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Synthesis of Polyhydroxylated Pyrano-Pyrrole Derivatives from Carbohydrate Precursors

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The efficient synthesis of novel polyhydroxy-tetrahydropyrano-pyrroles from acetylenic carbohydrate precursors in three to four steps is described. The methodology involves, as key steps, the ring contraction of pyridazine intermediates obtained by an inverse-demand Diels–Alder reaction and subsequent intramolecular lactonization.

Introduction

Styryl lactones, α-pyrone derivatives (5,6-dihydro-2*H*-pyran-2-one), isolated from natural sources have attracted much attention during the last decade owing to their medicinal potential, for example, as antiviral, antitumoral, antimalarial, or antifungal agents.[1]

The biological activities of such α,β-unsaturated δ-lactones are mainly attributed to their Michael acceptor character.[2,3] However, the broad range of biological targets aimed at by the α-pyrone skeleton can also be ascribed to the presence of various functionalized substituents, such as unsaturated alkyl, aryl, or hydroxylated side-chains. α-Pyrones with a polyol system form the basic skeleton of several natural products. For example, α-pyrones bearing free or acetylated polyhydroxylated side-chains, such as passifloricin A (**1**),[4] (+)-goniotriol (**2a**),[5] (+)-boronolide (**3a**),[6] and analogues **2b**[7] and **3b**, express antiprotozoal, antimalarial, and antitumoral activities (Figure 1). (+)-Furanopyrone goniothalenol [(+)-**4**], known as altholactone, isolated from *Goniothalamus giganteus,* is an example of a *cis*-fused bicyclic derivative and has been found to be very toxic towards mice during a P338 in vivo antileukemic screening.[8]

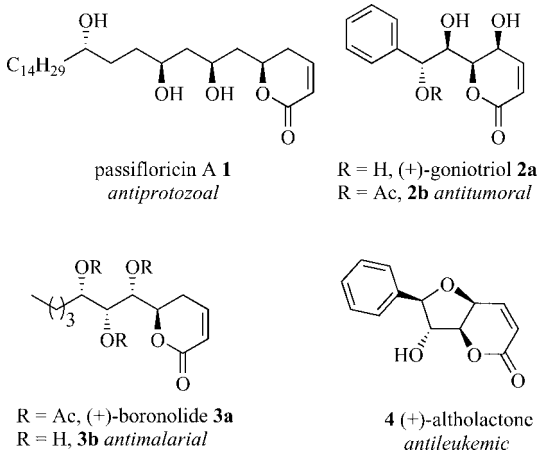

Figure 1. Examples of natural α-pyrones.

α-Pyrones fused to hydroxylated aromatic or nonaromatic rings (Figure 2) are also found in antimalarial dihydroisocoumarin derivatives **5**,[9] antitumoral psymberin (**6**),[10] and cytotoxic hippeastrine (**7**),[11] whereas dehydroaltenusin (**8**) has been observed to inhibit mammalian DNA polymerase α.[12]

A large number of active sesquiterpene lactones, like vernolepin (**9**),[13] have been isolated from plant extracts and show tumor-inhibiting activity. Recently, the indololactone (**10**),[14] obtained in the course of the production of quinolinone analogues of pancratistatin, has been shown to act by a different mechanism against pancreas and breast adenocarcinoma. In this particular case, a hydrogen-bonding donor–acceptor pairing effect between the indole ring and the keto ester group has been suggested. Bergenin (**11**) is a 1,2-*trans C*-aryl glucoside with anti-HIV and anti-inflammatory potential.[15]

