Tetrahedron 69 (2013) 3991–3999

Contents lists available at SciVerse ScienceDirect

Tetrahedron

journal homepage: www.elsevier.com/locate/tet

Regioselective and reductive cleavage of allyl ethers by $NaBH_4$–HOAc

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ARTICLE INFO

Article history:
Received 29 November 2012
Received in revised form 20 February 2013
Accepted 5 March 2013
Available online 15 March 2013

Keywords:
β-Enaminal
Reductive cleavage
Sodium borohydride
Regioselectivity
Formylglycal

ABSTRACT

β-Enaminals were successfully synthesized in good to excellent yields by the reaction of *C*2-formylglycals with primary amines. Subsequent reaction with $NaBH_4$ in HOAc led to unexpected reductive cleavage of allyl ether, i.e., the hydrodealkoxylation took place to produce the corresponding 3-deoxy-β-enaminals. In contrast, the reaction of β-enaminals with Zn/HOAc performed H4-elimination to afford a diene product. The result was attributed to the formation of a common eneiminium ion intermediate, and the different reduction reactivity.

1. Introduction

β-Enaminals are enamines that are conjugated with aldehyde. They have been shown to be useful in synthetic chemistry. For example, (*E*)-(3*R*,4*R*,5*R*)-1-benzylanimo-2-formyl-5-hydroxy-3,4,6-tri-*O*-benzyl-hex-1-ene (compound **9**) can be protected and reduced to give compound **1** that served as a key precursor in the synthesis of noeuromycin **2**, a potent inhibitor of α- and β-glucosidases discovered by Bols and co-workers[1] (see Fig. 1). As a matter of fact, β-enaminals are versatile synthetic building blocks and have been extensively investigated for preparation of various important molecules,[3–9] including pyrrole,[2] pyridine,[3] pyrazole,[4] isoxazole,[5] isothiazole,[6] benzo[*g*]quinoline,[7] benzo[*f*]quinoline,[7] and quinoline.[8]

Several methods were developed previously to prepare β-enaminal, such as the condensation reaction of malondialdehyde with amine,[7] the hydrolysis of 2-methyl-1-phenylamino-3-phenylimino-1-propene,[8] the pyrolysis of Meldrum's acid derivatives,[9] Michael addition of β-ethoxyacrolein and *p*-toluidine,[10] the condensation reaction of malondialdehyde and amino acid derivatives,[11] the iodotrichlorosilane-induced reactions of aromatic aldehydes with acrylonitrile,[12] and the amination of propargyl aldehyde.[13] To the best of our knowledge, there is no report to derive from *C*-2-formylglycal. Herein we reported one-step conversion from *C*2-formylglycals to β-enaminals. Interestingly further treatment of β-enaminals with $NaBH_4$ in HOAc or Zn/HOAc did not reduce the double bond or aldehyde. Instead, regioselective reduction

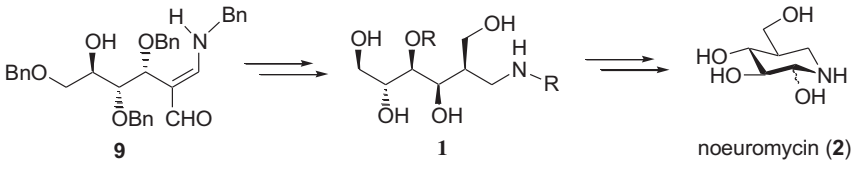

Fig. 1. Enamine **9** serves as a key intermediate in the synthesis of noeuromycin (**2**).

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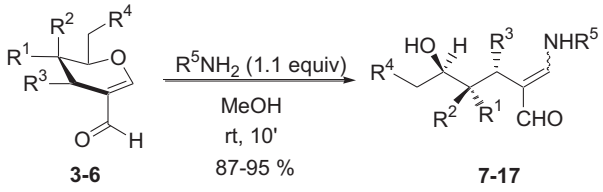
0040-4020/$ – see front matter
http://dx.doi.org/10.1016/j.tet.2013.03.020

was observed to remove the allyl ether to generate a common eneiminium ion intermediate, followed by either reduction or H4-elimination to produce the corresponding 3-deoxy-β-enaminals or dienes, respectively.

2. Results and discussion

C-2-Formylglycals **3**–**6** that had been prepared by Vilsmeier–Haack reactions[14] of D-glucals or D-galactals were subjected to Michael addition[15] with 1.1 equiv of primary amines (including benzylamine, *n*-butylamine, and *n*-octylamine) in MeOH for 10 min. The products, β-enaminals **7**–**17**, were obtained in 87–95% with high selectivity (ratio of *E*/*Z*-isomers: 85:15 ~ 93:7, Table 1). The major products were determined as the (*E*)-isomers according to the resonance of the enamine hydrogen (NH). The chemical shift of the (*Z*)-isomer (δ 10.5) was more downfield than that of (*E*)-isomer (δ 7.15) because only the former isomer is able to form the intramolecular hydrogen bonding between the NH and the carbonyl oxygen. The structures of (*E*)-β-enaminals were additionally characterized by ^{1}H and ^{13}C NMR, DEPT, COSY and other spectroscopic methods. For example, compound **9** possessed a characteristic broad resonance at δ 7.15 in correspondence with the amino proton, and a doublet resonance at δ 6.88 (J=13.6 Hz) that correlates with the alkene proton at C_1. In the corresponding ^{13}C NMR spectrum, δ 158.9 and 110.0 were assigned to C1 and C2 of β-enaminal **9**, respectively.

Table 1
The Michael addition of *C*-2-formylglycals **3**–**6** with primary amines



Substrate	Compounds **3**–**6**				Product	Compounds **7**–**17**[a]		
	R^1	R^2	R^3	R^4		R^5	Yields (%)	(*E*/*Z*)[b]
3	OBn	H	OBn	OBn	**7**	*n*-Oct	87	89:11
3	OBn	H	OBn	OBn	**8**	*n*-Bu	95	91:9
3	OBn	H	OBn	OBn	**9**	Bn	91	93:7
4	OMe	H	OMe	OMe	**10**	*n*-Oct	91	90:10
4	OMe	H	OMe	OMe	**11**	Bn	91	93:7
5	OPent	H	OPent	OPent	**12**	*n*-Oct	93	91:9
5	OPent	H	OPent	OPent	**13**	*n*-Bu	92	90:10
5	OPent	H	OPent	OPent	**14**	Bn	90	92:8
6	H	OBn	OBn	OBn	**15**	*n*-Oct	87	87:13
6	H	OBn	OBn	OBn	**16**	*n*-Bu	90	85:15
6	H	OBn	OBn	OBn	**17**	Bn	91	88:12

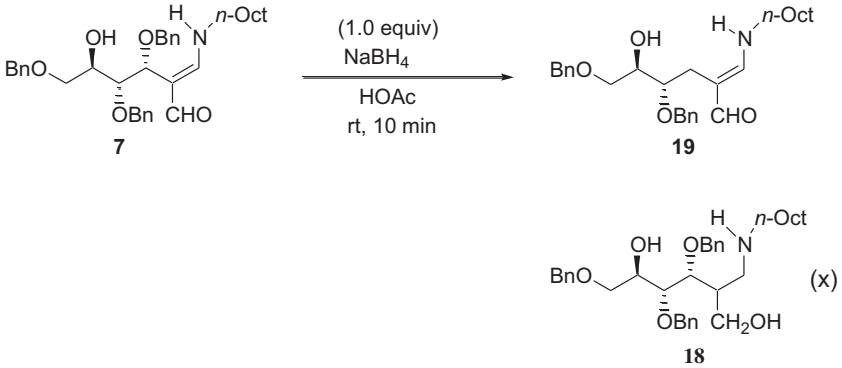
[a] The reactions were carried out with primary amines.
[b] The *E*-isomer is the major product. The ratio of *E*/*Z*-isomers (in the range of 85:15 ~ 93:7) was determined by ^{1}H NMR integration.

Originally our plan was to reduce the double bond or/and the aldehyde. Palmieri and co-workers[16] successfully reduced β-enamino ketones to γ-amino alcohol by using $NaBH_4$ in HOAc. To our surprise, the same reaction turned out to be a different outcome in our hand. Rather than obtain the expected γ-amino alcohol **18**, *N*-octyl-3-deoxy-β-enaminal **19** was found to be the resulting product, as shown in Scheme 1. Apparently the borohydride functioned to result in the reductive cleavage of allyl ether. To search for the optimal conditions, several organic solvents were studied, including CH_2Cl_2, THF, MeOH, acetonitrile (MeCN), and HOAc (entries 1–5 of Table 2). Except for HOAc, no reaction was found in these organic solvents. The result supported the idea that acidic condition is critical to the reductive cleavage. Our focus was then shifted to the use of borohydride. (*E*)-(3*R*,4*R*,5*R*)-β-Enaminal **7** in HOAc was treated with 1.0 equiv of $NaBH_4$, $NaCNBH_3$ or $Na(OAc)_3BH$ at room temperature for 10 min (see entries 5–7 of Table 2). The use of $NaBH_4$ gave the highest isolated yield of product **19** (90%).

Reductive cleavage of allylic oxygen-containing functional groups was widely used in organic synthesis,[17–32] including allyl ether,[17–25] allyl ester,[26–29] allyl alcohol,[30,31] or allyl carbonate.[32] A number of catalytic reagents were investigated, such as Pd–C/HCO_2NH_4,[17] Pd(dppe)Cl_2/$LiBHEt_3$,[18] $CeCl_3 \cdot 7H_2O$–NaI,[19] $NaBH_4/I_2$,[20] $Pd(PPh_3)_4/NaBH_4$,[21] polymethylhydrosiloxane–$ZnCl_2$/$Pd(PPh_3)_4$,[22] SmI_2/H_2O/amine,[23] $NaBH_4/RuCl_3$,[24] $NaBH_4/NiCl_2$/MeOH,[25] Pd(0)/$Ph_2SiH_2/ZnCl_2$,[26] $FeCl_3 \cdot 6H_2O$,[27] Ti(O-*i*-Pr)$_4$/TMSCl/Mg or Ti(O-*i*-Pr)$_4$/$MgBr_2$/Mg,[28] $PdCl_2$,[29] Et_3SiH/TFA,[30] $H_3[PW_{12}O_{40}] \cdot nH_2O$/$Et_3SiH$,[31] and $Pd_2(dba)_3/Bu_3P$.[32] Nevertheless, a few methods were reported to reductively cleave allyl ethers from β-enamino carbonyl compounds.[30a,34]

Furthermore, seven (*E*)-(3*R*,4*R*,5*R*)-β-enaminals (**8**–**14**) were examined under the same condition. Exclusive regioselectivity was observed, i.e., the 3-alkoxy ether was reductively removed to give the desired products (**20**–**26**) in 87–94% yields (see Table 3). The product structures were rigorously determined by using ^{1}H and ^{13}C NMR, DEPT, COSY and other spectroscopic methods. For example, the ^{1}H NMR spectrum of *N*-benzyl-1,2,3-trideoxy-β-enaminal (**21**) showed the characteristic signals, including the resonances of the NH at δ 6.74–6.68 (*m*), H3a at δ 2.28 (dd), and H3b at δ 2.50 (dd). In the corresponding ^{13}C NMR spectrum, δ 160.2, 110.8, and 24.2 were assigned for C1–C3 of **21**, respectively.

