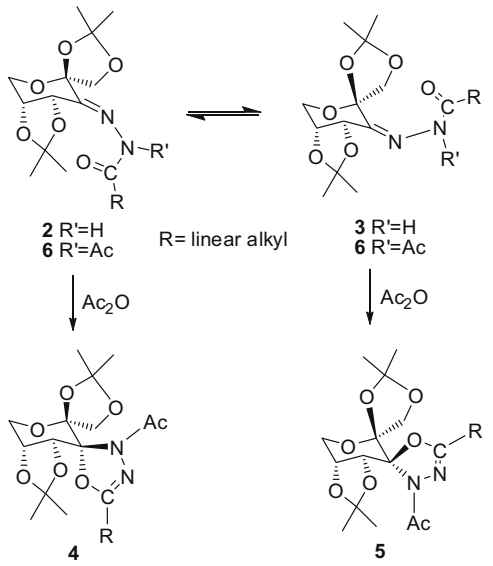
Temp. (°C)	Time (h)	Yield (%)
120	0.5	0
130	0.5	0
140	0.5	11
150	0.5	25
160	0.5	92
170	0.5	85
180	0.5	73

tigated the effects of temperature, heating methods (microwave irradiation or oil bath heating), and of catalysts (AcONa, pyridine, or $ZnCl_2$) on the ratio of **4** and **5**. The same ratio of **4** and **5** was obtained by the addition of pyridine, zinc chloride or sodium acetate (data not shown). As shown in Table 2, the influence of the temperature (120 vs 160 °C) or heating methods on the ratio of **4** and **5** is not significant, except when long chain substitutions are present such as **j**, **k** and **l**. For these long chain substituted products, the **4:5** ratio decreased under the higher temperature during microwave synthesis. Because the ratio of **2** and **3** was roughly around 2:1 under the reaction conditions and a similar ratio of **4** and **5**

Table 2
Synthesis of **4** and **5** under microwave irradiation and classical heating

	R	Oil bath heating			Microwave irradiation		
		Time (h)	Yield[a] (%)	Ratio[b] (**4**:**5**)	Time (h)	Yield[a] (%)	Ratio[b] (**4**:**5**)
a	CH_3	12	81	70:30	0.5	94	67:33
b	n-C_2H_5	12	51	65:35	0.5	92	66:34
c	n-C_3H_7	12	58	66:34	0.5	90	68:32
d	n-C_4H_9	24	51	65:35	0.5	89	65:35
e	n-C_5H_{11}	24	50	64:36	0.5	91	60:40
f	n-C_6H_{13}	24	54	63:37	0.5	88	66:34
g	n-C_7H_{15}	24	55	64:36	0.5	85	67:33
h	n-C_8H_{17}	24	48	62:38	0.5	86	66:34
i	n-C_9H_{19}	24	51	65:35	0.5	87	62:38
j	n-$C_{11}H_{23}$	48	47	74:26	0.66	83	69:31
k	n-$C_{15}H_{31}$	48	40	77:23	0.66	84	71:39
l	n-$C_{17}H_{35}$	48	45	87:13	0.66	80	72:38

Oil bath heating at 120 °C for 12 h and microwave irradiation at 160 °C for 30 min.
[a] Yield of **4** + **5**.
[b] The ratio was determined by column chromatography.



Scheme 4. The stereochemistry of heterocyclization.

was obtained, we propose that the formation of the (*R*/*S*)-configurations of **4** and **5** might be determined by the *E*/*Z* configurations of **2** and **3** (Scheme 4). Different geometric configurations of hydrazone **2** and **3** might lead to different directions (below or above the pyran ring) from where the carbonyl oxygen attacks the C-3 carbon during heterocyclization. The carbonyl oxygen of the major isomer **2** with an *E*-configuration would attack from below the pyran ring, and produce the major product **4** with an (*R*)-configuration; the minor product **5** with an (*S*)-configuration is obtained from the attacking of the carbonyl oxygen above the pyran ring of the minor isomer **3** with *Z* configuration.

Based on the above hypothesis, the stereoselective synthesis of **4** and **5** could be achieved by enhancing the proportion of one isomer under the heterocyclization conditions. For example, under higher temperature, the percentage of the sterically hindered *Z* configuration should increase and the formation of the minor product **5** with an (*S*)-configuration should increase too, as we noticed with the long chain substituted products. Moreover, compared with these 5-linear alkyl oxadiazole derivatives, the 5-aryl oxadiazole **1** was obtained mainly as the (*R*)-isomer, which holds the same configuration with the major isomer **4**. Our previous work indicated that the 5-aryl hydrazones were isolated only in the *E* configuration. Therefore, only oxadiazoles with the (*R*)-configuration were formed.

2.4. The cytotoxic activities of 4 and 5

The in vitro cytotoxic activities of the prepared compounds **4** and **5** against Hela, Hl-60, BGC-823, Bel-7402, and KP tumor cells were evaluated by MTT and SRB assays. Assays were performed using 96-well plates (Falcon, Becton Dickinson, Mountain View, CA, USA) seeded with 10^5 cells per well in 200 μL RPMI 1640 without phenol red and supplemented with 10% FCS. After 24 h incubation, the medium was replaced with fresh RPMI 1640 medium containing the tested compounds **4** and **5**. Cells were incubated for 48 h with molecules **4** and **5** (10 μM), followed by MTT or SRB Cell Inhibition Assay (Promega, Madison, WI, USA) (Table 3). The absorbance of each well was measured with a microplate reader at 570 nm (MTT) and 540 nm (SRB). As shown in Table 3, compounds **4** and **5** showed specific inhibiting activities toward Hela and HL-60 tumor cells, but showed no inhibiting activities toward BGC-823, Bel-7402, and KP tumor cells. Compounds **4i** and **5k** with long chain substitutions showed the best inhibition activities for Hela cells. However, the activities were generally not affected strongly by the length of the 5-alkyl substitution for HL-60 cells. There was generally no difference in the cytotoxic activity of the oxadiazoles with (*R*)- or (*S*)-configurations, except when the substitutions were **i**, **j**, and **k**. Even for those compounds showing a difference, no general trend can be observed. As analogs of the anti-tumor compound **1**, the in vitro cytotoxic activities of **4** and **5** were not strong. Because the anti-tumor mechanism of this type of compounds may depend on their inhibition of tumor adhesion,[16] studies on the activities of compounds **4** and **5** on the adhesion of tumor cell and transmembrane water absorption mediated by aquaporin-1 (AQP1) water channel are being investigated. Initially we carried out docking studies to examine the binding affinity of a selected few derivatives to AQP1. The docking energy of compounds **4a**, **4h,** and **4l,** which were substituted with linear alkyl groups of CH_3, C_8H_{17}, and $C_{15}H_{31}$, is −6.88 kJ/mol, −8.78 kJ/mol, and −7.81 kJ/mol, respectively, suggesting that **4h** has the highest binding affinity to AQP1. It seems the affinity to AQP1 revealed by docking energies correlates with the cytotoxicity toward HL60 cells, but not other cancer cells. More work is needed to understand the mechanism of action of these compounds.

3. Conclusion

In summary, a series of carbohydrate hydrazones and oxadiazoles were synthesized. The configurations of the hydrazones **2**, **3** and oxadiazoles **4**, **5** were confirmed by NMR and XRD data. Tautomerization of isomers **2** and **3** was observed in solution, which was

Table 3
Inhibition ratio (%) tumor cell proliferation by **1b**, **4** and **5**

	Hela[a]		HL-60[b]		BGC-823[a]		Bel-7402[a]		KP[a]	
	4	**5**	**4**	**5**	**4**	**5**	**4**	**5**	**4**	**5**
a	4.01	4.81	7.32	5.79	11.27	4.10	−0.24	1.96	2.61	−1.71
b	3.75	6.28	10.78	4.01	0.78	−9.27	−2.65	−7.90	−7.20	−7.97
c	3.88	2.64	5.62	11.81	−9.20	13.21	−8.39	2.08	−7.09	−3.99
d	2.29	4.34	12.31	19.84	10.55	−2.97	0.78	−3.55	−5.37	−8.06
e	2.64	3.87	15.68	9.89	2.61	−6.54	−8.76	−8.91	−7.66	−11.19
f	3.21	1.93	17.85	15.54	−2.83	9.74	−12.31	−0.79	−11.60	−4.11
g	3.26	3.13	13.16	18.96	7.79	9.79	1.74	−4.55	−4.54	−6.83
h	4.03	4.40	18.87	11.58	8.26	−4.19	−8.39	−9.09	−5.26	−10.21
i	26.85	3.09	12.70	16.41	−7.79	17.40	−13.47	−4.70	−11.57	−4.38
j	11.35	3.48	12.81	15.02	9.09	6.78	−3.62	−3.95	−3.61	−6.35
k	7.20	34.52	17.24	9.58	−11.02	−26.46	−3.50	−11.67	−0.97	−6.61
l	7.55	4.76	7.99	5.24	−3.29	7.44	−4.40	−2.67	10.49	2.01

[a] Detected by standard SRB method.
[b] Detected by standard MTT method.

accelerated by heating or in the presence of acetic acid. The isolation and identification of intermediate **6** provided evidence for the reaction mechanism and the formation of by-products. Based on these findings, an efficient method for the synthesis of **4** and **5** was developed with microwave irradiation. The stereochemistry of the hydrazones and oxadiazoles was studied and we proposed that the (*R*/*S*)-configurations of oxadiazoles were determined by the *E*/*Z* configurations of hydrazones.