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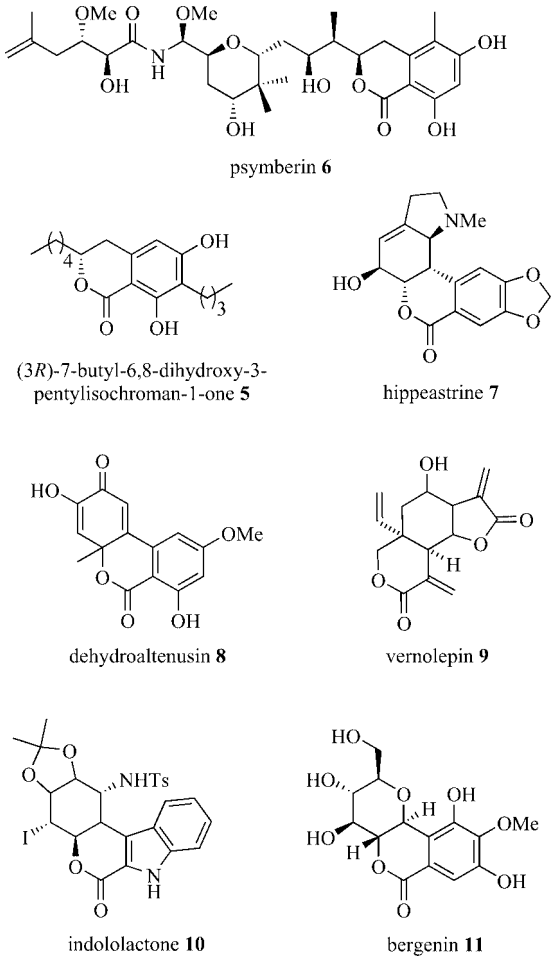


Figure 2. Biologically active compounds presenting an α-pyrone backbone.

As a result of our interest in the synthesis of pyrrole heterocycles by ring contraction of pyridazine precursors using Boger's chemical strategy[16] or an alternative electrosynthesis methodology developed in our laboratory,[17–20] we have developed a synthesis of novel linear (pyrone type **A**) and cyclic polyhydroxylated pyrrolo-pyrone derivatives (pyrone types **B** and **C**) (Figure 3) structurally analogous to boronolide (**3a**), altholactone (**4**), indololactone (**10**), or bergenin (**11**).

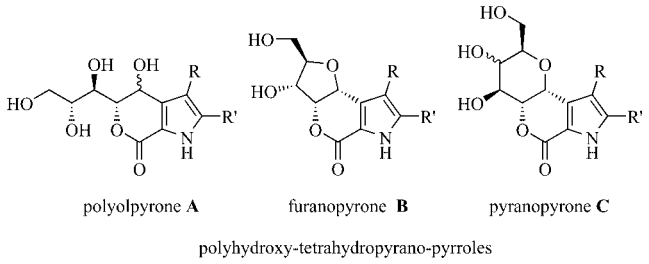


Figure 3. Targeted polyhydroxy-tetrahydropyrano-pyrroles.

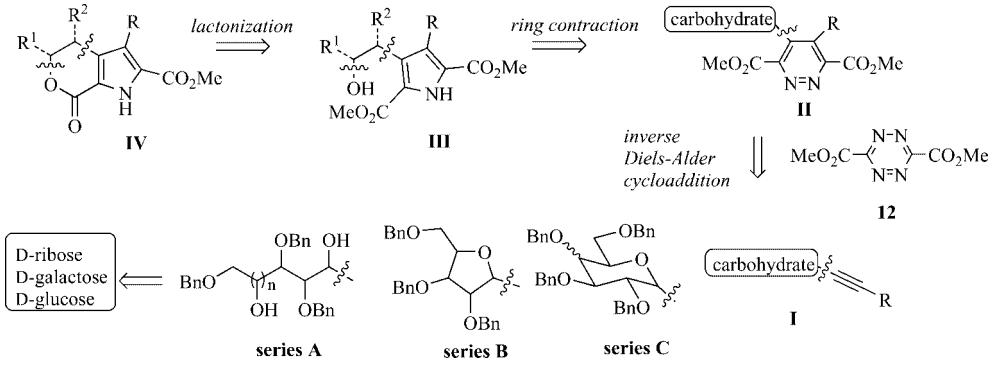
Recently, we validated a general efficient synthetic approach to pyrrolo-pyrones **A** bearing a polyol side-chain.[21] The synthetic route involves the successive introduction of pyrrolo and pyrone residues at the anomeric position of an open ribosyl sugar. We wish here to highlight the potential of this strategy by the preparation of furano- and pyrano-tetrahydropyrano-pyrrole analogues **B** and **C** using a similar synthetic approach (retrosynthesis 1, Scheme 1). Thus, access to the polyhydroxylated pyrano-pyrrole analogues **IV** was envisaged from acetylenic dienophile intermediates **I**, derived from furanose (series **A** and **B**) and pyranose (series **C**) sugars, by a reaction sequence involving cycloaddition, ring contraction, and lactonization.