Meanwhile, (*E*/*Z*)-(3*R*,4*S*,5*R*)-β-enaminals **15**–**17** (that are 4-epimers of compounds **7**–**9**, respectively) were examined under the same reaction condition (i.e., the treatment with $NaBH_4$ in HOAc at room temperature for 10 min). In addition to the desirable 3-deoxy products **27**–**29** in 72–85% yields (Table 4), we observed the formation of the diene side products **30**–**32** in 5–22% yields, respectively, which is realized to occur via H4-elimination.



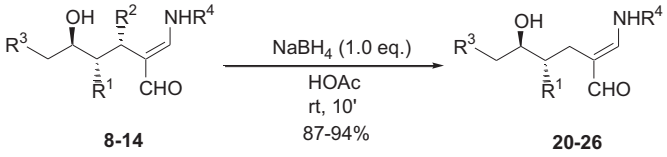
Scheme 1.

Table 2
Different solvents used in the regioselective hydrodebenzyloxylations[a]

Entry	Solvent	Reducing agent	Yield of **19**[b] (%)
1	MeOH	$NaBH_4$	0
2	CH_2Cl_2	$NaBH_4$	0
3	THF	$NaBH_4$	0
4	MeCN	$NaBH_4$	0
5	HOAc	$NaBH_4$	90
6	HOAc	$NaCNBH_3$	88
7	HOAc	$Na(OAc)_3BH$	11

[a] The reactions were the same as shown in Scheme 1 except that different solvents and borohydrides were examined here.
[b] Isolated yields.

Table 3
Regioselective hydrodealkoxylations of β-enaminals **8**.–**14**



8-14 **20-26**

Substrate	Compounds **8**–**14**				Compounds **20**–**26**[a,b]	
	R^1	R^2	R^3	R^4	Product	Yields (%)
8	OBn	OBn	OBn	*n*-Bu	**20**	89
9	OBn	OBn	OBn	Bn	**21**	90
10	OMe	OMe	OMe	*n*-Oct	**22**	87
11	OMe	OMe	OMe	Bn	**23**	87
12	OPent	OPent	OPent	*n*-Oct	**24**	94
13	OPent	OPent	OPent	*n*-Bu	**25**	88
14	OPent	OPent	Opent	Bn	**26**	92

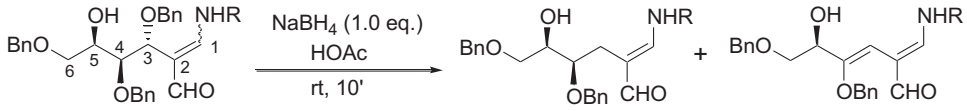
[a] Isolated yields.
[b] All the products were determined to be (*E*)-isomers.

Interestingly the dienes **30**–**32** became the sole products in 92–94% yields if the reactions occurred in the presence of HOAc only and the reaction time (of β-enaminals **7**–**9** or **15**–**17**) was prolonged from the original 10 min to 1.5 or 4 h (Scheme 2). Compounds **30**–**32** were further acetylated to produce **33**–**35** in all 95% yields, respectively, for the purpose of easy product characterization.

A plausible mechanism is proposed to explain the regioselectivity (Scheme 3). In the initial stage, the nitrogen of the enamine moiety is expected to be protonated under acidic condition. The proton likely translocates to the oxygen of the C3-benzyl ether via [1,5]-shift, in concert with C3-debenzyloxylation and the formation of eneiminium ion (i.e., compound **38** is the intermediate). The intermediate can be subjected to either reduction by $NaBH_4$ to produce 3-deoxy-β-enaminals (**29**), or H4-elimination to afford the diene product (**32**). Apparently, the former reaction is favored in the competition. It is interesting that under the same condition only the reduction products were obtained in the reactions of β-enaminals **7**–**14** (see Table 3).

Watson and co-workers were able to reduce the C–C double bond of β-enamino ketones by using Zn/HOAc.[33] The procedure was utilized to reduce the β-enaminal **8**, but the desirable product (**39**) did not form, neither did 3-deoxy-β-enaminal (**19**). Instead, a diene product (**31**) was obtained in 82% yield after 4 h reaction at room temperature. When compound **19** was subjected to the same treatment (Zn/HOAc at room temperature), a cyclized/eliminated product (**41**) was obtained in 50% yield, plus 45% unreacted starting material. Together with the aforementioned studies with $NaBH_4$ in HOAc, our results supported the idea that the two reactions ($NaBH_4$ in HOAc and Zn/HOAc) likely occur via the same initial stage to give a common intermediate, i.e., the protonation and subsequent proton translocation leading to formation of an eneiminium ion (as shown

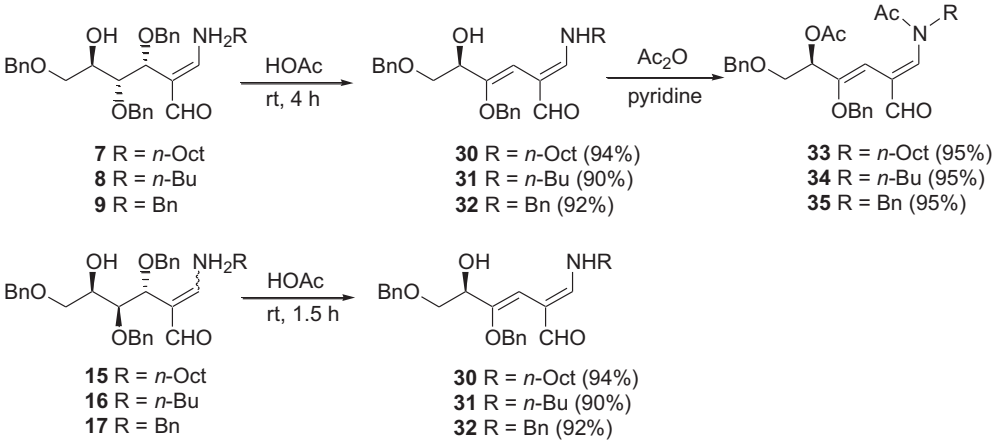
Table 4
Regioselective hydrodebenzyloxylation of β-enaminals **15**–**17**



15-17 **27-29** **30-32**

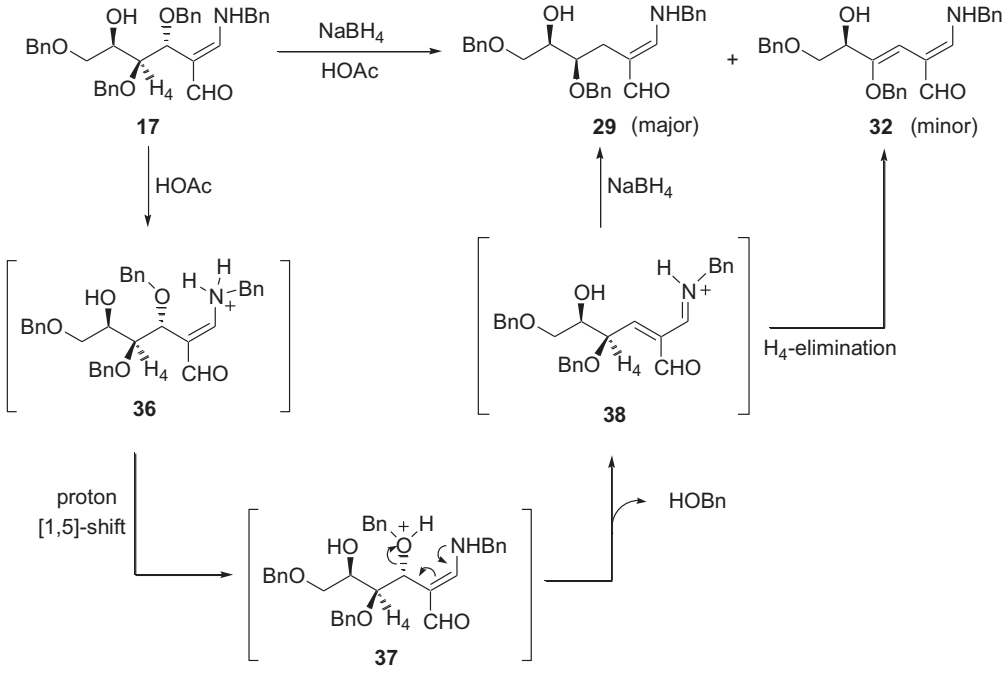
Substrate	Compounds **15**–**17**	Reduction product	Elimination product
	R	Yields[a,b] (%)	Yields[a] (%)
15	*n*-Oct	**27** (75)	**30** (19)
16	*n*-Bu	**28** (72)	**31** (22)
17	Bn	**29** (85)	**32** (5)

[a] Isolated yields.
[b] The reduction products were determined to be all (*E*)-isomers.



Scheme 2.