4. Experimental

4.1. General methods

Unless specified otherwise, all reactants and reagents were purchased commercially and used without further purification. Solvents were purified by standard procedures. Melting points were measured on an X4 melting point apparatus, which were uncorrected. Optical rotations were measured at 25 °C using an Optical Activity AA-10R automatic polarimeter. NMR spectra were recorded on Jeol-300 instrument and Inova-500 instrument. Mass spectra were measured on an IBI-MDS Sciex Q-star or an FAB-MS mass spectrometer or a Bruker APEX IV FT_MS. Elemental analyses were performed on a Perkin–Elmer 240 C instrument. TLC was performed on Silica Gel GF254 plates (Hai Yang Chemical Factory, Qingdao, Shandong, PR China) detected by UV fluorescence quenching and by spraying with 10% H_2SO_4. Column chromatography was performed on Silica Gel H 60 (Hai Yang Chemical Factory, Qingdao, Shandong, PR China). Microwave reaction was conducted using a Biotage-Initiator EXP EO Microwave Synthesizer.

4.2. General procedures for the preparation of compounds 2 and 3

AcOH (0.5 ml) was added slowly to a stirred solution of 1,2:4,5-di-*O*-isopropylidene-β-D-erythro-2,3-hexodiulo-2,6-pyranose (2.0 g, 7.75 mmol) and hydrazide (7.75 mmol) in MeOH (40.0 ml) at room temperature. The reaction was monitored by TLC (ethyl acetate/*n*-hexane, 1:8, v/v) until the reaction was completed in about 12 h, and the solvent was then removed. The residual foam was separated by column chromatography to obtain *E* isomer **2** and *Z* isomer **3**, respectively.

4.3. General procedures for the preparation of compounds 4 and 5 in oil bath heating

A mixture of **2** and **3** (4.0 mmol) was dissolved in acetic anhydride (5.0 ml) and boiled at 120 °C in an oil bath and stirred until TLC (ethyl acetate/cyclohexane, 1:5, v/v) showed that the reactant had disappeared. The solution was concentrated under reduced pressure. The residual solvent was removed by toluene under reduced pressure for three times. The residual syrup was purified by chromatography (ethyl acetate/cyclohexane, 1:8, v/v) to afford **4** and **5**, respectively.

4.4. General procedure for the preparation of compounds 4 and 5 under microwave irradiation

A mixture of **2** and **3** (2.0 mmol) was dissolved in acetic anhydride (1.0 ml) and boiled at 160 °C under microwave heating conditions for 30 min in the microwave initiator. The solution was concentrated and the residual solvent was removed by adding toluene under reduced pressure three times. The residual syrup was purified by chromatography (ethyl acetate/cyclohexane, 1:8, v/v) to afford **4** and **5**, respectively.

4.5. Separation of compound 6

A mixture of **2** and **3** (4.0 mmol) was dissolved in acetic anhydride (5.0 ml) and boiled at 120 °C in an oil bath and stirred. After 5 h, TLC showed that a new spot appeared with an R_f value of about 0.6 (ethyl acetate/cyclohexane, 1:5, v/v). The solution was concentrated under reduced pressure. The residual solvent was removed by toluene under reduced pressure three times. The residual syrup was purified by chromatography (ethyl acetate/cyclohexane, 1:8, v/v) to afford compound **6** as a colorless foam. Compounds **6a**, **6d** and **6k** were isolated.

4.6. Compounds 2–6

4.6.1. *E*-3-Acetylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 2a

Colorless crystal; mp 107–109 °C; $[\alpha]_D^{25} = -276.3$ (*c* 0.97, MeOH); ^{1}H NMR (500 MHz, $CDCl_3$): δ 10.23 (s, 1H, NH), 4.98 (d, 1H, $J_{4,5}$ 6 Hz, H-4), 4.77 (d, 1H, $J_{1a,1b}$ 9.0 Hz, H-1a), 4.33, (m, 1H, H-5), 4.27 (dd, 1H, $J_{6a,6b}$ 13.5 Hz, H-6a), 4.09 (d, 1H, $J_{6a,6b}$ 13.5 Hz, H-6b), 4.08 (d, 1H, $J_{1a,1b}$ 9.0 Hz, H-1b), 2.22 (s, 3H, Ac), 1.53, 1.43, 1.41, 1.40 (4s, 12H, $C(CH_3)_2$); ^{13}C NMR (125 MHz, $CDCl_3$): δ 173.3 (C=O), 141.1 (C-3), 113.0, 110.7 ($C(CH_3)_2$), 103.9 (C-2), 74.2 (C-6), 71.6 (C-4), 71.5 (C-1), 59.1 (C-5), 26.9, 26.6, 26.1, 26.0 ($C(CH_3)_2$), 19.8 ($COCH_3$); FAB-MS: *m*/*z* 315.1 $[M+H]^+$; Anal. Calcd for $C_{14}H_{22}N_2O_6$: C, 53.49; H, 7.05; N, 8.91. Found: C, 53.32; H, 7.28; N, 8.87.

4.6.2. *Z*-3-Acetylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 3a

White solid; mp 93–94 °C; $[\alpha]_D^{25} = -208.0$ (*c* 1.00, MeOH); ^{1}H NMR (500 MHz, $CDCl_3$): δ 10.05 (s, 1H, NH), 4.76 (d, 1H, $J_{4,5}$ 7.5 Hz, H-4), 4.47 (dd, 1H, H-5), 4.14 (dd, 2H, $J_{1a,1b}$ 10.0 Hz, H-1), 3.78 (m, 2H, $J_{6a,6b}$ 13.0 Hz, H-6), 2.26 (s, 3H, Ac), 1.68, 1.55, 1.51, 1.38 (4s, 12H, $C(CH_3)_2$); ^{13}C NMR (125 MHz, $CDCl_3$): δ 173.1 (C=O), 139.1 (C-3), 112.5, 110.6 ($C(CH_3)_2$), 103.2 (C-2), 76.1 (C-4), 74.4 (C-5), 74.0 (C-1), 64.7 (C-6), 26.7, 26.1, 25.8, 25.1 ($C(CH_3)_2$), 19.6 ($COCH_3$); FAB-MS: *m*/*z* 315.1 $[M+H]^+$; Anal. Calcd for $C_{14}H_{22}N_2O_6$: C, 53.49; H, 7.05; N, 8.91. Found: C, 53.57; H, 7.17; N, 8.87.

4.6.3. *E*-3-Propionylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 2b

Colorless crystal; mp 106–107 °C; $[\alpha]_D^{25} = -237.7$ (*c* 1.06, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.2 (s, 1H, NH), 4.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.77 (d, 1H, $J_{1a,1b}$ 9.0 Hz, H-1a), 4.32 (d, 1H, H-5), 4.26 (d, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 9.0 Hz, H-6), 2.61 (m, 2H, CH_2CO), 1.55, 1.43, 1.41, 1.39 (4s, 12H, $C(CH_3)_2$), 1.17 (t, 3H, CH_3CH_2,); ^{13}C NMR (75 MHz, $CDCl_3$): δ 176.4 (C=O), 140.7 (C-3), 112.9, 110.6 ($C(CH_3)_2$), 103.9 (C-2), 74.1 (C-5), 71.7 (C-1), 71.6 (C-4), 59.1 (C-6), 26.9, 26.6, 26.1, 26.0, 25.6 ($C(CH_3)_2$, $COCH_2$), 8.5 (CH_2CH_3); FAB-MS: *m*/*z* 328.8 $[M+H]^+$; Anal. Calcd for $C_{15}H_{24}N_2O_6$: C, 54.87; H, 7.37; N, 8.53. Found: C, 54.77; H, 7.11; N, 8.39.

4.6.4. *Z*-3-Propionylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 3b

White solid; mp 98–100 °C; $[\alpha]_D^{25} = -160.7$ (*c* 1.17, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.2 (s, 1H, NH), 4.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.76 (d, 1H, H-5), 4.30 (m, 2H, H-1), 4.10 (dd, 2H, $J_{6a,6b}$ 9.0 Hz, H-6), 2.61 (m, 2H, CH_2CO), 1.52, 1.42, 1.41, 1.39 (4s, 12H, $C(CH_3)_2$), 1.17 (t, 3H, CH_3CH_2); ^{13}C NMR (75 MHz, $CDCl_3$): δ 176.5 (C=O), 140.7 (C-3), 112.9, 110.6 ($C(CH_3)_2$), 103.9 (C-2), 74.1 (C-5), 71.7 (C-1), 71.6 (C-4), 59.1 (C-6), 27.0, 26.6, 26.1, 26.0, 25.6 ($C(CH_3)_2$, $COCH_2$), 8.5 (CH_2CH_3); FAB-MS: *m*/*z* 329.2 $[M+H]^+$; Anal. Calcd for $C_{15}H_{24}N_2O_6$: C, 54.87; H, 7.37; N, 8.53. Found: C, 54.90; H, 7.21; N, 8.46.

4.6.5. *E*-3-Butyrylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 2c

White foam; $[\alpha]_D^{25} = -220.0$ (*c* 1.00, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.16 (s, 1H, NH), 4.97 (d, 1H, $J_{4,5}$ 5.7 Hz, H-4), 4.76 (d, 1H, H-1a), 4.32 (d, 1H, H-5), 4.26 (s, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 9.0 Hz, H-6), 2.60 (m, 2H, CH_2CO), 1.68 (m, 2H, CH_2CH_3), 1.51, 1.42, 1.41, 1.39 (4s, 12H, $C(CH_3)_2$), 0.98 (t, 3H, CH_3CH_2); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.7 (C=O), 140.6 (C-3), 112.9, 110.6 ($C(CH_3)_2$), 103.9 (C-2), 74.1 (C-5), 71.6 (C-1), 71.5 (C-4), 59.1 (C-6), 34.1, 27.0, 26.6, 26.1, 26.0, 18.1, 13.9 ($C(CH_3)_2$, C_3H_7); FAB-MS: *m/z* 343.2 $[M+H]^+$; Anal. Calcd for $C_{16}H_{26}N_2O_6$: C, 56.13; H, 7.65; N, 8.18. Found: C, 56.00; H, 7.68; N, 7.93.