The formation of the α-pyrone skeletons **IV** is the result of an intramolecular transesterification reaction between a selected free hydroxy group of the sugar moiety and an ester group of the pyrrolo heterocycles **III**. The intermediates **III** result from the ring contraction of suitable functionalized pyridazine heterocycles **II** produced by an inverse-demand Diels–Alder cycloaddition reaction between acetylenic sugar dienophiles **I** and dimethyl 1,2,4,5-tetrazine-3,6-dicarboxylate (**12**). Thus, D-ribose, D-galactose, and D-glucose were chosen to initiate the syntheses as these sugars seem to be suitable precursors to express different chiral polyhydroxylated side-chains on the targeted α-pyrone analogues.

Results and Discussion

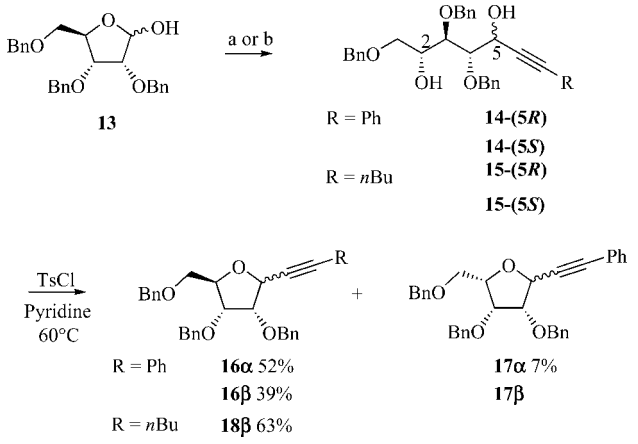
Preparation of Sugar *C*-Acetylenic Dienophiles

We have already shown[21] that the introduction of phenylacetylene and hexyne anions, generated in situ from phen-



Scheme 1. Retrosynthesis 1.

ylacetylene or hexyne in THF at –5 °C, onto the 2,3,5-tri-*O*-benzylribofuranose (**13**)[22,23] gives a 1:1 ratio of the diastereoisomers **14-(5*R*)/14-(5*S*)** and **15-(5*R*)/15-(5*S*)** in 87 and 85% yields, respectively (Scheme 2). If both diols **14** are candidates for producing linear polyhydroxylated pyrone analogues **IV** in series **A**, access to furanosylpyrone derivatives **IV** in series **B** from D-ribose entails the selection of the **14-(5*S*)** isomer to produce, by intramolecular cyclization, the required anomeric acetylenic furanosyl **16α** with the desired α configuration (Figure 4). Indeed, the anomer **16β**, resulting from the **14-(5*R*)** diol precursor, will not allow the final intramolecular formation of the pyrone ring.



Scheme 2. Reagents and conditions: (a) phenylacetylene (2.2 equiv.), *n*BuLi (2.0 equiv., 2.4 M in hexanes), THF, –5 °C, then **13** (1.0 equiv.) at 10 °C and then 2 h at room temp., 87%; (b) hexyne (2.2 equiv.), *n*BuLi (2.0 equiv., 2.4 M in hexanes), THF, –5 °C, then **13** (1.0 equiv.) at 10 °C and then 2 h at room temp., 85%.