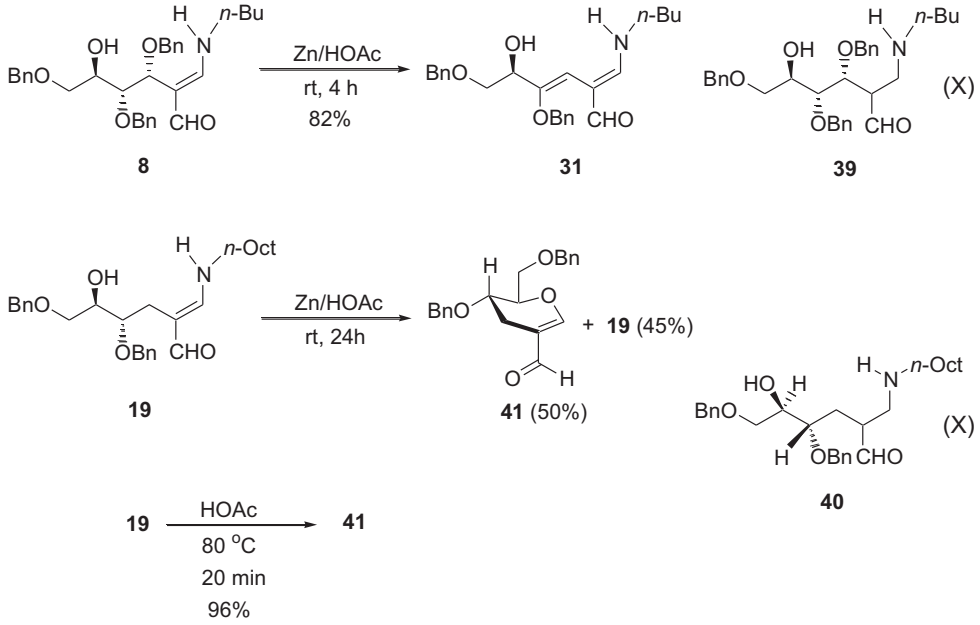
Mechanism:



Scheme 3.

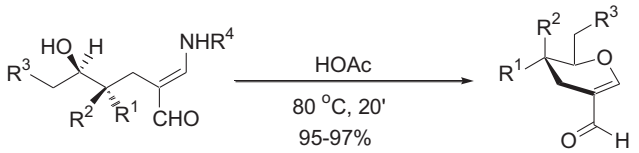
in Scheme 3). Nevertheless, the reducing power of Zn is lower than that of borohydride, which explains the reason why the reduction is much slower than H4-elimination in the reaction of Zn/HOAc. The elimination thus became exclusive to give a diene product. Moreover, when 3-deoxy-β-enaminal **19** reacted with Zn/HOAc, the intramolecular cyclization appeared to be predominant as compared to any possible reaction. Even in the absence of Zn, the reaction of **19** still resulted in the same product (**41**) in 55% yield at room temperature for 24 h, and in 96% at 80 °C for 20 min (Scheme 4). Likewise, other 3-deoxy-β-enaminals (**19**–**23** and **27**–**29**) all underwent the same intramolecular cyclization/elimination to generate 3-deoxy-*C*-2-formylglycals **41**–**43** in 95–97% yields (Table 5).

In conclusion, in addition to preparing β-enaminals by Michael addition of *C*2-formylglycal with primary amines, we discovered the unprecedented reduction of β-enaminals by using $NaBH_4$/HOAc, i.e., C3-allyl ether was removed. The formation of eneiminium ion intermediate was thus proposed, which also explained the different outcome of the Zn/HOAc reaction. The



Scheme 4.

Table 5
3-Deoxy-C-2-formylglycals obtained via consecutive cyclization and elimination of 3-deoxy-enaminals



19-23, **27-29** **41-43**

Substrate	Compounds **19**–**23**, **27**–**29**				Compounds **41**–**43**[a]	
	R^1	R^2	R^3	R^4	Product	Yields (%)
19	OBn	H	OBn	*n*-Oct	**41**	96
20	OBn	H	OBn	*n*-Bu	**41**	95
21	OBn	H	OBn	Bn	**41**	97
22	OMe	H	OMe	*n*-Oct	**42**	95
23	OMe	H	OMe	Bn	**42**	96
27	H	OBn	OBn	*n*-Oct	**43**	97
28	H	OBn	OBn	*n*-Bu	**43**	96
29	H	OBn	OBn	Bn	**43**	97

[a] Isolated yields.

treatment of β-enaminals with Zn/HOAc generated a diene product.

3. Experimental section

3.1. General procedure

All purchased chemicals were of reagent grade. All reactions were carried out under a nitrogen atmosphere and monitored by TLC analysis (layer thickness: 250 μm). Column chromatography was carried out with silica gel 60 (70–230 mesh for gravity column, or 230–400 mesh for flash column). Commercially available reagents were directly used without further purification unless otherwise noted. Dichloromethane, ethyl acetate, hexanes, and methanol were purchased from Mallinckrodt Chemical Co. The following compounds were purchased from Acros Chemical Co, including benzylamine, *n*-butylamine, *n*-octylamine, tri-*O*-acetyl-D-glucal, tri-*O*-acetyl-D-galactal, benzyl bromide, methyl iodide, *n*-pentyl iodide, phosphoryl chloride, sodium borohydride, sodium cyanoborohydride, sodium triacetoxyborohydride, tetrahydrofuran, dichloromethane, acetonitrile, acetic acid, methanol. Proton NMR spectra were recorded at a Bruker spectrometer (400 or 500 MHz) with $CDCl_3$ (δ_H 7.24) and DMSO-d_6 (δ_H 2.50) as the internal standard; ^{13}C NMR spectra were recorded at 100 or 125 MHz with $CDCl_3$ [δ_C 77.0 (central line of a triplet)]. Splitting patterns are shown by the abbreviations, such as s (singlet), d (doublet), t (triplet), q (quartet), and m (multiplet).

3.2. Standard procedure for Michael addition of *C*-2-formylglycals to prepare β-enaminal derivatives (7–17)

To a solution of *C*-2-formylglycals (**3**–**6**) (1.0 equiv) in MeOH (2 mL) was added primary amine (1.0 equiv). The resulting solution was stirred at room temperature for 10 min, concentrated under reduced pressure, and re-dissolved in CH_2Cl_2 (50 mL). The solution was washed with H_2O (20 mL×2), brine (20 mL×2), and concentrated under reduced pressure. The dry residue was purified by silica gel column chromatography with EtOAc/Hex (7:10) to give β-enaminals (**7**–**17**) in 80–96% yields.

*3.2.1. (E)-(3R,4R,5R)-2-Formyl-5-hydroxy-1-n-octylamino-3,4,6-tri-O-benzyl-hex-1-ene (**7**).* Pale yellow solid; mp 62–63 °C; IR ($CHCl_3$) 2926, 1651, 1597, 1207, 1064 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 8.85 (1H, s, CHO), 7.28–7.10 (15H, m, ArH), 6.79–6.77 (1H, m, NH), 6.74 (1H, d, $J_{1,NH}$=14.0 Hz, H1), 4.96 (1H, d, $J_{3,4}$=2.4 Hz, H3), 4.49 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.46 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.43 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.36 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.29 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.25 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.03 (1H, br s, H5), 3.60 (1H, dd, $J_{4,3}$=2.4 Hz, $J_{4,5}$=7.2 Hz, H4), 3.57–3.55 (2H, m, H6), 2.87–2.77 (3H, m, H1′, OH), 1.21–1.04 (12H, m, H2′, H3′, H4′, H5′, H6′, H7′), 0.80 (3H, t, *J*=6.8 Hz, H8′); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 187.55, 159.31, 138.15, 137.87, 137.55, 128.35, 128.34, 128.30, 128.29, 128.22, 128.21, 128.14, 128.13, 127.95, 127.94, 127.90, 127.89, 127.80, 127.67, 127.59, 108.96, 81.89, 74.60, 74.29, 73.38, 71.16, 71.15, 70.18, 49.22, 31.69, 30.58, 29.02, 29.01, 26.41, 22.56, 14.06; LRMS (FAB) *m*/*z* (rel intens) 574 (M^++1, 2), 302 (28), 210 (19), 91 (100), 54 (22); HRMS (FAB) *m*/*z* calcd for $C_{36}H_{48}NO_5$ (M^++1) 574.3527, found 574.3525. Anal. Calcd for $C_{36}H_{47}NO_5$; C: 75.36; H: 8.26. Found: C: 75.38; H: 8.30.

*3.2.2. (E)-(3R,4R,5R)-1-n-Butylamino-2-formyl-5-hydroxy-3,4,6-tri-O-benzyl-hex-1-ene (**8**).* Pale yellow solid; mp 78–79 °C; IR ($CHCl_3$) 2926, 1616, 1595, 1211, 1062 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 8.92 (1H, s, CHO), 7.32–7.16 (15H, m, ArH), 6.78 (2H, br s, NH, H1), 5.02 (1H, d, $J_{3,4}$=2.0 Hz, H3), 4.55 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.52 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.48 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.42 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.35 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.31 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.08 (1H, br s, H5), 3.65 (1H, dd, $J_{4,3}$=2.0 Hz, $J_{4,5}$=7.2 Hz, H4), 3.63–3.61 (2H, m, H6), 2.89–2.86 (2H, m, H1′), 1.24–1.10 (4H, m, H2′, H3′), 0.76 (3H, t, *J*=7.2 Hz, H4′); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 187.55, 159.25, 138.29, 137.98, 137.65, 128.38, 128.37, 128.34, 128.33, 128.27, 128.26, 128.18, 128.17, 127.98, 127.97, 127.92, 127.91, 127.83, 127.69, 127.61, 109.19, 82.05, 74.78, 74.33, 73.45, 71.31, 71.26, 70.34, 48.89, 32.62, 19.60, 13.51; LRMS (FAB) *m*/*z* (rel intens) 518 (M^++1, 11), 246 (67), 154 (38), 136 (13), 91 (100); HRMS (FAB) *m*/*z* calcd for $C_{32}H_{40}NO_5$ (M^++1) 518.2901, found 518.2918. Anal. Calcd for $C_{32}H_{39}NO_5$; C: 74.25; H: 7.59. Found: C: 74.31; H: 7.64.