4.6.6. *Z*-3-Butyrylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-erythro-2-hexulopyranose 3c

White foam; $[\alpha]_D^{25} = -192.2$ (*c* 1.02, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.17 (s, 1H, NH), 4.97 (d, 1H, $J_{4,5}$ 5.7 Hz, H-4), 4.76 (d, 1H, H-1a), 4.32 (d, 1H, H-5), 4.26 (s, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 9.0 Hz, H-6), 2.57 (m, 2H, CH_2CO), 1.68 (m, 2H, CH_2CH_3), 1.53, 1.42, 1.41, 1.39 (4s, 12H, $C(CH_3)_2$), 0.98 (t, 3H, CH_3CH_2); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.7 (C=O), 140.6 (C-3), 112.9, 110.6 ($C(CH_3)_2$), 103.9 (C-2), 74.1 (C-5), 71.6 (C-1), 71.5 (C-4), 59.1 (C-6), 34.1, 27.0, 26.6, 26.1, 26.0, 18.1, 13.9 ($C(CH_3)_2$, C_3H_7); FAB-MS: *m/z* 343.3 $[M+H]^+$; Anal. Calcd for $C_{16}H_{26}N_2O_6$: C, 56.13; H, 7.65; N, 8.18. Found: C, 56.22, H, 7.50; N, 7.91.

4.6.7. *E*-3-Valerylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 2d

Yellowish foam; $[\alpha]_D^{25} = -211.8$ (*c* 1.02, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.16 (s, 1H, NH), 4.97 (d, 1H, $J_{4,5}$ 5.7 Hz, H-4), 4.76 (d, 1H, H-1a), 4.32 (d, 1H, H-5), 4.26 (d, 1H, H-1b), 4.11(dd, 2H, $J_{6a,6b}$ 9.0 Hz, H-6), 2.57 (m, 2H, CH_2CO), 1.63 (m, 4H, $C_2H_4CH_3$), 1.53, 1.43, 1.41, 1.39 (4s, 12H, $C(CH_3)_2$), 0.94 (m, 3H, CH_3CH_2); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.9 (C=O), 140.7 (C-3), 112.9, 110.6 ($C(CH_3)_2$), 103.9 (C-2), 74.1 (C-5), 71.6 (C-1), 71.5 (C-4), 59.1 (C-6), 32.0, 27.0, 26.9, 26.6, 26.1, 26.0, 22.5, 13.8 ($C(CH_3)_2$, C_4H_9); FAB-MS: *m/z* 357.1 $[M+H]^+$; Anal. Calcd for $C_{17}H_{28}N_2O_6$: C, 57.29; H, 7.92; N, 7.86. Found: C, 57.23; H, 7.82; N, 7.95.

4.6.8. *Z*-3-Valerylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 3d

Yellowish foam; $[\alpha]_D^{25} = -167.6$ (*c* 1.05, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.18 (s, 1H, NH), 5.00 (d, 1H, $J_{4,5}$ 5.7 Hz, H-4), 4.76 (d, 1H, H-1a), 4.34 (d, 1H, H-5), 4.25 (d, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 9.0 Hz, H-6), 2.60 (m, 2H, CH_2CO), 1.63 (m, 4H, $C_2H_4CH_3$), 1.52, 1.42, 1.41, 1.39 (4s, 12H, $C(CH_3)_2$), 0.94 (m, 3H, CH_3CH_2); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.6 (C=O), 140.6 (C-3), 112.7, 110.4 ($C(CH_3)_2$), 103.7 (C-2), 74.0 (C-5), 71.4 (C-1), 71.3 (C-4), 59.0 (C-6), 31.8, 26.7, 26.4, 26.3, 25.9, 25.8, 22.3, 13.6 ($C(CH_3)_2$, C_4H_9); FAB-MS: *m/z* 357.0 $[M+H]^+$; Anal. Calcd for $C_{17}H_{28}N_2O_6$: C, 57.29; H, 7.92; N, 7.86. Found: C, 57.02; H, 7.94; N, 7.80.

4.6.9. *E*-3-Caproylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 2e

Yellowish foam; $[\alpha]_D^{25} = -192.0$ (*c* 1.00, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.16 (s, 1H, NH), 4.98 (d, 1H, $J_{4,5}$ 5.7 Hz, H-4), 4.75 (d, 1H, $J_{1a,1b}$ 9.0 Hz, H-1a), 4.32(d, 1H, H-5), 4.27 (d, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 9.0 Hz, H-6), 2.58 (m, 2H, CH_2CO), 1.68–0.87 (m, 21H, $C(CH_3)_2$, C_4H_9); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.9 (C=O), 140.6 (C-3), 112.9, 110.6 (*C*(CH3)2), 103.9 (C-2), 74.1 (C-5), 71.6 (C-1), 71.5 (C-4), 59.1 (C-6), 32.2, 31.5, 26.9, 26.5, 26.1, 26.0, 24.4, 22.4, 13.9 ($C(CH_3)_2$, C_5H_{11}); FAB-MS: *m/z* 370.8 $[M+H]^+$; Anal. Calcd for $C_{18}H_{30}N_2O_6$: C, 58.36; H, 8.16; N, 7.56. Found: C, 58.14; H, 8.09; N, 7.29.

4.6.10. *Z*-3-Caproylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 3e

Yellowish foam; $[\alpha]_D^{25} = -178.6$ (*c* 1.03, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.16 (s, 1H, NH), 4.97 (d, 1H, $J_{4,5}$ 5.7 Hz, H-4), 4.75 (d, 1H, $J_{1a,1b}$ 9.0 Hz, H-1a), 4.32 (d, 1H, H-5), 4.26 (d, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 9.0 Hz, H-6), 2.58 (m, 2H, CH_2CO), 1.56–0.87 (m, 21H, $C(CH_3)_2$, C_4H_9); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.9 (C=O), 140.6 (C-3), 112.9, 110.6 ($C(CH_3)_2$), 103.9 (C-2), 74.1 (C-5), 71.5 (C-1), 71.4 (C-4), 59.1 (C-6), 32.2, 31.5, 26.9, 26.5, 26.1, 26.0, 24.4, 22.4, 13.9 ($C(CH_3)_2$, C_5H_{11}); FAB-MS: 371.1 $[M+H]^+$; Anal. Calcd for $C_{18}H_{30}N_2O_6$: C, 58.36; H, 8.16; N, 7.56. Found: C, 58.53; H, 7.97; N, 7.31.

4.6.11. *E*-3-Heptanoylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 2f

Yellowish foam; $[\alpha]_D^{25} = -195.9$ (*c* 0.98, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.18 (s, 1H, NH), 5.01 (d, 1H, $J_{4,5}$ 5.4 Hz, H-4), 4.75 (d, 1H, $J_{1a,1b}$ 8.7 Hz, H-1a), 4.33 (d, 1H, H-5), 4.27 (d, 1H, H-1b), 4.07 (dd, 2H, $J_{6a,6b}$ 9.0 Hz, H-6), 2.57 (m, 2H, CH_2CO), 1.65–0.88 (m, 23H, $C(CH_3)_2$, C_5H_{11}); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.4 (C=O), 140.4 (C-3), 112.5, 110.2 ($C(CH_3)_2$), 103.6 (C-2), 73.9 (C-5), 71.3 (C-1), 71.2 (C-4), 58.8 (C-6), 31.9, 31.2, 28.7, 26.6, 26.2, 25.8, 25.6, 24.4, 22.1, 13.6 ($C(CH_3)_2$, C_6H_{13}); FAB-MS: *m/z* 385.3 $[M+H]^+$; Anal. Calcd for $C_{19}H_{32}N_2O_6$: C, 59.36; H, 8.39; N, 7.29. Found: C, 59.39; H, 7.31; N, 7.25.

4.6.12. *Z*-3-Heptanoylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 3f

Yellowish foam; $[\alpha]_D^{25} = -170.9$ (*c* 1.03, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.16 (s, 1H, NH), 4.98 (d, 1H, $J_{4,5}$ 5.7 Hz, H-4), 4.75 (d, 1H, $J_{1a,1b}$ 9.0 Hz, H-1a), 4.33 (d, 1H, H-5), 4.26 (d, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 9.0 Hz, H-6), 2.58 (m, 2H, CH_2CO), 1.68–0.86 (m, 23H, $C(CH_3)_2$, C_5H_{11}); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.7 (C=O), 140.6 (C-3), 112.8, 110.5 ($C(CH_3)_2$), 103.8 (C-2), 74.1 (C-5), 71.6 (C-1), 71.5 (C-4), 59.0 (C-6), 32.2, 31.4, 28.9, 26.9, 26.4, 26.0, 25.9, 24.6, 22.4, 13.9 ($C(CH_3)_2$, C_6H_{13}); FAB-MS: *m/z* 385.4 $[M+H]^+$. Anal. Calcd for $C_{19}H_{32}N_2O_6$: C, 59.36; H, 8.39; N, 7.29. Found: C, 59.42; H, 7.28; N, 7.33.

4.6.13. *E*-3-Oxtanoylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 2g

Yellowish foam; $[\alpha]_D^{25} = -234.3$ (*c* 0.99, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.18 (s, 1H, NH), 4.98 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.75 (d, 1H, $J_{1a,1b}$ 9.0 Hz, H-1a), 4.32 (s, 1H, H-5), 4.25 (s, 1H, H-1b), 4.09 (d, 2H, H-6), 2.57 (m, 2H, CH_2CO), 1.65∼0.85 (m, 25H, $C(CH_3)_2$, C_6H_{13}); ^{13}C NMR (75 MHz, DMSO): δ 174.7 (C=O), 141.5 (C-3), 111.7, 109.4 ($C(CH_3)_2$), 103.5 (C-2), 73.2 (C-5), 72.6 (C-1), 68.5 (C-4), 59.9 (C-6), 31.7, 31.1, 28.7, 28.4, 26.9, 26.2, 25.8, 25.4, 24.3, 22.0, 13.8 ($C(CH_3)_2$, C_7H_{15}); FAB-MS: *m/z* 399.0 $[M+H]^+$; Anal. Calcd for $C_{20}H_{34}N_2O_6$: C, 60.28; H, 8.60; N, 7.03. Found: C, 60.14; H, 8.78; N, 6.98.