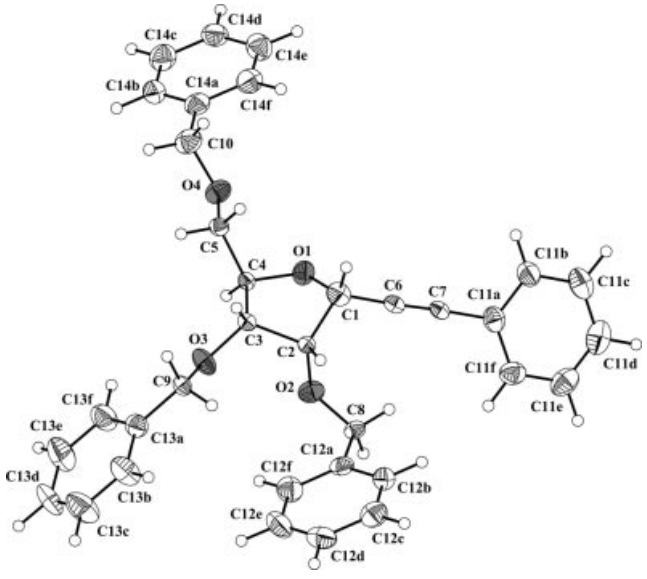
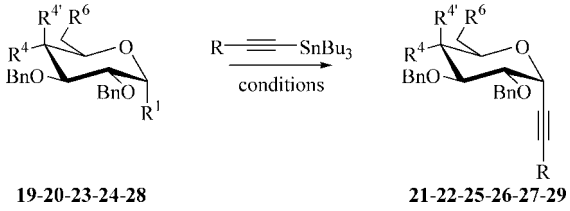


Figure 4. ORTEP diagram of acetylenic **16α**.

The cyclization process, occurring by a favorable regioselective intramolecular S_N2 substitution at the C-5 center with inversion of configuration, was initiated by treatment with tosyl chloride in pyridine.[24] Thus, the target furanosyl α-acetylenic **16α** was formed from **14-(5*S*)** in 52% yield together with a small amount of the L-lyxose analogue **17α** (7%) resulting from a tosylation side-reaction at the C-2 hydroxy function. The structure of *C*-ribosyl **16α** was unambiguously confirmed by X-ray crystallography (Scheme 2).[25] The formation of the L isomer **17β** was not detected during the cyclization of the **14-(5*R*)** isomer by the same procedure, which occurred in a moderate 39% yield. Alcohol activation using triflic anhydride or the Mitsunobu[26] procedure does not improve the intramolecular cyclization reaction of this series of compounds.

As Marco-Contelles et al. have already described for 2,3,4,6-tetra-*O*-benzylglucopyranose,[27] we also failed to achieve acetylenic anion addition followed by intermolecular cyclization to the corresponding acetylenic α-*C*-pyranosyl in the galacto series.

We therefore studied a *C*-glycosylation process (Scheme 3, Table 1) to access the target α-*C*-glycopyranosyl dienophiles **21**, **27**, and **29** required to prepare the type **C** pyrrolo-pyrone.



19-20-23-24-28 **21-22-25-26-27-29**

Scheme 3.

2,3,4,6-Tetra-*O*-benzylglucopyranosyl bromide (**19**) and 6-*O*-acetyl-2,3,4-tri-*O*-benzylglucopyranosyl chloride (**20**) are described in the literature as the best potent glycosyl donors to provide the corresponding α-*C*-glucopyranosyls **21** and **22** in the presence of (phenylethynyl)tributylstannane and $ZnCl_2$ (61%)[28] or $AgBF_4$ (73%)[29] promoters, respectively (Table 1, entries 1 and 2). Dondoni et al.[30] have observed that stereoselective α-*C*-glycosylation of 1-*O*-acetyl-2,3,4,6-tetra-*O*-benzylglucose and -galactose donors **23** and **24** can also occur when tributylstannyl(trimethylsilyl)acetylene is used in the presence of TMSOTf, providing the α-*C*-acetylenic glycosyls **25** and **26** in 65 and 87% yields, respectively (entries 3 and 4). We prepared 1,2-*cis* phenylacetylene glucosyl **21** and galactosyl **27** from donors **23** and **24** in the presence of TMSOTf (2 equiv.) in CH_2Cl_2 at room temp. in lower yields of 42 and 51%, respectively (entries 5 and 6). No improvement in the reaction was observed starting from 1,6-di-*O*-acetylated galactoside donor **28** and the corresponding phenylacetylene α-*C*-galactosyl **29** was isolated in a similar yield of 52% (entry 7). Note that, surprisingly, the formation of the β-*C*-galactosyl anomer was not observed during these latter processes.