*3.2.3. (E)-(3R,4R,5R)-1-Benzylamino-2-formyl-5-hydroxy-3,4,6-tri-O-benzyl-hex-1-ene (**9**).* Pale yellow oil; IR ($CHCl_3$) 2924, 1676, 1598, 1207, 1064 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 8.93 (1H, s, CHO), 7.31–6.99 (21H, m, ArH, NH), 6.88 (1H, d, $J_{1,NH}$=13.6 Hz, H1), 5.01 (1H, br s, H3), 4.54 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.50 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.46 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.40 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.30 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.24 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.06–4.00 (2H, m, H5, CH_2Ph), 3.90 (1H, dd, *J*=4.0 Hz, $J_{a,b}$=14.8 Hz, CH_2Ph), 3.65 (1H, dd, $J_{4,3}$=1.2 Hz, $J_{4,5}$=6.8 Hz, H4), 3.60–3.59 (2H, m, H6), 2.91 (1H, br s, OH); ^{13}C NMR ($CDCl_3$, 50 MHz) δ 187.89, 158.91, 138.21, 137.89, 137.34, 137.00, 128.81, 128.80, 128.37, 128.36, 128.35, 128.34, 128.33, 128.32, 128.31, 128.01, 128.00, 127.91, 127.90, 127.89, 127.75, 127.74, 127.67, 127.66, 127.38, 127.37, 110.06, 82.01, 74.77, 74.33, 73.40, 71.43, 71.20, 70.18, 52.70; LRMS (FAB) *m*/*z* (rel intens) 552 (M^++1, 4), 136 (10), 105 (14), 91 (100); HRMS (FAB) *m*/*z* calcd for $C_{35}H_{38}NO_5$ (M^++1) 552.2744, found 552.2760. Anal. Calcd for $C_{35}H_{37}NO_5$; C: 76.20; H: 6.76. Found: C: 76.23; H: 6.84.

*3.2.4. (E)-(3R,4R,5R)-2-Formyl-5-hydroxy-1-n-octylamino-3,4,6-tri-O-methyl-hex-1-ene (**10**).* Pale yellow oil; ^1H NMR ($CDCl_3$, 500 MHz) δ 8.87 (1H, s, CHO), 6.87–6.79 (2H, m, H1, NH), 4.67 (1H, d, $J_{3,4}$=2.0 Hz, H3), 3.89–3.86 (1H, m, H5), 3.49–3.47 (2H, m, H6), 3.33 (3H, s, OCH_3), 3.31 (3H, s, OCH_3), 3.22 (1H, dd, $J_{4,3}$=2.0 Hz, $J_{4,5}$=7.0 Hz, H4), 3.19–3.14 (6H, m, OCH_3, OH, H1′), 1.53–1.47 (2H, m, H2′), 1.30–1.16 (10H, m, H3′, H4′, H5′, H6′, H7′), 0.81 (3H, t, *J*=6.5 Hz, H8′); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 187.80, 159.13, 109.05, 83.88, 76.17, 73.64, 69.93, 59.92, 58.99, 56.61, 49.43, 31.68, 31.21, 29.11, 29.10, 26.39, 22.55, 14.00; LRMS (EI) *m*/*z* (rel intens) 345 (M^+, 1), 266 (13), 250 (33), 226 (100), 208 (19); HRMS (EI) *m*/*z* calcd for

$C_{18}H_{35}NO_5$ (M^+) 345.2515, found 345.2522. Anal. Calcd for $C_{18}H_{35}NO_5$; C: 62.58; H: 10.21. Found: C: 62.63; H: 10.24.

*3.2.5. (E)-(3R,4R,5R)-1-Benzylamino-2-formyl-5-hydroxy-3,4,6-tri-O-methyl-hex-1-ene (**11**).* Pale yellow solid; mp 105–106 °C; IR ($CHCl_3$) 2931, 1651, 1593, 1211, 1089 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 8.91 (1H, s, CHO), 7.32–7.20 (6H, m, ArH, NH), 6.93 (1H, d, $J_{1,NH}$=13.6 Hz, H1), 4.68 (1H, br s, H3), 4.36 (2H, d, J=6.4 Hz, CH_2Ph), 3.89–3.86 (1H, m, H5), 3.49–3.44 (2H, m, H6), 3.32 (3H, s, OCH_3), 3.23–3.18 (7H, m, H4, OCH_3); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 188.15, 158.92, 137.51, 128.82, 128.81, 127.93, 127.17, 127.16, 109.88, 83.63, 76.14, 73.53, 69.71, 59.79, 58.95, 56.69, 52.99; LRMS (FAB) *m*/*z* (rel intens) 324 (M^++1, 25), 292 (38), 218 (36), 204 (82), 91 (100); HRMS (FAB) *m*/*z* calcd for $C_{17}H_{26}NO_5$ (M^++1) 324.1805, found 324.1798. Anal. Calcd for $C_{17}H_{25}NO_5$; C: 63.14; H: 7.79. Found: C: 63.18; H: 7.85.

*3.2.6. (E)-(3R,4R,5R)-2-Formyl-5-hydroxy-1-n-octylamino-3,4,6-tri-O-pentyl-hex-1-ene (**12**).* Pale yellow oil; IR ($CHCl_3$) 2927, 1656, 1606, 1222, 1089 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 8.83 (1H, s, CHO), 6.94–6.91 (1H, m, NH), 6.77 (1H, d, $J_{1,NH}$=13.5 Hz, H1), 4.76 (1H, br s, H3), 3.89 (1H, br s, H5), 3.50 (2H, br s, H6), 3.44–3.04 (9H, m, OCH_2, H4, H1′), 2.91 (1H, d, J=7.0 Hz, OH), 1.51–1.37 (8H, m, CH_2, H2′), 1.24–1.21 (22H, m, CH_2, H3′, H4′, H5′, H6′, H7′), 0.81–0.80 (12H, m, CH_3); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 187.61, 159.24, 110.05, 82.19, 75.07, 72.66, 71.80, 71.53, 70.22, 69.54, 49.33, 31.73, 31.10, 30.02, 29.49, 29.32, 29.18, 29.14, 28.39, 28.30, 28.21, 26.57, 22.57, 22.54, 22.51, 22.48, 13.98, 13.97, 13.96, 13.95; LRMS (EI) *m*/*z* (rel intens) 513 (M^+, 1), 306 (82), 282 (80), 224 (51), 196 (62), 71 (100); HRMS (EI) *m*/*z* calcd for $C_{30}H_{59}NO_5$ (M^+) 513.4393, found 513.4399. Anal. Calcd for $C_{30}H_{59}NO_5$; C: 70.13; H: 11.57. Found: C: 70.14; H: 11.59.

*3.2.7. (E)-(3R,4R,5R)-1-n-Butylamino-2-formyl-5-hydroxy-3,4,6-tri-O-pentyl-hex-1-ene (**13**).* Pale yellow oil; IR ($CHCl_3$) 2931, 1651, 1606, 1211, 1091 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 8.83 (1H, s, CHO), 6.96–6.91 (1H, m, NH), 6.77 (1H, d, $J_{1,NH}$=14.0 Hz, H1), 4.76 (1H, d, $J_{3,4}$=2.0 Hz, H3), 3.90–3.87 (1H, m, H5), 3.51–3.50 (2H, m, H6), 3.44–3.06 (9H, m, OCH_2, H4, H1′), 2.93 (1H, br s, OH), 1.56–1.15 (22H, m, CH_2, H2′, H3′), 0.89–0.80 (12H, m, CH_3, H4′); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 187.61, 159.26, 110.06, 82.18, 75.06, 72.67, 71.80, 71.53, 70.21, 69.54, 49.00, 33.12, 30.01, 29.47, 29.31, 28.38, 28.29, 28.19, 22.52, 22.49, 22.48, 19.70, 13.97, 13.96, 13.94, 13.59; LRMS (EI) *m*/*z* (rel intens) 457 (M^+, 1), 266 (24), 250 (57), 239 (30), 226 (100), 168 (47); HRMS (EI) *m*/*z* calcd for $C_{26}H_{51}NO_5$ (M^+) 457.3767, found 457.3762. Anal. Calcd for $C_{26}H_{51}NO_5$; C: 68.23; H: 11.23. Found: C: 68.27; H: 11.25.

*3.2.8. (E)-(3R,4R,5R)-1-Benzylamino-2-formyl-5-hydroxy-3,4,6-tri-O-pentyl-hex-1-ene (**14**).* Pale yellow oil; IR ($CHCl_3$) 2927, 1647, 1602, 1205, 1089 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 8.96 (1H, s, CHO), 7.40–7.27 (6H, m, ArH, NH), 6.97 (1H, d, $J_{1,NH}$=13.2 Hz, H1), 4.84 (1H, br s, H3), 4.44 (1H, dd, J=4.4, 14.8 Hz, CH_2Ph), 4.36 (1H, dd, J=7.2 Hz, $J_{a,b}$=14.8 Hz, CH_2Ph), 3.95 (1H, br s, H5), 3.58–3.57 (2H, m, H6), 3.49–3.27 (7H, m, H4, OCH_2), 2.97 (1H, br s, OH), 1.61–1.15 (18H, m, CH_2), 0.92–0.83 (9H, m, CH_3); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 187.98, 158.83, 137.31, 128.88, 128.87, 128.06, 127.42, 127.41, 111.01, 82.14, 75.12, 72.68, 71.76, 71.53, 70.15, 69.69, 53.03, 29.94, 29.31, 29.30, 28.29, 28.22, 28.21, 22.51, 22.47, 22.43, 14.01, 13.96, 13.90; LRMS (EI) *m*/*z* (rel intens) 491 (M^+, 1), 236 (18), 212 (15), 91 (100); HRMS (EI) *m*/*z* calcd for $C_{29}H_{49}NO_5$ (M^+) 491.3611, found 491.3618. Anal. Calcd for $C_{29}H_{49}NO_5$; C: 70.84; H: 10.04. Found: C: 70.88; H: 10.07.