4.6.14. *Z*-3-Oxtanoylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 3g

Yellowish foam; $[\alpha]_D^{25} = -192.2$ (*c* 1.02, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.15 (s, 1H, NH), 4.97 (d, 1H, $J_{4,5}$ 5.7 Hz, H-4), 4.75(d, 1H, $J_{1a,1b}$ 8.7 Hz, H-1a), 4.32 (d, 1H, H-5), 4.26 (d, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 9.0 Hz, H-6), 2.57 (m, 2H, CH_2CO), 1.68–0.86 (m, 25H, $C(CH_3)_2$, C_6H_{13}); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.9 (C=O), 140.6 (C-3), 112.9, 110.6 ($C(CH_3)_2$), 103.9 (C-2), 74.1 (C-5), 71.6 (C-1), 71.5 (C-4), 59.1 (C-6), 32.3, 31.6, 29.3, 29.0, 27.0, 26.5, 26.1, 26.0, 24.7, 22.5, 14.0 ($C(CH_3)_2$, C_7H_{15}); FAB-MS: *m/z* 398.8 $[M+H]^+$; Anal. Calcd for $C_{20}H_{34}N_2O_6$: C, 60.28; H, 8.60; N, 7.03. Found: C, 60.19; H, 8.68; N, 6.94.

4.6.15. *E*-3-Nonanoylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 2h

Yellowish foam; $[\alpha]_D^{25} = -210.1$ (*c* 0.99, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.16 (s, 1H, NH), 4.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.76 (d, 1H, $J_{1a,1b}$ 9.0 Hz, H-1a), 4.32 (d, 1H, H-5), 4.26 (d, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 9.0 Hz, H-6), 2.57 (m, 2H, CH_2CO), 1.68–0.85 (m, 27H, $C(CH_3)_2$, C_7H_{15}); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.9 (C=O), 140.7 (C-3), 112.9, 110.6 ($C(CH_3)_2$), 103.9 (C-2), 74.1 (C-5), 71.6 (C-1), 71.5 (C-4), 59.1 (C-6), 32.3, 31.8, 29.4, 29.3, 29.1, 27.0, 26.6, 26.1, 26.0, 24.8, 22.6, 14.0 ($C(CH_3)_2$, C_8H_{17}); FAB-MS: *m/z* 413.1 $[M+H]^+$; Anal. Calcd for $C_{21}H_{36}N_2O_6$: C, 61.14; H, 8.80; N, 6.79. Found: C, 61.38; H, 8.67; N, 6.68.

4.6.16. *Z*-3-Nonanoylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 3h

Yellowish foam; $[\alpha]_D^{25} = -193.9$ (*c* 0.99, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.16 (s, 1H, NH), 4.98 (d, 1H, $J_{4,5}$ 5.7 Hz, H-4), 4.76 (d, 1H, $J_{1a,1b}$ 9.0 Hz, H-1a), 4.32 (d, 1H, H-5), 4.2 (d, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 8.7 Hz, H-6), 2.57 (m, 2H, CH_2CO), 1.68–0.85 (m, 27H, $C(CH_3)_2$, C_7H_{15}); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.7 (C=O), 140.6 (C-3), 112.8, 110.5 ($C(CH_3)_2$), 103.8 (C-2), 74.1 (C-5), 71.5 (C-1), 71.4 (C-4), 59.0 (C-6), 32.2, 31.7, 29.3, 29.2, 29.0, 26.9, 26.5, 26.0, 25.9, 24.7, 22.5, 13.9 ($C(CH_3)_2$, C_8H_{17}); FAB-MS: *m/z* 413.0 $[M+H]^+$; Anal. Calcd for $C_{21}H_{36}N_2O_6$: C, 61.14; H, 8.80; N, 6.79. Found: C, 61.20; H, 8.79; N, 6.66.

4.6.17. *E*-3-Decanoylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 2i

Yellowish foam; $[\alpha]_D^{25} = -196.6$ (*c* 1.03, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.16 (s, 1H, NH), 4.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.76 (d, 1H, $J_{1a,1b}$ 8.7 Hz, H-1a), 4.32 (d, 1H, H-5), 4.25 (s, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 8.7 Hz, H-6), 2.58 (m, 2H, CH_2CO), 1.68–0.85 (m, 29H, $C(CH_3)_2$, C_8H_{17}); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.8 (C=O), 140.6 (C-3), 112.9, 110.6 ($C(CH_3)_2$), 103.9 (C-2), 74.1 (C-5), 71.6 (C-1), 71.5 (C-4), 59.1 (C-6), 32.3, 31.8, 29.4, 29.2, 26.9, 26.5, 26.1, 26.0, 24.7, 22.6, 14.0 ($C(CH_3)_2$, C_9H_{19}); FAB-MS: *m/z* 426.7 $[M+H]^+$; Anal. Calcd for $C_{22}H_{38}N_2O_6$: C, 61.95; H, 8.98; N, 6.57. Found: C, 61.68; H, 8.76; N, 6.33.

4.6.18. *Z*-3-Decanoylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 3i

Yellowish foam; $[\alpha]_D^{25} = -157.2$ (*c* 0.97, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.15 (s, 1H, NH), 4.97 (d, 1H, $J_{4,5}$ 5.7 Hz, H-4), 4.76 (d, 1H, $J_{1a,1b}$ 9.0 Hz, H-1a), 4.32 (d, 1H, H-5), 4.25 (s, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 8.7 Hz, H-6), 2.58 (m, 2H, CH_2CO), 1.68–0.85 (m, 29H, $C(CH_3)_2$, C_8H_{17}); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.9 (C=O), 140.6 (C-3), 112.9, 110.6 ($C(CH_3)_2$), 103.9 (C-2), 74.1 (C-5), 71.6 (C-1), 71.5 (C-4), 59.1 (C-6), 32.3, 31.8, 29.4, 29.2, 27.0, 26.7, 26.6, 26.1, 26.0, 24.8, 22.6, 14.1 ($C(CH_3)_2$, C_9H_{19}); FAB-MS: *m/z* 427.1 $[M+H]^+$; Anal. Calcd for $C_{22}H_{38}N_2O_6$: C, 61.95; H, 8.98; N, 6.57. Found: C, 61.79; H, 8.79; N, 6.41.

4.6.19. *E*-3-Lauroylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 2j

White wax; $[\alpha]_D^{25} = -192.0$ (*c* 1.00, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.16 (s, 1H, NH), 4.97 (d, 1H, $J_{4,5}$ 5.7 Hz, H-4), 4.76 (d, 1H, $J_{1a,1b}$ 9.0 Hz, H-1a), 4.30 (m, 1H, H-5), 4.26 (s, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 9.0 Hz, H-6), 2.57 (m, 2H, CH_2CO), 1.55–0.86 (m, 33H, $C(CH_3)_2$, $C_{10}H_{21}$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.9 (C=O), 140.6 (C-3), 112.9, 110.6 ($C(CH_3)_2$), 103.9 (C-2), 74.1 (C-5), 71.6 (C-1), 71.5 (C-4), 59.1 (C-6), 32.3, 31.9, 29.6, 29.5, 29.4, 29.3, 27.0, 26.6, 26.1, 26.0, 24.8, 22.6, 14.1 ($C(CH_3)_2$, $C_{11}H_{23}$); FAB-MS: *m/z* 454.9 $[M+H]^+$; Anal. Calcd for $C_{24}H_{42}N_2O_6$: C, 63.41; H, 9.31; N, 6.16. Found: C, 63.31; H, 9.45; N, 6.08.

4.6.20. *Z*-3-Lauroylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 3j

White wax; $[\alpha]_D^{25} = -154.8$ (*c* 0.93, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.15 (s, 1H, NH), 4.97 (d, 1H, $J_{4,5}$ 5.7 Hz, H-4), 4.76 (d, 1H, $J_{1a,1b}$ 9.0 Hz, H-1a), 4.30 (s, 1H, H-5), 4.26 (s, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 9.0 Hz, H-6), 2.57 (m, 2H, CH_2CO), 1.68–0.86 (m, 33H, $C(CH_3)_2$, $C_{10}H_{21}$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.9 (C=O), 140.6 (C-3), 112.9, 110.6 ($C(CH_3)_2$), 103.9 (C-2), 74.1 (C-5), 71.6 (C-1), 71.5 (C-4), 59.1 (C-6), 32.3, 31.9, 29.6, 29.4, 29.3, 27.0, 26.6, 26.1, 26.0, 24.8, 22.7, 14.1 ($C(CH_3)_2$, $C_{11}H_{23}$); FAB-MS: *m/z* 455.0 $[M+H]^+$; Anal. Calcd for $C_{24}H_{42}N_2O_6$ C, 63.41; H, 9.31; N, 6.16. Found: C, 63.32; H, 9.51; N, 6.00.

4.6.21. *E*-3-Palmitoylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 2k

White wax; $[\alpha]_D^{25} = -193.9$ (*c* 0.99, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.16 (s, 1H, NH), 4.98 (d, 1H, $J_{4,5}$ 5.4 Hz, H-4), 4.76 (d, 1H, $J_{1a,1b}$ 8.7 Hz, H-1a), 4.32 (m, 1H, H-5), 4.25 (s, 1H, H-1b), 4.07 (m, 2H, $J_{6a,6b}$ 8.7 Hz, H-6), 2.56 (m, 2H, CH_2CO), 1.67–0.88 (m, 41H, $C(CH_3)_2$, $C_{14}H_{29}$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.9 (C=O), 140.6 (C-3), 112.9, 110.7 ($C(CH_3)_2$), 103.9 (C-2), 74.1 (C-5), 71.6 (C-1), 71.5 (C-4), 59.1 (C-6), 32.3, 31.9, 29.7, 29.5, 29.4, 29.3, 27.0, 26.6, 26.1, 26.0, 24.8, 22.7, 14.1 ($C(CH_3)_2$, $C_{15}H_{31}$); FAB-MS: *m/z* 511.3 $[M+H]^+$; Anal. Calcd for $C_{28}H_{50}N_2O_6$: C, 65.85; H, 9.87; N, 5.49. Found: C, 65.80; H, 9.65; N, 5.53.