Table 1. α-*C*-Glycosylation yields.

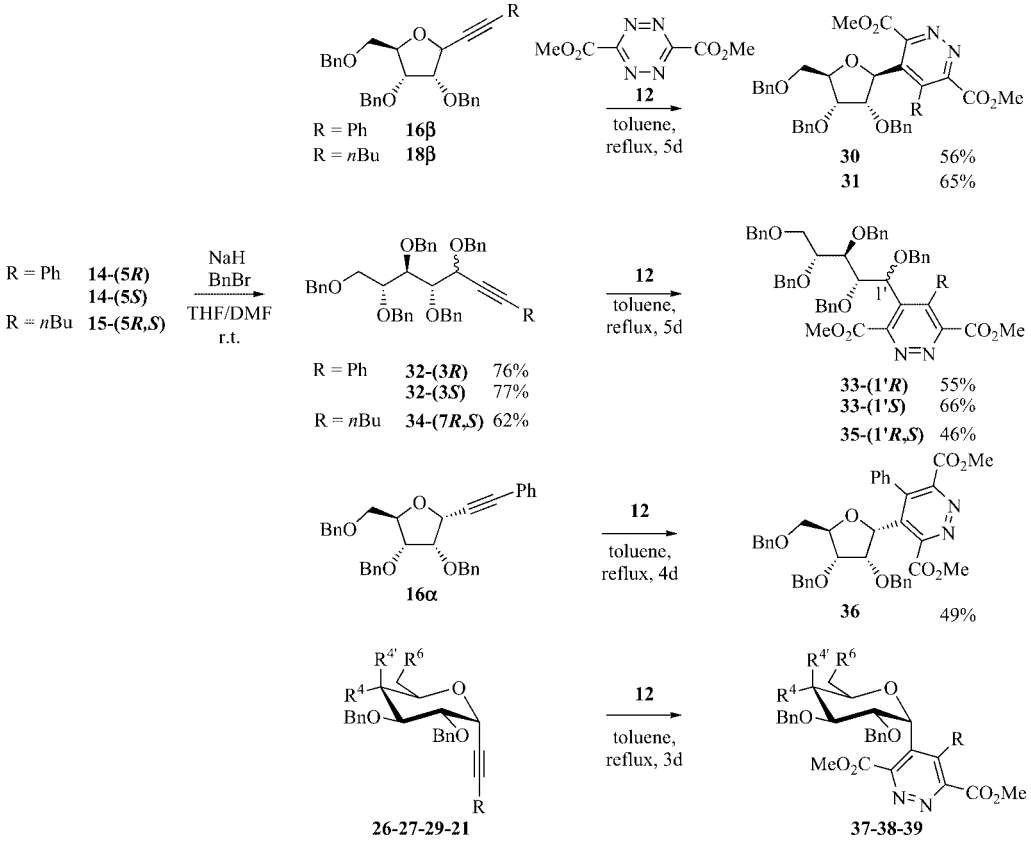
Entry	Glycosyl donor	R^1	R^4	$R^{4'}$	R^6	R	Conditions	Product, yield [%]	Ref.
1	**19**	Br	OBn	H	OBn	Ph	$ZnCl_2$, CCl_4, reflux	**21**, 61	[28]
2	**20**	Cl	OBn	H	OAc	Ph	$AgBF_4$, 4 Å MS, 1,2-DCE, –30 °C	**22**, 73	[29]
3	**23**	OAc	OBn	H	OBn	TMS	TMSOTf, CH_2Cl_2, room temp.	**25**, 65	[30]
4	**24**	OAc	H	OBn	OBn	TMS	TMSOTf, CH_2Cl_2, room temp.	**26**, 87	[30]
5	**23**	OAc	OBn	H	OBn	Ph	TMSOTf, CH_2Cl_2, room temp.	**21**, 42	
6	**24**	OAc	H	OBn	OBn	Ph	TMSOTf, CH_2Cl_2, room temp.	**27**, 51	
7	**28**	OAc	H	OBn	OAc	Ph	TMSOTf, CH_2Cl_2, room temp.	**29**, 52	