*3.2.9. (E)-(3R,4S,5R)-2-Formyl-5-hydroxy-1-n-octylamino-3,4,6-tri-O-benzyl-hex-1-ene (**15**).* Pale yellow oil; IR ($CHCl_3$) 2924, 1654, 1602, 1207, 1062 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 8.84 (1H, s, CHO), 7.29–7.18 (15H, m, ArH), 7.05–7.01 (1H, m, NH), 6.73 (1H, d, $J_{1,NH}$=14.0 Hz, H1), 4.89 (1H, d, $J_{3,4}$=3.5 Hz, H3), 4.64 (1H, d, $J_{a,b}$=11.0 Hz, CH_2Ph), 4.60 (1H, d, $J_{a,b}$=11.0 Hz, CH_2Ph), 4.44 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.40 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.35 (1H, d, $J_{a,b}$=11.0 Hz, CH_2Ph), 4.28 (1H, d, $J_{a,b}$=11.0 Hz, CH_2Ph), 3.84 (1H, dd, $J_{4,3}$=4.5 Hz, $J_{4,5}$=4.5 Hz, H4), 3.70 (1H, br s, H5), 3.49–3.45 (2H, m, H6), 2.89–2.85 (2H, m, H1′), 1.23–1.02 (12H, m, H2′, H3′, H4′, H5′, H6′, H7′), 0.81 (3H, t, J=7.0 Hz, H8′); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 187.97, 159.52, 138.18, 138.17, 138.09, 128.55, 128.54, 128.38, 128.37, 128.36, 128.32, 128.31, 128.30, 127.85, 127.84, 127.83, 127.73, 127.72, 127.62, 127.58, 108.03, 81.63, 74.83, 74.51, 73.36, 71.08, 71.03, 70.71, 49.50, 31.72, 30.61, 29.07, 29.05, 26.36, 22.58, 14.04; LRMS (EI) *m*/*z* (rel intens) 573 (M^+, 1), 326 (10), 224 (30), 108 (42), 91 (100); HRMS (EI) *m*/*z* calcd for $C_{36}H_{47}NO_5$ (M^+) 573.3454, found 573.3448. Anal. Calcd for $C_{36}H_{47}NO_5$; C: 75.36; H: 8.26. Found: C: 75.38; H: 8.27.

*3.2.10. (E)-(3R,4S,5R)-1-n-Butylamino-2-formyl-5-hydroxy-3,4,6-tri-O-benzyl-hex-1-ene (**16**).* Pale yellow oil; IR ($CHCl_3$) 2927, 1613, 1597, 1213, 1061 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 8.84 (1H, s, CHO), 7.34–7.16 (15H, m, ArH), 7.05–7.01 (1H, m, NH), 6.73 (1H, d, $J_{1,NH}$=14.0 Hz, H1), 4.89 (1H, d, $J_{3,4}$=3.5 Hz, H3), 4.64 (1H, d, $J_{a,b}$=11.0 Hz, CH_2Ph), 4.60 (1H, d, $J_{a,b}$=11.0 Hz, CH_2Ph), 4.44 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.40 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.35 (1H, d, $J_{a,b}$=11.5 Hz, CH_2Ph), 4.29 (1H, d, $J_{a,b}$=11.5 Hz, CH_2Ph), 3.84 (1H, dd, $J_{4,3}$=4.5 Hz, $J_{4,5}$=4.5 Hz, H4), 3.71–3.68 (1H, m, H5), 3.49–3.45 (2H, m, H6), 2.90–2.86 (2H, m, H1′), 1.13–1.03 (4H, m, H2′, H3′), 0.72 (3H, t, J=7.0 Hz, H4′); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 187.97, 159.55, 138.18, 138.16, 138.08, 128.56, 128.55, 128.38, 128.37, 128.36, 128.31, 128.30, 128.29, 127.88, 127.83, 127.82, 127.76, 127.75, 127.62, 127.58, 108.07, 81.62, 74.84, 74.15, 73.35, 71.10, 71.03, 70.72, 49.16, 32.59, 19.49, 13.50; LRMS (FAB) *m*/*z* (rel intens) 518 (M^++1, 11), 246 (67), 154 (38), 136 (13), 91 (100); HRMS (FAB) *m*/*z* calcd for $C_{32}H_{40}NO_5$ (M^++1) 518.2901, found 518.2918. Anal. Calcd for $C_{32}H_{39}NO_5$; C: 74.25; H: 7.59. Found: C: 74.31; H: 7.64.

*3.2.11. (E)-(3R,4S,5R)-1-Benzylamino-2-formyl-5-hydroxy-3,4,6-tri-O-benzyl-hex-1-ene (**17**).* Pale yellow oil; IR ($CHCl_3$) 2918, 1654, 1600, 1207, 1066 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 8.87 (1H, s, CHO), 7.39–7.35 (1H, m, NH), 7.29–6.94 (20H, m, ArH), 6.83 (1H, d, $J_{1,NH}$=13.5 Hz, H1), 4.89 (1H, br s, H3), 4.62 (1H, d, $J_{a,b}$=11.0 Hz, CH_2Ph), 4.59 (1H, d, $J_{a,b}$=11.0 Hz, CH_2Ph), 4.43 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.39 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.34 (1H, d, $J_{a,b}$=11.5 Hz, CH_2Ph), 4.27 (1H, d, $J_{a,b}$=11.5 Hz, CH_2Ph), 4.05–4.03 (2H, m, CH_2Ph), 3.86 (1H, dd, $J_{4,3}$=4.5 Hz, $J_{4,5}$=4.5 Hz, H4), 3.73–3.70 (1H, m, H5), 3.48 (2H, d, J=5.0 Hz, H6); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 188.34, 159.39, 138.16, 137.96, 137.92, 137.27, 128.81, 128.80, 128.51, 128.50, 128.39, 128.38, 128.37, 128.33, 128.32, 128.31, 128.30, 127.88, 127.87, 127.86, 127.80, 127.79, 127.61, 127.60, 127.07, 127.06, 109.16, 81.63, 74.94, 73.38, 73.37, 71.08, 70.93, 70.89, 52.73; LRMS (EI) *m*/*z* (rel intens) 551 (M^+, 1), 304 (15), 202 (7), 107 (7), 91 (100); HRMS (EI) *m*/*z* calcd for $C_{35}H_{37}NO_5$ (M^+) 551.2672, found 551.2661. Anal. Calcd for $C_{35}H_{37}NO_5$; C: 76.20; H: 6.76. Found: C: 76.24; H: 6.79.

3.3. Standard procedure for regioselective reductive cleavage of allyl ethers to prepare 1,2,3-trideoxy-2-formyl-hex-1-ene derivatives (19–29)

To a solution of β-enaminal (**7**–**17**) (1.0 equiv) in acetic acid (2 mL) was added sodium borohydride (1.0 equiv). The resulting solution was stirred at room temperature for 10 min, concentrated under reduced pressure, and re-dissolved in CH_2Cl_2 (50 mL). The mixture was washed with H_2O (20 mL×2), brine (20 mL×2), and concentrated under reduced pressure. The dry residue was purified by silica gel column chromatography with EtOAc/Hex (3:4) to give 1,2,3-trideoxy-2-formyl-hex-1-enes (**19**–**29**) in 72–94% yields.

*3.3.1. (E)-(4R,5R)-1,2,3-Trideoxy-2-formyl-5-hydroxy-1-n-octylamino-4,6-di-O-benzyl-hex-1-ene (**19**).* Pale yellow oil; $[\alpha]_D^{25}$ +7.3 (*c*

0.74, $CHCl_3$); IR ($CHCl_3$) 2924, 1649, 1591, 1269, 1072 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 8.81 (1H, s, CHO), 7.32–7.17 (10H, m, ArH), 6.79 (1H, d, $J_{1,NH}$=13.6 Hz, H1), 6.30–6.24 (1H, m, NH), 4.57 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.50 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.47 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.46 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.17 (1H, br s, OH), 3.75–3.71 (1H, m, H4), 3.66 (1H, dd, $J_{6a,5}$=2.8 Hz, $J_{6a,6b}$=9.6 Hz, H6a), 3.58 (1H, dd, $J_{6b,5}$=4.8 Hz, $J_{6b,6a}$=9.6 Hz, H6b), 3.49–3.46 (1H, m, H5), 2.88–2.82 (2H, m, H1′), 2.76 (1H, dd, $J_{3a,4}$=4.0 Hz, $J_{3a,3b}$=15.2 Hz, H3a), 2.36 (1H, dd, $J_{3b,4}$=3.2 Hz, $J_{3b,3a}$=15.2 Hz, H3b), 1.23–1.02 (12H, m, H2′, H3′, H4′, H5′, H6′, H7′), 0.82 (3H, t, J=6.8 Hz, H8′); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 189.57, 160.60, 138.03, 137.98, 128.54, 128.53, 128.32, 128.31, 128.22, 128.21, 127.99, 127.98, 127.97, 127.62, 109.72, 80.25, 73.50, 73.17, 70.95, 70.73, 48.82, 31.69, 30.58, 29.07, 29.02, 26.30, 24.33, 22.58, 14.07; LRMS (FAB) m/z (rel intens) 468 (M^++1, 28), 196 (25), 109 (29), 91 (94), 55 (100); HRMS (FAB) m/z calcd for $C_{29}H_{42}NO_4$ (M^++1) 468.3108, found 468.3115. Anal. Calcd for $C_{29}H_{41}NO_4$; C: 74.48; H: 8.84. Found: C: 74.52; H: 8.87.

*3.3.2. (E)-(4R,5R)-1-n-Butylanimo-1,2,3-trideoxy-2-formyl-5-hydroxy-4,6-di-O-benzyl-hex-1-ene (**20**).* Pale yellow oil; $[\alpha]_D^{25}$ +5.1 (c 1.26, $CHCl_3$); IR ($CHCl_3$) 2927, 1651, 1593, 1215, 1072 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 8.81 (1H, s, CHO), 7.27–7.17 (10H, m, ArH), 6.78 (1H, d, $J_{1,NH}$=13.6 Hz, H1), 6.27–6.24 (1H, m, NH), 4.56 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.51 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.47 (2H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 3.72–3.68 (1H, m, H4), 3.66 (1H, dd, $J_{6a,5}$=2.8 Hz, $J_{6a,6b}$=10.0 Hz, H6a), 3.57 (1H, dd, $J_{6b,5}$=4.8 Hz, $J_{6b,6a}$=10.0 Hz, H6b), 3.51–3.47 (1H, m, H5), 2.88–2.84 (2H, m, H1′), 2.73 (1H, dd, $J_{3a,4}$=4.0 Hz, $J_{3a,3b}$=14.8 Hz, H3a), 2.38 (1H, dd, $J_{3b,4}$=3.2 Hz, $J_{3b,3a}$=14.8 Hz, H3b), 1.11–1.06 (4H, m, H2′, H3′), 0.75 (3H, t, J=6.8 Hz, H4′); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 189.49, 160.44, 138.11, 138.08, 128.50, 128.49, 128.31, 128.30, 128.20, 128.19, 127.97, 127.93, 127.92, 127.60, 109.94, 80.36, 73.52, 73.11, 71.09, 70.89, 48.47, 32.61, 24.30, 19.47, 13.51; LRMS (FAB) m/z (rel intens) 412 (M^++1, 36), 181 (9), 140 (36), 91 (100); HRMS (FAB) m/z calcd for $C_{25}H_{34}NO_4$ (M^++1) 412.2482, found 412.2500. Anal. Calcd for $C_{25}H_{33}NO_4$; C: 72.96; H: 8.08. Found: C: 72.99; H: 8.91.