4.6.22. *Z*-3-Palmitoylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 3k

White wax; $[\alpha]_D^{25} = -134.7$ (*c* 1.01, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.15 (s, 1H, NH), 4.97 (d, 1H, $J_{4,5}$ 5.4 Hz, H-4), 4.76 (d, 1H, $J_{1a,1b}$ 8.7 Hz, H-1a), 4.30 (d, 1H, H-5), 4.25 (s, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 8.7 Hz, H-6), 2.57 (m, 2H, CH_2CO), 1.68–0.86 (m, 41H, $C(CH_3)_2$, $C_{14}H_{29}$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.9 (C=O), 140.6 (C-3), 112.9, 110.7 ($C(CH_3)_2$), 103.9 (C-2), 74.2 (C-5), 71.6 (C-1), 71.5 (C-4), 59.1 (C-6), 32.3, 31.9, 29.7, 29.5, 29.4, 29.3, 27.0, 26.6, 26.1, 26.0, 24.8, 22.7, 14.1 ($C(CH_3)_2$, $C_{15}H_{31}$); ESI-TOF-MS: *m/z* 511.5448 $[M+H]^+$, 533.5283 $(M+Na^+)$; Anal. Calcd for $C_{28}H_{50}N_2O_6$: C, 65.85; H, 9.87; N, 5.49. Found: C, 66.00; H, 9.72; N, 5.49.

4.6.23. *E*-3-Stearoylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 2l

White wax; $[\alpha]_D^{25} = -148.6$ (*c* 1.05, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.15 (s, 1H, NH), 4.97 (d, 1H, $J_{4,5}$ 5.4 Hz, H-4), 4.76 (d, 1H, $J_{1a,1b}$ 8.7 Hz, H-1a), 4.30 (d, 1H, H-5), 4.26 (s, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 9.0 Hz, H-6), 2.56 (m, 2H, CH_2CO), 1.68–0.86 (m, 45H, $C(CH_3)_2$, $C_{16}H_{33}$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.9 (C=O), 140.6 (C-3), 112.9, 110.6 ($C(CH_3)_2$), 103.9 (C-2), 74.2 (C-5), 71.6 (C-1), 71.5 (C-4), 59.1 (C-6), 32.3, 31.9, 29.7, 29.5, 29.4, 29.3, 27.0, 26.6, 26.1, 26.0, 24.8, 22.7, 14.1 ($C(CH_3)_2$, $C_{17}H_{35}$); FAB-MS: *m/z* 539.4 $[M+H]^+$; Anal. Calcd for $C_{30}H_{54}N_2O_6$): C, 66.88; H, 10.10; N, 5.20. Found: C, 67.09; H, 9.96; N, 5.04.

4.6.24. *Z*-3-Stearoylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 3l

White wax; $[\alpha]_D^{25} = -114.9$ (*c* 1.01, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 10.15 (s, 1H, NH), 4.97 (d, 1H, $J_{4,5}$ 5.4 Hz, H-4), 4.76 (d, 1H, $J_{1a,1b}$ 8.7 Hz, H-1a), 4.30 (d, 1H, H-5), 4.25 (s, 1H, H-1b), 4.10 (dd, 2H, $J_{6a,6b}$ 9.3 Hz, H-6), 2.57 (m, 2H, CH_2CO), 1.68–0.86 (m, 45H, $C(CH_3)_2$, $C_{16}H_{33}$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 175.9 (C=O), 140.6 (C-3), 112.9, 110.7 ($C(CH_3)_2$), 103.9 (C-2), 74.2 (C-5), 71.6 (C-1), 71.5 (C-4), 59.1 (C-6), 32.3, 31.9, 29.7, 29.6, 29.5, 29.4, 29.4, 29.3, 27.0, 26.6, 26.1, 26.0, 24.8, 22.7, 14.1 ($C(CH_3)_2$, $C_{17}H_{35}$); FAB-MS: *m/z* 539.1 $[M+H]^+$; Anal. Calcd for $C_{30}H_{54}N_2O_6$: C, 66.88; H, 10.10; N, 5.20. Found: C, 67.01; H, 9.89; N, 4.92.

4.6.25. (2*R*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-methyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 4a

Colorless crystal. mp 126–128 °C; $[\alpha]_D^{25} = -11.2$ (*c* 1.07, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.96 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.38 (d, 1H, H-5), 4.26 (dd, 2H, $J_{6a,6b}$ 13.5 Hz, H-6), 4.01 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.07 (s, 3H, CH_3C=N), 2.27 (s, 3H, Ac), 1.55, 1.51, 1.36 (4s, 12H, C(CH_3)$_2$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.1 (C=O), 153.9 (C=N), 114.1, 109.6 (*C*(CH_3)$_2$), 105.1 (C-2), 96.9 (C-3), 72.5 (C-5), 71.0 (C-1), 68.2 (C-4), 59.6 (C-6), 26.3, 25.8, 25.6 (C(*C*H_3)$_2$), 23.8 (CO*C*H_3), 11.3 (*C*H_3C=N); FAB-MS: *m/z* 356.5 $[M+H]^+$; Anal. Calcd for $C_{16}H_{24}N_2O_7$: C, 53.92; H, 6.79; N, 7.86. Found: C, 53.80; H, 6.75; N, 7.71.

4.6.26. (2*S*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-methyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) (5a)

Colorless foam. $[\alpha]_D^{25} = -18.5$ (*c* 0.96, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.91 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.33 (dd, 1H, H-5), 4.21 (dd, 2H, $J_{6a,6b}$ 13.5 Hz, H-6), 3.96 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.22 (s, 3H, CH_3C=N), 2.03 (s, 3H, Ac), 1.51, 1.47, 1.33, 1.32 (4s, 12H, C(CH_3)$_2$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.1 (C=O), 153.9 (C=N), 114.0, 109.7 (*C*(CH_3)$_2$), 105.1 (C-2), 96.9 (C-3), 72.5 (C-5), 71.1 (C-1), 68.2 (C-4), 59.6 (C-6), 26.3, 25.8, 25.5 (C(*C*H_3)$_2$), 23.8 (CO*C*H_3), 11.3 (*C*H_3C=N); FAB-MS: *m/z* 356.5 $[M+H]^+$; Anal. Calcd for $C_{16}H_{24}N_2O_7$: C, 53.92; H, 6.79; N, 7.86. Found: C, 53.73; H, 6.74; N, 7.89.

4.6.27. (2*R*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-ethyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 4b

Colorless crystal. mp 99–102 °C; $[\alpha]_D^{25} = -35.0$ (*c* 1.03, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.98 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.37 (dd, 1H, H-5), 4.26 (dd, 2H, $J_{6a,6b}$ 13.5 Hz, H-6), 3.99 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.38 (m, 2H, CH_2C=N), 2.28 (s, 3H, Ac), 1.55, 1.51, 1.36 (4s, 12H, C(CH_3)$_2$), 1.26, 1.23, 1.21 (t, 3H, *C*H_3CH$_2$). ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.3 (C=O), 158.1 (C=N), 114.1, 109.7 (*C*(CH_3)$_2$), 105.2 (C-2), 96.7 (C-3), 72.4 (C-5), 71.0 (C-1), 68.3 (C-4), 59.5 (C-6), 26.4, 25.8, 25.5 (C(*C*H_3)$_2$), 23.9 (CO*C*H_3), 19.2, 9.9 (C_2H_5); FAB-MS: *m/z* 370.7 $[M+H]^+$; Anal. Calcd for $C_{17}H_{26}N_2O_7$: C, 55.13; H, 7.08; N, 7.56. Found: C, 55.05; H, 6.92; N, 7.51.

4.6.28. (2*S*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-ethyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 5b

Colorless foam. $[\alpha]_D^{25} = -34.3$ (*c* 1.04, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.98 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.37 (dd, 1H, H-5), 4.26 (dd, 2H, $J_{6a,6b}$ 13.5 Hz, H-6), 3.99 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.62 (m, 2H, CH_2C=N), 2.07 (s, 3H, Ac), 1.55, 1.50, 1.37, 1.35 (4s, 12H, C(CH_3)$_2$), 1.14, 1.12, 1.09 (t, 3H, *C*H_3CH$_2$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 171.5 (C=O), 153.8 (C=N), 114.0, 109.6 (*C*(CH_3)$_2$), 105.2 (C-2), 96.8 (C-3), 72.5 (C-5), 71.1 (C-1), 68.3 (C-4), 59.6 (C-6), 29.0, 26.3, 25.8, 25.5 (C(*C*H_3)$_2$, CO*C*H_3), 11.3, 8.7 (C_2H_5); FAB-MS: *m/z* 371.2 $[M+H]^+$; Anal. Calcd for $C_{17}H_{26}N_2O_7$: C, 55.13; H, 7.08; N, 7.56. Found: C, 55.20; H, 6.98; N, 7.47.