Access to Pyridazine *C*-Sugars

We have previously achieved the [4+2] cycloaddition of acetylenic *C*-ribosyls **16β** and **18β** with tetrazine **12**, leading to the pyridazinic ribosyl analogues **30** (56%) and **31** (65%), respectively.[31] Thus, a similar process was applied to the acetylenic dienophiles **14-(5*R*)**, **32**, **34**, **16α**, **21**, **26**, **27**, and **29** (Scheme 4).

Unexpectedly, the attempted inverse-demand Diels–Alder reaction between acetylenic **14-(5*R*)** and the electron-deficient dimethyl 1,2,4,5-tetrazine-3,6-dicarboxylate (**12**)[32,33] failed to give the expected pyridazine and the acetylenic *C*-ribosyl **16β** was obtained instead as a single isolable product in a low 28% yield. This failure can be ascribed to the intrinsic reactivity of the free hydroxy groups of the acetylenic diol **14** as Seitz[34] has shown that alcohols, thiols, or amines react by nucleophilic addition with tetrazine **12**. This behavior could then be used to explain the partial recyclizing process that can occur following an intramolecular Mitsunobu-like rearrangement and the predominant degradation of the reagents observed in the course of this reaction.

Therefore, the acetylenic diols **14** and **15** have to be protected. Thus, after benzylation of the free hydroxy groups at C-2 and C-4 of diols **14-(5*R*)**, **14-(5*S*)**, and **15-(5*R*,*S*)**, the benzylated acetylenic dienophiles **32-(3*R*)**, **32-(3*S*)**, and **34-(7*R*,*S*)** were treated with tetrazine **12** in the [4+2] cycload-



Scheme 4.

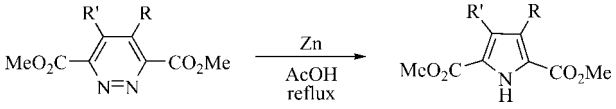
dition step to give, after 5 d under toluene reflux, the expected pyridazines **33-(1′*R*)**, **33-(1′*S*)**, and **35-(1′*R*,*S*)** in 55, 66, and 46% yields, respectively (Scheme 4). These yields are a result of the steric hindrance between the two partners slowing down the reaction, during which a partial degradation of tetrazine occurred. The pyridazine isomers **35-(1′*R*)** and **35-(1′*S*)** were isolated by semipreparative HPLC on a silica gel column. Inlactosyl-, and α-*C*-glucosyl-phenylpyridazines **36**, **37**, **38**, and **39** were formed in 49, 46, 45, and 50% yields, respectively, from dienophiles **16*α***, **27**, **29**, and **21** (Scheme 4). However, we were surprised to observe that no reaction occurred starting from trimethylsilylacetylene dienophile **26**, even after increasing the amount of diene **12** and the time of the cycloaddition process (Scheme 4, Table 2).

Table 2. [4+2] Cycloaddition process of acetylenic pyranosyls with dimethyl 1,2,4,5-tetrazine-3,6-dicarboxylate (**12**).