*3.3.3. (E)-(4R,5R)-1-Benzylanimo-1,2,3-trideoxy-2-formyl-5-hydroxy-4,6-di-O-benzyl-hex-1-ene (**21**).* Pale yellow oil; $[\alpha]_D^{25}$ +12.3 (c 0.62, $CHCl_3$); IR ($CHCl_3$) 2922, 1645, 1598, 1217, 1072 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 8.95 (1H, s, CHO), 7.38–7.06 (15H, m, ArH), 6.97 (1H, d, $J_{1,NH}$=13.6 Hz, H1), 6.74–6.68 (1H, m, NH), 4.64 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.58 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.55 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.53 (1H, d, $J_{a,b}$=11.2 Hz, CH_2Ph), 4.14 (2H, d, J=6.0 Hz, CH_2Ph), 3.83–3.79 (1H, m, H4), 3.74 (1H, dd, $J_{6a,5}$=2.8 Hz, $J_{6a,6b}$=9.6 Hz, H6a), 3.65 (1H, dd, $J_{6b,5}$=5.2 Hz, $J_{6b,6a}$=9.6 Hz, H6b), 3.61–3.57 (1H, m, H5), 2.82 (1H, dd, $J_{3a,4}$=4.0 Hz, $J_{3a,3b}$=14.8 Hz, H3a), 2.50 (1H, dd, $J_{3b,4}$=3.6 Hz, $J_{3b,3a}$=14.8 Hz, H3b); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 190.01, 160.25, 137.99, 137.88, 137.40, 128.79, 128.78, 128.56, 128.55, 128.35, 128.34, 128.24, 128.23, 127.99, 127.98, 127.97, 127.83, 127.67, 127.04, 127.03, 110.80, 80.10, 73.50, 73.08, 70.92, 70.75, 52.09, 24.23; LRMS (FAB) m/z (rel intens) 446 (M^++1, 79), 181 (24), 174 (71), 154 (95), 91 (100); HRMS (FAB) m/z calcd for $C_{28}H_{32}NO_4$ (M^++1) 446.2326, found 446.2325. Anal. Calcd for $C_{28}H_{31}NO_4$; C: 75.48; H: 7.01. Found: C: 75.51; H: 7.05.

*3.3.4. (E)-(4R,5R)-1,2,3-Trideoxy-2-formyl-5-hydroxy-1-n-octylanimo-4,6-di-O-methyl-hex-1-ene (**22**).* Pale yellow oil; $[\alpha]_D^{25}$ +37.8 (c 0.11, $CHCl_3$); ^1H NMR ($CDCl_3$, 500 MHz) δ 8.84 (1H, s, CHO), 6.87 (1H, d, $J_{1,NH}$=13.5 Hz, H1), 6.40–6.37 (1H, m, NH), 3.79 (1H, br s, OH), 3.49 (1H, dd, $J_{6a,5}$=2.5 Hz, $J_{6a,6b}$=9.5 Hz, H6a), 3.46–3.43 (1H, m, H5), 3.39 (1H, dd, $J_{6b,5}$=5.5 Hz, $J_{6b,6a}$=9.5 Hz, H6b), 3.36 (3H, s, OCH_3), 3.34–3.29 (4H, m, H4, OCH_3), 3.20–3.16 (2H, m, H1′), 2.62 (1H, dd, $J_{3a,4}$=4.5 Hz, $J_{3a,3b}$=15.0 Hz, H3a), 2.40 (1H, dd, $J_{3b,4}$=3.0 Hz, $J_{3b,3a}$=15.0 Hz, H3b), 2.27 (1H, dd, $J_{3b,4}$=8.0 Hz, $J_{3b,3a}$=14.0 Hz, H3b), 1.52–1.47 (2H, m, H2′), 1.24–1.21 (10H, m, H3′, H4′, H5′, H6′, H7′), 0.82 (3H, t, J=6.7 Hz, H8′); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 189.35, 160.39, 110.33, 82.34, 73.37, 70.75, 59.06, 58.27, 48.87, 31.68, 30.86, 29.09, 29.08, 26.39, 23.48, 22.54, 14.00; LRMS (EI) m/z (rel intens) 315 (M^+, 1), 266 (10), 147 (24), 146 (100); HRMS (EI) m/z calcd for $C_{17}H_{33}NO_4$ (M^+) 315.2403, found 315.2410. Anal. Calcd for $C_{17}H_{33}NO_4$; C: 64.73; H: 10.54. Found: C: 64.77; H: 10.58.

*3.3.5. (E)-(4R,5R)-1-Benzylanimo-1,2,3-trideoxy-2-formyl-5-hydroxy-4,6-di-O-methyl-hex-1-ene (**23**).* Pale yellow oil; $[\alpha]_D^{25}$ −1.0 (c 0.19, $CHCl_3$); IR ($CHCl_3$) 2922, 1693, 1606, 1217, 1091 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 8.90 (1H, s, CHO), 7.34–7.19 (5H, m, ArH), 6.97 (1H, d, $J_{1,NH}$=13.6 Hz, H1), 6.69–6.66 (1H, m, NH), 4.38 (1H, d, J=5.6 Hz, CH_2Ph), 4.37 (1H, d, J=5.6 Hz, CH_2Ph), 3.68 (1H, br s, OH), 3.51–3.46 (2H, m, H6a, H5), 3.41–3.36 (1H, m, H6b), 3.34–3.30 (4H, m, H4, OCH_3), 3.28 (3H, s, OMe), 2.61 (1H, dd, $J_{3a,4}$=4.8 Hz, $J_{3a,3b}$=15.2 Hz, H3a), 2.45 (1H, dd, $J_{3b,4}$=3.6 Hz, $J_{3b,3a}$=15.2 Hz, H3b); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 189.83, 160.07, 137.46, 128.94, 128.93, 128.00, 127.10, 127.09, 111.25, 82.27, 73.31, 70.60, 59.09, 58.25, 52.51, 23.46; LRMS (EI) m/z (rel intens) 293 (M^+, 1), 244 (10), 174 (10), 91 (100); HRMS (EI) m/z calcd for $C_{16}H_{23}NO_4$ (M^+) 293.1627, found 293.1620. Anal. Calcd for $C_{16}H_{23}NO_4$; C: 65.51; H: 7.90. Found: C: 65.55; H: 7.96.

*3.3.6. (E)-(4R,5R)-1,2,3-Trideoxy-2-formyl-5-hydroxy-1-n-octylanimo-4,6-di-O-pentyl-hex-1-ene (**24**).* Pale yellow oil; $[\alpha]_D^{25}$ −32.6 (c 1.05, $CHCl_3$); IR ($CHCl_3$) 2926, 1654, 1597, 1292, 1095 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 8.85 (1H, s, CHO), 6.86 (1H, d, $J_{1,NH}$=13.5 Hz, H1), 6.54–6.52 (1H, m, NH), 3.72 (1H, br s, OH), 3.59–3.51 (2H, m, OCH_2), 3.42–3.32 (6H, m, H4, H5, H6, OCH_2), 3.18–3.14 (2H, m, H1′), 2.65 (1H, dd, $J_{3a,4}$=3.0 Hz, $J_{3a,3b}$=15.0 Hz, H3a), 2.36 (1H, dd, $J_{3b,4}$=2.5 Hz, $J_{3b,3a}$=15.0 Hz, H3b), 1.52–1.45 (6H, m, CH_2), 1.23–1.21 (18H, m, CH_2), 0.83–0.82 (9H, m, CH_3); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 189.40, 160.32, 110.45, 80.41, 71.60, 71.41, 71.03, 70.96, 48.89, 31.72, 31.02, 30.05, 29.33, 29.14, 29.12, 28.35, 28.32, 26.50, 24.07, 22.57, 22.52, 22.50, 14.01, 13.98, 13.97; LRMS (EI) m/z (rel intens) 427 (M^+, 3), 315 (20), 208 (14), 196 (100), 71 (52); HRMS (EI) m/z calcd for $C_{25}H_{49}NO_4$ (M^+) 427.3662, found 427.3649. Anal. Calcd for $C_{25}H_{49}NO_4$; C: 70.21; H: 11.55. Found: C: 70.25; H: 11.59.

*3.3.7. (E)-(4R,5R)-1-Butylanimo-1,2,3-trideoxy-2-formyl-5-hydroxy-4,6-di-O-pentyl-hex-1-ene (**25**).* Pale yellow oil; $[\alpha]_D^{25}$ −32.2 (c 0.59, $CHCl_3$); IR ($CHCl_3$) 2929, 1654, 1597, 1215, 1093 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 8.85 (1H, s, CHO), 6.86 (1H, d, $J_{1,NH}$=13.5 Hz, H1), 6.54–6.51 (1H, m, NH), 3.73 (1H, br s, OH), 3.59–3.51 (2H, m, OCH_2), 3.44–3.33 (6H, m, H4, H5, H6, OCH_2), 3.20–3.16 (2H, m, H1′), 2.65 (1H, dd, $J_{3a,4}$=3.0 Hz, $J_{3a,3b}$=14.5 Hz, H3a), 2.36 (1H, dd, $J_{3b,4}$=2.5 Hz, $J_{3b,3a}$=14.5 Hz, H3b), 1.55–1.19 (6H, m, CH_2), 1.35–1.18 (10H, m, CH_2), 0.89–0.81 (9H, m, CH_3); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 189.39, 160.33, 110.47, 80.41, 71.59, 71.42, 71.04, 70.95, 48.55, 33.05, 30.02, 29.32, 28.34, 28.31, 24.04, 22.50, 22.49, 19.64, 13.97, 13.96, 13.60; LRMS (EI) m/z (rel intens) 371 (M^+, 3), 140 (100), 109 (11), 71 (24); HRMS (EI) m/z calcd for $C_{21}H_{41}NO_4$ (M^+) 371.3036, found 371.3031. Anal. Calcd for $C_{21}H_{41}NO_4$; C: 67.88; H: 11.12. Found: C: 67.92; H: 11.14.