4.6.29. (2*R*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-propyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 4c

Colorless foam. $[\alpha]_D^{25} = -16.7$ (*c* 1.05, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.36 (d, 1H, H-5), 4.25 (dd, 2H, $J_{6a,6b}$ 13.2 Hz, H-6), 3.99(dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.32 (m, 2H, CH_2C=N), 2.28 (s, 3H, Ac), 1.68 (dd, 2H, CH_3CH_2,), 1.54, 1.51, 1.36 (4s, 12H, C(CH_3)$_2$), 1.01 (t, 3H, *C*H_3CH$_2$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.3 (C=O), 157.0 (C=N), 114.1, 109.6 (*C*(CH_3)$_2$), 105.2 (C-2), 96.6 (C-3), 72.4 (C-5), 71.1 (C-1), 68.2 (C-4), 59.5 (C-6), 27.5, 26.4, 25.8, 25.6, 23.9, 19.0, 13.6 (C(*C*H_3)$_2$, CO*C*H_3, C_3H_7); FAB-MS: *m/z* 384.8 $[M+H]^+$; Anal. Calcd for $C_{18}H_{28}N_2O_7$: C, 56.24; H, 7.34; N, 7.29. Found: C, 56.21; H, 7.30; N, 7.27.

4.6.30. (2*S*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-propyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 5c

Colorless foam. $[\alpha]_D^{25} = -33.0$ (*c* 1.08, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.37 (dd, 1H, H-5), 4.26 (dd, 2H, $J_{6a,6b}$ 13.5 Hz, H-6),3.99 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.58 (m, 2H, CH_2C=N), 2.07 (s, 3H, Ac), 1.65 (m, 2H, CH_2CH_3), 1.55, 1.50, 1.36, 1.35 (4s, 12H, C(CH_3)$_2$), 0.99, 0.97, 0.94 (t, 3H, *C*H_3CH$_2$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 170.6 (C=O), 153.6 (C=N), 113.8, 109.5 (*C*(CH_3)$_2$), 105.1 (C-2), 96.8 (C-3), 72.4 (C-5), 71.2 (C-1), 68.2 (C-4), 59.5 (C-6), 37.5, 26.3, 26.2, 25.8, 25.6, 17.9, 13.6, 11.2 (C(CH_3)$_2$, CO*C*H_3, C_3H_7); FAB-MS: *m/z* 384.8 $[M+H]^+$; Anal. Calcd for $C_{18}H_{28}N_2O_7$: C, 56.24; H, 7.34; N, 7.29. Found: C, 56.23; H, 7.33; N, 7.25.

4.6.31. (2*R*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-butyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 4d

Colorless foam. $[\alpha]_D^{25} = -29.8$ (*c* 0.94, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.37 (dd, 1H, H-5), 4.25 (m, 2H, $J_{6a,6b}$ 13.5 Hz, H-6), 3.99 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.36 (m, 2H, CH_2C=N), 2.27 (s, 3H, Ac), 1.75–0.91 (m, 19H, C(CH_3)$_2$, C_3H_7); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.1 (C=O), 157.0 (C=N), 113.9, 109.5 (*C*(CH_3)$_2$), 105.1 (C-2), 96.4 (C-3), 72.3 (C-5), 70.9 (C-1), 68.1 (C-4), 59.4 (C-6), 27.4, 26.3, 25.7, 25.4, 25.2, 23.8, 22.0, 13.4 (C(CH_3)$_2$, CO*C*H_3, C_4H_9); FAB-MS: *m/z* 398.9 $[M+H]^+$; Anal. Calcd for $C_{19}H_{30}N_2O_7$: C, 57.27; H, 7.59; N, 7.03. Found: C, 57.11; H, 7.50; N, 6.95.

4.6.32. (2*S*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-butyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 5d

Colorless foam. $[\alpha]_D^{25} = -11.0$ (*c* 1.09, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97(d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.37 (dd, 1H, H-5), 4.25 (dd, 2H, $J_{6a,6b}$ 13.5 Hz, H-6), 4.00 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.60 (m, 2H, CH_2C=N), 2.07 (s, 3H, Ac), 1.73–0.89 (m, 19H, C(CH_3)$_2$, C_3H_7); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.1 (C=O), 157.1 (C=N), 113.9, 109.5 (*C*(CH_3)$_2$), 105.1 (C-2), 96.5 (C-3), 72.3 (C-5), 70.9 (C-1), 68.1 (C-4), 59.4 (C-6), 27.4, 26.3, 25.7, 25.4, 25.2, 23.7, 22.0, 13.4 (C(CH_3)$_2$, CO*C*H_3, C_4H_9); FAB-MS: *m/z* 399.0 $[M+H]^+$; Anal. Calcd for $C_{19}H_{30}N_2O_7$: C, 57.27; H, 7.59; N, 7.03. Found: C, 57.06; H, 7.46; N, 6.94.

4.6.33. (2*R*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-pentyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 4e

Colorless foam. $[\alpha]_D^{25} = -24.0$ (*c* 1.00, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.37 (dd, 1H, H-5), 4.25 (m, 2H, $J_{6a,6b}$ 13.2 Hz, H-6), 3.99 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.36 (m, 2H, CH_2C=N), 2.27 (s, 3H, Ac), 1.67–0.89 (m, 21H, C(CH_3)$_2$, C_4H_9); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.1 (C=O), 157.0 (C=N), 113.9, 109.4 (*C*(CH_3)$_2$), 105.1 (C-2), 96.4 (C-3), 72.3 (C-5), 71.0 (C-1), 68.1 (C-4), 59.4 (C-6), 31.0, 26.3, 25.7, 25.4, 25.0, 23.7, 22.0, 13.7 (C(CH_3)$_2$, CO*C*H_3, C_5H_{11}); FAB-MS: *m/z* $[M+H]^+$; Anal. Calcd for $C_{20}H_{32}N_2O_7$: C, 58.24; H, 7.82; N, 6.79. Found: C, 58.19; H, 7.80; N, 6.75.

4.6.34. (2*S*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-pentyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 5e

Colorless foam. $[\alpha]_D^{25} = -43.5$ (*c* 0.92, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.37 (dd, 1H, H-

5), 4.25 (dd, 2H, $J_{6a,6b}$ 13.2 Hz, H-6), 3.99 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.58 (m, 2H, CH_2C=N), 2.07 (s, 3H, Ac), 1.59–0.86 (m, 21H, $C(CH_3)_2$, C_4H_9); ^{13}C NMR (75 MHz, $CDCl_3$): δ 171.0 (C=O), 153.7 (C=N), 114.0, 109.6 ($C(CH_3)_2$), 105.2 (C-2), 96.9 (C-3), 72.5 (C-5), 71.1 (C-1), 68.3 (C-4), 59.6 (C-6), 35.6, 31.4, 26.3, 25.8, 25.6, 25.5, 24.2, 22.4, 13.9, 11.3 ($C(CH_3)_2$, $COCH_3$, C_5H_{11}); FAB-MS: *m/z* 412.3 $[M+H]^+$; Anal. Calcd for $C_{20}H_{32}N_2O_7$: C, 58.24; H, 7.82; N, 6.79. Found: C, 58.22; H, 7.86; N, 6.71.

4.6.35. (2*R*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-hexyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 4f

Colorless foam. $[\alpha]_D^{25} = -8.4$ (*c* 0.95, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.37 (d, 1H, H-5), 4.25 (dd, 2H, $J_{6a,6b}$ 13.5 Hz, H-6), 3.98 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.35 (m, 2H, CH_2C=N), 2.27 (s, 3H, Ac), 1.69–0.87 (m, 23H, $C(CH_3)_2$, C_5H_{11}); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.1 (C=O), 157.1 (C=N), 113.8, 109.4 ($C(CH_3)_2$), 105.0 (C-2), 96.4 (C-3), 72.2 (C-5), 70.9 (C-1), 68.0 (C-4), 59.3 (C-6), 31.0, 28.5, 26.2, 25.7, 25.4, 25.3, 23.6, 22.2, 13.8 ($C(CH_3)_2$, $COCH_3$, C_6H_{13}); FAB-MS: *m/z* 427.0 $[M+H]^+$; Anal. Calcd for $C_{21}H_{34}N_2O_7$: C, 59.14; H, 8.04; N, 6.57. Found: C, 59.06; H, 7.92; N, 6.55.

4.6.36. (2*S*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-hexyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 5f

Colorless foam. $[\alpha]_D^{25} = -25.0$ (*c* 1.12, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.95 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.37 (d, 1H, H-5), 4.25 (dd, 2H, $J_{6a,6b}$ 13.5 Hz, H-6), 3.99 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.65 (m, 2H, CH_2C=N), 2.07 (s, 3H, Ac), 1.63–0.86 (m, 23H, $C(CH_3)_2$, C_5H_{11}); ^{13}C NMR (75 MHz, $CDCl_3$): δ 170.8 (C=O), 153.6 (C=N), 113.7, 109.4 ($C(CH_3)_2$), 105.0 (C-2), 96.7 (C-3), 72.3 (C-5), 70.9 (C-1), 68.1 (C-4), 59.4 (C-6), 35.5, 31.4, 28.7, 26.1, 25.6, 25.5, 25.4, 24.3, 22.3, 13.8, 11.1 ($C(CH_3)_2$, $COCH_3$, C_6H_{13}); FAB-MS: *m/z* 427.0 $[M+H]^+$; Anal. Calcd for $C_{21}H_{34}N_2O_7$: C, 59.14; H, 8.04; N, 6.57. Found: C, 58.99; H, 7.97; N, 6.51.

4.6.37. (2*R*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-heptyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 4g

Colorless foam. $[\alpha]_D^{25} = -46.3$ (*c* 0.95, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.37 (dd, 1H, H-5), 4.25 (m, 2H, $J_{6a,6b}$ 13.5 Hz, H-6), 3.99 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.34 (m, 2H, CH_2C=N), 2.27 (s, 3H, Ac), 1.68–0.86 (m, 25H, $C(CH_3)_2$, C_6H_{13}); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.3 (C=O), 157.2 (C=N), 114.1, 109.7 ($C(CH_3)_2$), 105.2 (C-2), 96.6 (C-3), 72.5 (C-5), 71.1 (C-1), 68.2 (C-4), 59.5 (C-6), 31.9, 29.5, 29.4, 29.3, 29.1, 29.0, 26.5, 25.9 25.6, 23.9, 22.6, 14.1 ($C(CH_3)_2$, $COCH_3$, C_7H_{15}); FAB-MS: *m/z* 442.0 $[M+H]^+$; Anal. Calcd for $C_{22}H_{36}N_2O_7$: C, 59.98; H, 8.24; N, 6.36. Found: C, 59.96; H, 8.20; N, 6.33.

4.6.38. (2*S*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-heptyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 5g

Colorless foam. $[\alpha]_D^{25} = -47.3$ (*c* 1.10, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.96 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.36 (dd, 1H, H-5), 4.25 (dd, 2H, $J_{6a,6b}$ 13.2 Hz, H-6), 3.98 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 58 (m, 2H, CH_2C=N), 2.06 (s, 3H, Ac), 1.65–0.84 (m, 25H, $C(CH_3)_2$, C_6H_{13}); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.3 (C=O), 157.2 (C=N), 114.1, 109.7 ($C(CH_3)_2$), 105.2 (C-2), 96.6 (C-3), 72.5 (C-5), 71.1 (C-1), 68.2 (C-4), 59.6 (C-6), 31.5, 29.0, 28.7, 26.5, 25.9, 25.6, 23.9, 22.5, 14.0 ($C(CH_3)_2$, $COCH_3$, C_7H_{15}); FAB-MS: *m/z* 441.9 $[M+H]^+$; Anal. Calcd for $C_{22}H_{36}N_2O_7$: C, 59.98; H, 8.24; N, 6.36. Found: C, 59.94; H, 8.23; N, 6.35.

4.6.39. (2*R*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-octyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 4h

Colorless foam. $[\alpha]_D^{25} = -11.5$ (*c* 1.04, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.37 (dd, 1H, H-5), 4.25 (dd, 2H, $J_{6a,6b}$ 13.2 Hz, H-6), 3.99 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.35 (m, 2H, CH_2C=N), 2.27 (s, 3H, Ac), 1.71–0.86 (m, 27H, $C(CH_3)_2$, C_7H_{15}); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.2 (C=O), 157.2 (C=N), 114.0, 109.6 ($C(CH_3)_2$), 105.2 (C-2), 96.5 (C-3), 72.4 (C-5), 71.0 (C-1), 68.2 (C-4), 59.5 (C-6), 31.7, 29.6, 29.0, 26.4, 25.8, 25.5, 23.8, 22.5, 14.0, ($C(CH_3)_2$, $COCH_3$, C_8H_{17}); FAB-MS: *m/z* 455.2 $[M+H]^+$; Anal. Calcd for $C_{23}H_{38}N_2O_7$: C, 60.77; H, 8.43; N, 6.16. Found: C, 60.74; H, 8.38; N, 6.05.

4.6.40. (2*S*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-octyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 5h

Colorless foam. $[\alpha]_D^{25} = -30.5$ (*c* 1.05, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.37 (dd, 1H, H-5), 4.25 (dd, 2H, $J_{6a,6b}$ 13.2 Hz, H-6), 3.99 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.57 (m, 2H, CH_2C=N), 2.07 (s, 3H, Ac), 1.64–0.85 (m, 27H, $C(CH_3)_2$, C_7H_{15}); ^{13}C NMR (75 MHz, $CDCl_3$): δ 170.9 (C=O), 153.7 (C=N), 113.9, 109.6 ($C(CH_3)_2$), 105.1 (C-2), 96.9 (C-3), 72.5 (C-5), 71.0 (C-1), 68.2 (C-4), 59.5 (C-6), 35.6, 31.7, 29.2, 29.1, 29.0, 26.3, 25.9, 25.8, 25.6, 25.5, 24.5, 22.5, 14.0, 11.2 ($C(CH_3)_2$, $COCH_3$, C_8H_{17}); FAB-MS: *m/z* 455.0 $[M+H]^+$; Anal. Calcd for $C_{23}H_{38}N_2O_7$: C, 60.77; H, 8.43; N, 6.16. Found: C, 60.65; H, 8.37; N, 6.11.

4.6.41. (2*R*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-nonyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 4i

Colorless foam. $[\alpha]_D^{25} = -33.0$ (*c* 0.97, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.98 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.37 (dd, 1H, H-5), 4.25 (dd, 2H, $J_{6a,6b}$ 13.2 Hz, H-6), 3.99 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.34 (m, 2H, CH_2C=N), 2.27 (s, 3H, Ac), 1.69–0.86 (m, 29H, $C(CH_3)_2$, C_8H_{17}); ^{13}C NMR (75 MHz, $CDCl_3$): δ 171.0 (C=O), 153.7 (C=N), 114.0, 109.6 ($C(CH_3)_2$), 105.2 (C-2), 96.9 (C-3), 72.5 (C-5), 71.1 (C-1), 68.3 (C-4), 59.6 (C-6), 35.7, 31.8, 29.4, 29.3, 29.2, 26.3, 25.8, 25.6, 25.5, 24.5, 22.6, 14.1, 11.3 ($C(CH_3)_2$, $COCH_3$, C_9H_{19}); FAB-MS: *m/z* 469.0 $[M+H]^+$; Anal. Calcd for $C_{24}H_{40}N_2O_7$: C, 61.52; H, 8.60; N, 5.98. Found: C, 61.48; H, 8.51; N, 5.92.

4.6.42. (2*S*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-nonyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 5i

Colorless foam. $[\alpha]_D^{25} = -53.6$ (*c* 0.97, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.37 (dd, 1H, H-5), 4.25 (dd, 2H, $J_{6a,6b}$ 13.2 Hz, H-6), 3.99 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.59 (m, 2H, CH_2C=N), 2.07 (s, 3H, Ac), 1.63–0.85 (m, 29H, $C(CH_3)_2$, C_8H_{17}); ^{13}C NMR (75 MHz, $CDCl_3$): δ 171.0 (C=O), 153.7 (C=N), 114.0, 109.6 ($C(CH_3)_2$), 105.2 (C-2), 96.9 (C-3), 72.5 (C-5), 71.1 (C-1), 68.3 (C-4), 59.6 (C-6), 35.7, 31.8, 29.4, 29.3, 29.2, 26.3, 25.8, 25.6, 25.5, 24.5, 22.6, 14.1, 11.3 ($C(CH_3)_2$, $COCH_3$, C_9H_{19}); FAB-MS: *m/z* 469.1 $[M+H]^+$; Anal. Calcd for $C_{24}H_{40}N_2O_7$: C, 61.52; H, 8.60; N, 5.98. Found: C, 61.50; H, 8.59; N, 5.93.

4.6.43. (2*R*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-undecyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 4j

Yellowish foam. $[\alpha]_D^{25} = -23.5$ (*c* 1.36, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.36 (dd, 1H, H-5), 4.24 (dd, 2H, $J_{6a,6b}$ 13.2 Hz, H-6), 3.98 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.32 (m, 2H, CH_2C=N), 2.26 (s, 3H, Ac), 1.67–0.86 (m, 33H, $C(CH_3)_2$, $C_{10}H_{21}$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.2

(C=O), 157.1 (C=N), 114.0, 109.6 ($C(CH_3)_2$), 105.2 (C-2), 96.5 (C-3), 72.4 (C-5), 71.0 (C-1), 68.2 (C-4), 59.5 (C-6), 31.8, 29.5, 29.3, 29.2, 29.0, 28.9, 27.3, 26.4, 25.8, 25.5, 25.4, 23.8, 22.6, 14.0 ($C(CH_3)_2$, $COCH_3$, $C_{11}H_{23}$); FAB-MS: *m/z* 496.6 $[M+H]^+$; Anal. Calcd for $C_{26}H_{44}N_2O_7$: C, 62.88; H, 8.93; N, 5.64. Found: C, 62.69; H, 8.80; N, 5.53.

4.6.44. (2*S*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-undecyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 5j

Yellowish foam. $[\alpha]_D^{25} = -39.3$ (*c* 1.12, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.37 (dd, 1H, H-5), 4.25 (dd, 2H, $J_{6a,6b}$ 13.2 Hz, H-6), 3.99 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.58 (m, 2H, CH_2C=N), 2.07 (s, 3H, Ac), 1.64–0.86 (m, 33H, $C(CH_3)_2$, $C_{10}H_{21}$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 170.9 (C=O), 153.7 (C=N), 113.9, 109.5 ($C(CH_3)_2$), 105.2 (C-2), 96.9 (C-3), 72.5 (C-5), 71.0 (C-1), 68.2 (C-4), 59.5 (C-6), 35.6, 31.8, 29.5, 29.4, 29.3, 29.2, 29.1, 26.4, 26.3, 26.2, 25.9, 25.8, 25.7, 25.6, 25.5, 24.5, 22.6, 14.0, 11.3, 11.2 ($C(CH_3)_2$, $COCH_3$, $C_{11}H_{23}$); FAB-MS: *m/z* 496.9 $[M+H]^+$; Anal. Calcd for $C_{26}H_{44}N_2O_7$: C, 62.88; H, 8.93; N, 5.64. Found: C, 62.65; H, 8.81; N, 5.50.

4.6.45. (2*R*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-pentadecyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 4k

White wax. $[\alpha]_D^{25} = -3.6$ (*c* 1.11, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.37 (dd, 1H, H-5), 4.25 (dd, 2H, $J_{6a,6b}$ 13.2 Hz, H-6), 3.99 (dd, 2H, H-1, $J_{1a,1b}$ 9.0 Hz, H-1), 2.34 (m, 2H, CH_2C=N), 2.27 (s, 3H, Ac), 1.67–0.86 (m, 41H, $C(CH_3)_2$, $C_{14}H_{29}$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.3 (C=O), 157.2 (C=N), 114.1, 109.6 ($C(CH_3)_2$), 105.2 (C-2), 96.6 (C-3), 72.4 (C-5), 71.1 (C-1), 68.2 (C-4), 59.5 (C-6), 31.9, 29.6, 29.5, 29.4, 29.1, 27.3, 26.4, 25.9, 25.5, 23.9, 22.6, 14.1 ($C(CH_3)_2$, $COCH_3$, $C_{15}H_{31}$); FAB-MS: *m/z* 552.9 $[M+H]^+$; Anal. Calcd for $C_{30}H_{52}N_2O_7$: C, 65.19; H, 9.48; N, 5.07. Found: C, 64.98; H, 9.22; N, 5.17.