*3.3.8. (E)-(4R,5R)-1-Benzylanimo-1,2,3-trideoxy-2-formyl-5-hydroxy-4,6-di-O-pentyl-hex-1-ene (**26**).* Pale yellow oil; $[\alpha]_D^{25}$ +54.5 (c 0.06, $CHCl_3$); IR ($CHCl_3$) 2924, 1654, 1595, 1217, 1089 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 8.90 (1H, s, CHO), 7.33–7.19 (5H, m, ArH), 6.96 (1H, d, $J_{1,NH}$=13.0 Hz, H1), 6.89–6.87 (1H, m, NH), 4.36 (2H, d, J=5.0 Hz, CH_2Ph), 3.56–3.31 (9H, m, H4, H5, H6, OH, OCH_2), 2.66 (1H, d, $J_{3a,3b}$=15.0 Hz, H3a), 2.42 (1H, d, $J_{3b,3a}$=15.0 Hz, H3b), 1.54–1.09 (12H, m, CH_2), 0.82–0.75 (6H, m, CH_3); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 189.83, 159.97, 137.50, 128.93, 128.92, 128.02, 127.24, 127.23, 109.98, 80.48, 71.63, 71.43, 71.01, 70.96, 52.47, 29.85, 29.34, 28.33, 28.29, 24.07, 22.51, 22.44, 14.01, 13.96; LRMS (EI) m/z (rel intens) 405 (M^+, 3), 300 (20), 213 (14), 174 (92), 91 (100); HRMS (EI) m/z calcd for

$C_{24}H_{39}NO_4$ (M^+) 405.2879, found 405.2870. Anal. Calcd for $C_{24}H_{39}NO_4$; C: 71.07; H: 9.69. Found: C: 71.12; H: 9.75.

*3.3.9. (E)-(4R,5R)-1,2,3-Trideoxy-2-formyl-5-hydroxy-1-n-octylanimo-4,6-di-O-benzyl-hex-1-ene (**27**).* Pale yellow oil; $[\alpha]_D^{25}$ +41.0 (*c* 0.20, $CHCl_3$); IR ($CHCl_3$) 2924, 1656, 1589, 1207, 1066 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 8.82 (1H, s, CHO), 7.28–7.19 (10H, m, ArH), 6.75 (1H, d, $J_{1,NH}$=14.0 Hz, H1), 6.18–6.15 (1H, m, NH), 4.62 (1H, d, $J_{a,b}$=11.5 Hz, CH_2Ph), 4.52 (1H, d, $J_{a,b}$=11.5 Hz, CH_2Ph), 4.46 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.41 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 3.54–3.41 (4H, m, H4, H5, H6), 3.09–2.98 (2H, m, H1′), 2.72 (1H, dd, $J_{3a,4}$=5.0 Hz, $J_{3a,3b}$=14.0 Hz, H3a), 2.28 (1H, dd, $J_{3b,4}$=8.5 Hz, $J_{3b,3a}$=14.0 Hz, H3b), 1.36–1.34 (2H, m, H2′), 1.22–1.18 (10H, m, H3′, H4′, H5′, H6′, H7′), 0.81 (3H, t, *J*=7.0 Hz, H8′); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 188.63, 159.44, 138.23, 137.93, 128.40, 128.39, 128.37, 128.36, 128.28, 128.27, 127.86, 127.85, 127.80, 127.74, 109.49, 77.71, 73.47, 72.56, 71.50, 71.19, 48.94, 31.73, 30.91, 29.12, 29.11, 26.44, 23.34, 22.59, 14.05; LRMS (EI) *m*/*z* (rel intens) 467 (M^+, 1), 392 (11), 208 (10), 196 (43), 91 (100); HRMS (EI) *m*/*z* calcd for $C_{29}H_{41}NO_4$ (M^+) 467.3036, found 467.3030. Anal. Calcd for $C_{29}H_{41}NO_4$; C: 74.48; H: 8.84. Found: C: 74.52; H: 8.88.

*3.3.10. (E)-(4S,5R)-1-Butylanimo-1,2,3-trideoxy-2-formyl-5-hydroxy-4,6–di-O-benzyl-hex-1-ene (**28**).* Pale yellow oil; $[\alpha]_D^{25}$ +62.6 (*c* 0.23, $CHCl_3$); IR ($CHCl_3$) 2924, 1651, 1591, 1213, 1066 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 8.83 (1H, s, CHO), 7.28–7.19 (10H, m, ArH), 6.74 (1H, d, $J_{1,NH}$=13.5 Hz, H1), 6.16–6.12 (1H, m, NH), 4.62 (1H, d, $J_{a,b}$=11.5 Hz, CH_2Ph), 4.52 (1H, d, $J_{a,b}$=11.5 Hz, CH_2Ph), 4.46 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.41 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 3.54–3.41 (4H, m, H4, H5, H6), 3.09–2.97 (2H, m, H1′), 2.72 (1H, dd, $J_{3a,4}$=5.0 Hz, $J_{3a,3b}$=14.0 Hz, H3a), 2.65 (1H, br s, OH), 2.27 (1H, dd, $J_{3b,4}$=8.0 Hz, $J_{3b,3a}$=14.0 Hz, H3b), 1.37–1.31 (2H, m, H2′), 1.25–1.17 (2H, m, H3′), 0.82 (3H, t, *J*=7.0 Hz, H4′); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 188.65, 159.39, 138.26, 137.97, 128.40, 128.39, 128.37, 128.36, 128.28, 128.27, 127.85, 127.84, 127.80, 127.73, 109.56, 77.76, 73.46, 72.58, 71.55, 71.24, 48.61, 32.93, 23.37, 19.60, 13.59; LRMS (EI) *m*/*z* (rel intens) 411 (M^+, 1), 164 (13), 140 (74), 91 (100); HRMS (EI) *m*/*z* calcd for $C_{25}H_{33}NO_4$ (M^+) 411.2410, found 411.2405. Anal. Calcd for $C_{25}H_{33}NO_4$; C: 72.96; H: 8.08. Found: C: 72.99; H: 8.10.

*3.3.11. (E)-(4S,5R)-1-Benzylanimo-1,2,3-trideoxy-2-formyl-5-O-acetyl-4,6-di-O-benzyl-hex-1-ene (**29**).* Pale yellow oil; $[\alpha]_D^{25}$ +75.1 (*c* 0.71, $CHCl_3$); IR ($CHCl_3$) 2920, 1651, 1597, 1215, 1068 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 8.87 (1H, s, CHO), 7.28–7.09 (15H, m, ArH), 6.84 (1H, d, $J_{1,NH}$=13.5 Hz, H1), 6.49–6.46 (1H, m, NH), 4.61 (1H, d, $J_{a,b}$=11.5 Hz, CH_2Ph), 4.51 (1H, d, $J_{a,b}$=11.5 Hz, CH_2Ph), 4.44 (1H, d, $J_{a,b}$=11.5 Hz, CH_2Ph), 4.40 (1H, d, $J_{a,b}$=11.5 Hz, CH_2Ph), 4.21 (1H, d, *J*=6.0 Hz, CH_2Ph), 4.20 (1H, d, *J*=6.0 Hz, CH_2Ph), 3.57–3.46 (3H, m, H4, H5, H6a), 3.42 (1H, dd, $J_{6b,5}$=4.5 Hz, $J_{6b,6a}$=9.0 Hz, H6b), 2.73 (1H, dd, $J_{3a,4}$=5.5 Hz, $J_{3a,3b}$=14.0 Hz, H3a), 2.32 (1H, dd, $J_{3b,4}$=8.0 Hz, $J_{3b,3a}$=14.0 Hz, H3b); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 189.02, 159.07, 138.15, 137.92, 137.64, 128.87, 128.86, 128.38, 128.37, 128.34, 128.33, 128.25, 128.24, 127.86, 127.85, 127.84, 127.77, 127.72, 127.09, 127.08, 110.51, 77.61, 73.43, 72.53, 71.50, 71.11, 52.34, 23.38; LRMS (EI) *m*/*z* (rel intens) 445 (M^+, 1), 198 (12), 174 (22), 91 (100); HRMS (EI) *m*/*z* calcd for $C_{28}H_{31}NO_4$ (M^+) 445.2253, found 445.2246. Anal. Calcd for $C_{28}H_{31}NO_4$; C: 75.48; H: 7.01. Found: C: 75.52; H: 7.06.

3.4. Standard procedure to prepare the diene derivatives (33–35)

The solution of β-enaminals (**7**–**9** or **15**–**17**) (1.0 equiv) in acetic acid (2 mL) was stirred at room temperature for 1.5–4 h, concentrated under reduced pressure, and then re-dissolved in pyridine (2 mL). The resulting mixture was mixed with acetic anhydride (2.5 equiv), followed by stirring at room temperature for 1 h. The reaction mixture was concentrated under reduced pressure and re-dissolved in CH_2Cl_2 (50 mL). The resulting solution was washed with H_2O (20 mL×2), brine (20 mL×2), and concentrated under reduced pressure. The dry residue was purified by silica gel column chromatography with EtOAc/Hex (2:3) to give the diene products (**33**–**35**) in 85–90% yields.

*3.4.1. (E)-(5R)-1-(N-Acetyl-octylanimo)-1,2,3-trideoxy-2-formyl-5-O-acetyl-4,6-di-O-benzyl-hex-1,3-diene (**33**).* Pale yellow oil; $[\alpha]_D^{25}$ −2.3 (*c* 1.21, $CHCl_3$); IR ($CHCl_3$) 2924, 1682, 1605, 1227, 1080 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 9.24 (1H, s, CHO), 7.43–7.10 (11H, m, ArH, H1), 5.59 (1H, s, H3), 5.51 (1H, t, *J*=5.5 Hz, H5), 4.70 (1H, d, $J_{a,b}$=11.0 Hz, CH_2Ph), 4.62 (1H, d, $J_{a,b}$=11.5 Hz, CH_2Ph), 4.48 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.45 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 3.66 (2H, d, $J_{5,6}$=6.0 Hz, H6), 3.63–3.60 (2H, m, H1′), 2.10 (3H, s, Ac), 2.04 (3H, s, Ac), 1.30–1.10 (12H, m, H2′, H3′, H4′, H5′, H6′, H7′), 0.79 (3H, t, *J*=7.0 Hz, H8′); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 192.01, 170.88, 169.86, 154.97, 145.65, 137.67, 136.76, 128.40, 128.39, 128.38, 128.37, 128.02, 127.76, 127.68, 127.67, 127.64, 127.63, 119.01, 102.14, 73.22, 72.13, 72.12, 69.97, 31.73, 31.72, 29.30, 29.11, 28.93, 26.30, 22.56, 22.23, 21.06, 14.03; LRMS (EI) *m*/*z* (rel intens) 549 (M^+, 1), 356 (6), 107 (10), 91 (100); HRMS (EI) *m*/*z* calcd for $C_{33}H_{43}NO_6$ (M^+) 549.3090, found 549.3095. Anal. Calcd for $C_{33}H_{43}NO_6$; C: 72.10; H: 7.90. Found: C: 72.14; H: 7.95.

*3.4.2. (E)-(5R)-1-(N-Acetyl-butylanimo)-1,2,3-trideoxy-2-formyl-5-O-acetyl-4,6-di-O-benzyl-hex-1,3-diene (**34**).* Pale yellow oil; $[\alpha]_D^{25}$ −1.3 (*c* 0.52, $CHCl_3$); IR ($CHCl_3$) 2932, 1682, 1605, 1227, 1080 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 9.24 (1H, s, CHO), 7.44–7.10 (11H, m, ArH, H1), 5.59 (1H, s, H3), 5.52 (1H, t, *J*=5.0 Hz, H5), 4.70 (1H, d, $J_{a,b}$=11.0 Hz, CH_2Ph), 4.63 (1H, d, $J_{a,b}$=11.5 Hz, CH_2Ph), 4.49 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.45 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 3.66 (2H, d, $J_{5,6}$=6.0 Hz, H6), 3.64–3.60 (2H, m, H1′), 2.10 (3H, s, Ac), 2.04 (3H, s, Ac), 1.29–1.10 (4H, m, H2′, H3′), 0.78 (3H, t, *J*=7.5 Hz, H4′); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 192.00, 170.88, 169.89, 154.96, 145.63, 137.67, 136.76, 128.41, 128.40, 128.39, 128.38, 128.03, 127.77, 127.71, 127.70, 127.65, 127.64, 118.98, 102.15, 73.23, 72.14, 72.13, 69.96, 31.03, 22.22, 21.06, 19.56, 19.55, 13.80; LRMS (EI) *m*/*z* (rel intens) 493 (M^+, 1), 300 (27), 270 (12), 91 (100); HRMS (EI) *m*/*z* calcd for $C_{29}H_{35}NO_6$ (M^+) 493.2464, found 493.2460. Anal. Calcd for $C_{29}H_{35}NO_6$; C: 70.60; H: 7.20. Found: C: 70.65; H: 7.26.

*3.4.3. (E)-(5R)-1-(N-Acetyl-benzylanimo)-1,2,3-trideoxy-2-formyl-5-O-acetyl-4,6-di-O-benzyl-hex-1,3-diene (**35**).* Pale yellow oil; $[\alpha]_D^{25}$ +17.0 (*c* 0.88, $CHCl_3$); IR ($CHCl_3$) 2931, 1682, 1605, 1211, 1080 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 9.26 (1H, s, CHO), 7.72–6.94 (11H, m, ArH, H1), 5.41 (1H, t, *J*=5.5 Hz, H5), 5.38 (1H, s, H3), 4.89 (1H, d, $J_{a,b}$=17.0 Hz, CH_2Ph), 4.83 (1H, d, $J_{a,b}$=17.5 Hz, CH_2Ph), 4.69 (1H, d, $J_{a,b}$=11.0 Hz, CH_2Ph), 4.61 (1H, d, $J_{a,b}$=11.5 Hz, CH_2Ph), 4.45 (1H, d, $J_{a,b}$=12.5 Hz, CH_2Ph), 4.42 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 3.61 (2H, d, $J_{5,6}$=5.0 Hz, H6), 2.07 (3H, s, Ac), 1.88 (3H, s, Ac); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 191.90, 171.27, 169.94, 154.91, 145.23, 137.66, 136.93, 136.80, 128.81, 128.80, 128.39, 128.38, 128.37, 128.03, 128.02, 127.77, 127.76, 127.75, 127.74, 127.73, 127.41, 127.40, 125.96, 119.20, 101.55, 73.25, 72.09, 72.08, 69.92, 31.02, 22.18, 20.91; LRMS (EI) *m*/*z* (rel intens) 527 (M^+, 1), 394 (6), 289 (25), 91 (100); HRMS (EI) *m*/*z* calcd for $C_{32}H_{33}NO_6$ (M^+) 527.2308, found 527.2300. Anal. Calcd for $C_{32}H_{33}NO_6$; C: 72.90; H: 6.30. Found: C: 72.94; H: 6.36.

3.5. Standard procedure for cyclization of 3-deoxy-β-enaminals to produce 3-deoxy-C-2-formylglycals (41–43)

The solution of 3-deoxy-β-enaminals (**19**–**23** or **27**–**29**) (1.0 equiv) in HOAc (3 mL) was stirred at 80 °C for 20 min, concentrated under reduced pressure, and then re-dissolved in CH_2Cl_2 (50 mL). The resulting mixture was washed with H_2O (20 mL×2),

brine (20 mL×2), and concentrated under reduced pressure. The dry residue was purified by silica gel column chromatography with EtOAc/Hex (1:4) to give 3-deoxy-C-2-formylglycals (**41**–**43**) in 95–97% yields.

*3.5.1. 1,5-Anhydro-4,6-di-O-benzyl-2,3-dideoxy-2-C-formyl-D-erythro-hex-1-enitol (**41**).* Pale yellow oil; $[\alpha]_D^{25}$ +65.7 (*c* 0.28, $CHCl_3$); IR ($CHCl_3$) 2940, 1676, 1625, 1197, 1095 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 9.24 (1H, s, CHO), 7.29–7.19 (11H, m, ArH, H1), 4.61 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.52 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.49 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.44 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.14–4.11 (1H, m, H5), 3.77–3.73 (1H, m, H4), 3.72–3.68 (2H, m, H6), 2.64 (1H, dd, $J_{3a,4}$=5.0 Hz, $J_{3a,3b}$=16.5 Hz, H3a), 2.20 (1H, dd, $J_{3b,4}$=7.5 Hz, $J_{3b,3a}$=16.5 Hz, H3b); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 189.88, 163.45, 137.60, 137.54, 128.49, 128.48, 128.47, 128.46, 127.92, 127.88, 127.80, 127.79, 127.75, 127.74, 116.96, 79.45, 73.64, 70.99, 68.47, 68.35, 22.46; LRMS (EI) *m*/*z* (rel intens) 338 (M^+, 1), 221 (10), 141 (8), 91 (100); HRMS (EI) *m*/*z* calcd for $C_{21}H_{22}O_4$ (M^+) 338.1518, found 338.1514. Anal. Calcd for $C_{21}H_{22}O_4$; C: 74.54; H: 6.55. Found: C: 74.59; H: 6.61.

*3.5.2. 1,5-Anhydro-4,6-di-O-methyl-2,3-dideoxy-2-C-formyl-D-erythro-hex-1-enitol (**42**).* Pale yellow oil; $[\alpha]_D^{25}$ +70.8 (*c* 0.24, $CHCl_3$); IR ($CHCl_3$) 2935, 1672, 1624, 1200, 1105 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 9.25 (1H, s, CHO), 7.23 (1H, s, H1), 4.09–4.06 (1H, m, H5), 3.57 (2H, d, $J_{6,5}$=4.0 Hz, H6), 3.52–3.48 (1H, m, H4), 3.35 (6H, s, OCH_3), 2.60 (1H, dd, $J_{3a,4}$=5.0 Hz, $J_{3a,3b}$=16.5 Hz, H3a), 2.14 (1H, dd, $J_{3b,4}$=7.0 Hz, $J_{3b,3a}$=16.5 Hz, H3b); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 189.93, 163.29, 116.85, 79.07, 71.01, 70.65, 59.46, 56.68, 21.70; LRMS (EI) *m*/*z* (rel intens) 186 (M^+, 1), 91 (100); HRMS (EI) *m*/*z* calcd for $C_9H_{14}O_4$ (M^+) 186.0892, found 186.0896. Anal. Calcd for $C_9H_{14}O_4$; C: 58.05; H: 7.58. Found: C: 58.12; H: 7.65.

*3.5.3. 1,5-Anhydro-4,6-di-O-benzyl-2,3-dideoxy-2-C-formyl-D-threo-hex-1-enitol (**43**).* Pale yellow oil; $[\alpha]_D^{25}$ +74.2 (*c* 0.62, $CHCl_3$); IR ($CHCl_3$) 2945, 1674, 1635, 1195, 1090 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 9.25 (1H, s, CHO), 7.27–7.17 (11H, m, ArH, H1), 4.56 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.49 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.42 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.33 (1H, d, $J_{a,b}$=12.0 Hz, CH_2Ph), 4.17–4.14 (1H, m, H5), 3.88 (1H, br s, H4), 3.72 (1H, dd, $J_{6a,5}$=7.0 Hz, $J_{6a,6b}$=10.0 Hz, H6a), 3.65 (1H, dd, $J_{6b,5}$=5.5 Hz, $J_{6b,6a}$=10.0 Hz, H6b), 2.61 (1H, dd, $J_{3a,4}$=2.5 Hz, $J_{3a,3b}$=17.5 Hz, H3a), 2.17 (1H, dd, $J_{3b,4}$=3.5 Hz, $J_{3b,3a}$=17.5 Hz, H3b); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 190.41, 163.95, 137.58, 137.48, 128.47, 128.46, 128.45, 128.44, 127.92, 127.89, 127.88, 127.87, 127.80, 127.79, 116.75, 78.65, 73.61, 70.96, 68.60, 67.63, 21.18; LRMS (EI) *m*/*z* (rel intens) 338 (M^+, 1), 221 (8), 125 (11), 91 (100); HRMS (EI) *m*/*z* calcd for $C_{21}H_{22}O_4$ (M^+) 338.1518, found 338.1510. Anal. Calcd for $C_{21}H_{22}O_4$; C: 74.54; H: 6.55. Found: C: 74.56; H: 6.57.

Acknowledgements

The authors thank the National Science Council of Taiwan (NSC100-2113-M-039-001-MY2) and China Medical University, Taiwan (CMU99-S-32) for their financial support.

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