4.6.46. (2*S*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-pentadecyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 5k

White wax. $[\alpha]_D^{25} = -11.3$ (*c* 1.06, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.36 (m, 1H, H-5), 4.25 (dd, 2H, $J_{6a,6b}$ 13.2 Hz, H-6), 3.99 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.59 (m, 2H, CH_2C=N), 2.07 (s, 3H, Ac), 1.63–0.86 (m, 41H, $C(CH_3)_2$, $C_{14}H_{29}$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 170.9 (C=O), 153.7 (C=N), 113.9, 109.5 ($C(CH_3)_2$), 105.2 (C-2), 96.9 (C-3), 72.5 (C-5), 71.0 (C-1), 68.2 (C-4), 59.5 (C-6), 35.6, 31.8, 29.5, 29.4, 29.3, 29.2, 29.1, 26.4, 26.3, 26.2, 25.9, 25.8, 25.7, 25.6, 25.5, 24.5, 22.6, 14.0, 11.3, 11.2 ($C(CH_3)_2$, $COCH_3$, $C_{15}H_{31}$); FAB-MS: *m/z* 553.3 $[M+H]^+$; Anal. Calcd for $C_{30}H_{52}N_2O_7$: C, 65.19; H, 9.48; N, 5.07. Found: C, 65.37; H, 9.50; N, 5.02.

4.6.47. (2*R*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-heptadecyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 4l

White wax. $[\alpha]_D^{25} = -12.6$ (*c* 0.95, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.35 (dd, 1H, H-5), 4.24 (dd, 2H, $J_{6a,6b}$ 13.2 Hz, H-6), 3.98 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.34 (m, 2H, CH_2C=N), 2.27 (s, 3H, Ac), 1.67–0.86 (m, 45H, $C(CH_3)_2$, $C_{16}H_{33}$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.2 (C=O), 157.1 (C=N), 114.0, 109.6 ($C(CH_3)_2$), 105.2 (C-2), 96.5 (C-3), 72.4 (C-5), 71.0 (C-1), 68.2 (C-4), 59.5 (C-6), 31.8, 29.5, 29.3, 29.2, 29.0, 28.9, 27.3, 26.4, 25.8, 25.5, 25.4, 23.8, 22.6, 14.0 ($C(CH_3)_2$, $COCH_3$, $C_{17}H_{35}$). FAB-MS: *m/z* 580.7 $[M+H]^+$; Anal. Calcd for $C_{32}H_{56}N_2O_7$: C, 66.18; H, 9.72; N, 4.82. Found: C, 65.99; H, 9.70; N, 4.77.

4.6.48. (2*S*,3a′*R*,6′*S*,7a′*R*)-3-Acetyl-2′,2′,2″,2″-tetramethyl-5-heptadecyl-2,3-dihydro-1,3,4-oxadiazole-2-spiro-7′-{1′,3′-dioxolano[4,5-c]pyrano}-6′-spiro-4″-(1″,3″-diaoxolane) 5l

White wax. $[\alpha]_D^{25} = -24.0$ (*c* 0.5, MeOH); ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97 (d, 1H, $J_{4,5}$ 6.0 Hz, H-4), 4.36 (dd, 1H, H-5), 4.24 (dd, 2H, $J_{6a,6b}$ 13.2 Hz, H-6), 3.98 (dd, 2H, $J_{1a,1b}$ 9.0 Hz, H-1), 2.62 (m, 2H, CH_2C=N), 2.07 (s, 3H, Ac), 1.65–0.86 (m, 45H, $C(CH_3)_2$, $C_{16}H_{33}$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.2 (C=O), 157.1 (C=N), 114.1, 109.6 ($C(CH_3)_2$), 105.2 (C-2), 96.5 (C-3), 72.5 (C-5), 71.0 (C-1), 68.2 (C-4), 59.5 (C-6), 31.8, 29.5, 29.3, 29.2, 29.0, 28.9, 27.3, 26.4, 25.8, 25.5, 25.4, 23.8, 22.6, 14.0, 11.2, 11.1 ($C(CH_3)_2$, $COCH_3$, $C_{17}H_{35}$); FAB-MS: *m/z* 581.3 $[M+H]^+$; Anal. Calcd for $C_{32}H_{56}N_2O_7$: C, 66.18; H, 9.72; N, 4.82. Found: C, 66.33; H, 9.91; N, 4.65.

4.6.49. *N*-Acetyl-3-acetylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 6a

Colorless foam; ^{1}H NMR (300 MHz, $CDCl_3$): δ 4.72 (d, 1H, $J_{4,5}$ 6.3 Hz, H-4), 4.65 (d, 1H, $J_{1a,1b}$ 9.3 Hz, H-1a), 4.38 (dd, 1H, H-5), 4.22 (dd, 1H, $J_{6a,6b}$ 13.2 Hz, H-6a), 4.03 (d, 1H, H-1b), 3.99 (d, 1H, H-6b), 2.42 (s, 6H, Ac), 1.53, 1.45, 1.37, 1.32 (4s, 12H, $C(CH_3)_2$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 169.6 (C=O), 166.8 (C-3), 112.7, 110.3 ($C(CH_3)_2$), 104.3 (C-2), 75.4 (C-5), 72.4 (C-4), 72.1 (C-1), 61.9 (C-6), 26.5, 26.4, 26.0, 26.0 ($C(CH_3)_2$), 25.8 ($COCH_3$); HR-ESI-MS: Calcd for $C_{16}H_{25}N_2O_7$: 357.1662 $[M+H]^+$. Found: 357.1667$[M+H]^+$.

4.6.50. *N*-Acetyl-3-valerylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 6d

Colorless foam; ^{1}H NMR (300 MHz, $CDCl_3$): δ 4.72 (d, 1H, $J_{4,5}$ 6.3 Hz, H-4), 4.64 (d, 1H, $J_{1a,1b}$ 9.3 Hz, H-1a), 4.38 (dd, 1H, H-5), 4.22 (dd, 1H, $J_{6a,6b}$ 13.2 Hz, H-6a), 4.08 (d, 1H, H-1b), 3.98 (d, 1H, H-6b), 2.57 (m, 2H, CH_2CO), 2.43 (s, 6H, Ac), 1.65 (m, 4H, $C_2H_4CH_3$), 1.55, 1.44, 1.42, 1.39 (4s, 12H, $C(CH_3)_2$), 0.90 (m, 3H, CH_3CH_2); ^{13}C NMR (75 MHz, $CDCl_3$): δ 170.8 ($COC_{15}H_{31}$), 169.9 (C=O), 166.9 (C-3), 112.8, 110.6 ($C(CH_3)_2$), 104.2 (C-2), 74.7 (C-6), 72.0 (C-4), 71.8 (C-1), 62.0 (C-5), 37.5, 32.1, 31.6, 26.9, 26.5, 26.1, 26.0, 24.4, 22.4, 13.9 ($C(CH_3)_2$, C_5H_{11}); HR-ESI-MS: Calcd for $C_{19}H_{31}N_2O_7$: 399.2131 $[M+H]^+$. Found: 399.2124 $[M+H]^+$.

4.6.51. *N*-Acetyl-3-palmitoylhydrazono-1,2:4,5-di-*O*-isopropylidene-β-D-*erythro*-2-hexulopyranose 6k

Colorless foam; ^{1}H NMR (300 MHz, $CDCl_3$): δ 4.70 (d, 1H, $J_{4,5}$ 6.3 Hz, H-4), 4.61 (d, 1H, $J_{1a,1b}$ 9.3 Hz, H-1a), 4.39 (dd, 1H, H-5), 4.20 (dd, 1H, $J_{6a,6b}$ 13.2 Hz, H-6a), 4.15 (d, 1H, H-1b), 3.97 (d, 1H, H-6b), 2.57 (m, 2H, CH_2CO), 2.43 (s, 3H, Ac), 1.65–0.86 (m, 41H, $C(CH_3)_2$, $C_{14}H_{29}$); ^{13}C NMR (75 MHz, $CDCl_3$): δ 172.9 ($COC_{15}H_{31}$), 169.6 ($COCH_3$), 166.8 (C-3), 112.7, 110.3 ($C(CH_3)_2$), 104.3 (C-2), 75.4 (C-6), 72.4 (C-4), 72.1 (C-1), 61.9 (C-5), 26.5, 26.4, 26.0, 26.0 ($C(CH_3)_2$), 25.8 ($COCH_3$); 167.0 (C-3), 112.7, 110.4 (CMe2), 104.4 (C-2), 75.6 (C-5), 72.7 (C-4), 71.8 (C-1), 62.2 (C-6), 37.6, 31.9, 29.7, 29.5, 29.4, 29.3, 29.2, 26.6, 26.4, 26.2, 26.0, 25.8, 24.3, 22.7, 14.1($C(CH_3)_2$, $C_{15}H_{31}$); HR-ESI-MS: Calcd for $C_{30}H_{53}N_2O_7$: 553.3853 $[M+H]^+$. Found: 553.3857 $[M+H]^+$.

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31. Complete crystallographic data for the structural analysis have been deposited with the Cambridge Crystallographic Data Centre, CCDC No. 634,353 **2a** and 668,704 **4a**. Copies of this information may be obtained free of charge from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge, CB21EZ, UK. (fax: +44-1223-336033, e-mail: deposit @ccdc.cam.ac.uk or via: www.ccdc.cam.ac.uk).