Acetylenic pyranosyl	R^4	$R^{4'}$	R^6	R	Product, % yield
26	H	OBn	OBn	TMS	no reaction
27	H	OBn	OBn	Ph	**37**, 46
29	H	OBn	OAc	Ph	**38**, 45
21	OBn	H	OBn	Ph	**39**, 50

Preparation of the Pyrrole *C*-Analogues

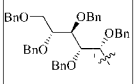
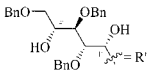
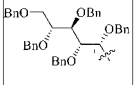
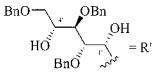
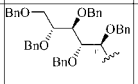
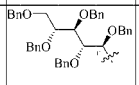
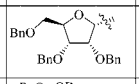
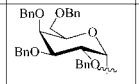
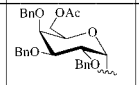
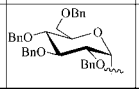
Pyridazines **33** and **35**–**39** were converted into pyrroles **40**, **41**, and **44**–**47** by a ring contraction process with 20 equiv. of zinc dust in refluxing acetic acid, according to the Boger procedure (Scheme 5, Table 3).[16]



Scheme 5.

When the reactions were carried out with the **1′*R*** series over several hours, the yields of pyrroles **40-(1′*R*)** and **41-(1′*R*)** did not exceed 18% after 15 h (entries 1 and 3). Under these reaction conditions, a surprising concomitant partial deprotection of the benzyl ether groups at C-1′ and C-4′ was observed leading to the formation of diols **42-(1′*R*)** and **43-(1′*R*)** as byproducts in 44 and 16% yields, respectively. The position of the free hydroxy groups was assigned thanks to an HMBC NMR experiment. Indeed, the 2'-H, 3'-H, and 5'-H atoms of pyrroles **42-(1′*R*)** and **43-(1′*R*)** are correlated with a benzylic methylenic carbon atom, whereas 1'-H and 4'-H do not show such correlations. These experiments prove that the hydroxy groups at C-1' and C-4' are deprotected under extended catalyzed reduction conditions. This unexpected selective benzyl ether cleavage is probably due to the prior release of the activated propargylic benzyl group at C-1' in the presence of zinc.[16] The subsequent reduction of benzyl at C-4' could be ascribed to an intermolecular assistance occurring by the predominant formation of a furanosyl ring under thermal conditions. However, a decrease in the reaction time to 30 min limited the debenzylation side-reaction to the production of just traces of byproducts and the targeted pyrroles **40-(1′*R*)** and **41-(1′*R*)** were isolated in 46 and 68% yields, respectively (entries 2 and 4). Ring contraction of pyridazines **33-(1′*S*)** and **35-(1′*S*)** was also performed over 30 min, leading to the pyrroles **40-(1′*S*)** and **41-(1′*S*)** in yields of 60% (entries 5 and 6). In this series, after 15 h, no hydroxy deprotection was detected even though the isolated yields were somewhat lower. The transformation of pyridazines *C*-ribosyl **36** and *C*-pyranosyl **37**, **38**, and **39** was also performed similarly to provide the pyrroles *C*-ribosyl **44** in 56% yield and *C*-galacto- and glucopyranosyls **45**, **46**, and **47** in yields of 70, 57, and 27%, respectively (entries 7–10).

Table 3. Ring contraction process of pyridazine derivatives.

Entry	R	R'	Pyridazine	Reaction time	Pyrrole (yield)
1	Ph		**33-(1′*R*)**	15 h	**40-(1′*R*)** <5% + **42-(1′*R*)** 44% 
2				30 min	**40-(1′*R*)** 46%
3	Bu		**35-(1′*R*)**	15 h	**41-(1′*R*)** 18% + **43-(1′*R*)** 16% 
4				30 min	**41-(1′*R*)** 68%
5	Ph		**33-(1′*S*)**	30 min	**40-(1′*S*)** 60%
6	Bu		**35-(1′*S*)**	30 min	**41-(1′*S*)** 60%
7	Ph		**36**	30 min	**44** 56%
8	Ph		**37**	30 min	**45** 70%
9	Ph		**38**	30 min	**46** 57%
10	Ph		**39**	30 min	**47** 27%

Synthesis of Pyrano Analogues

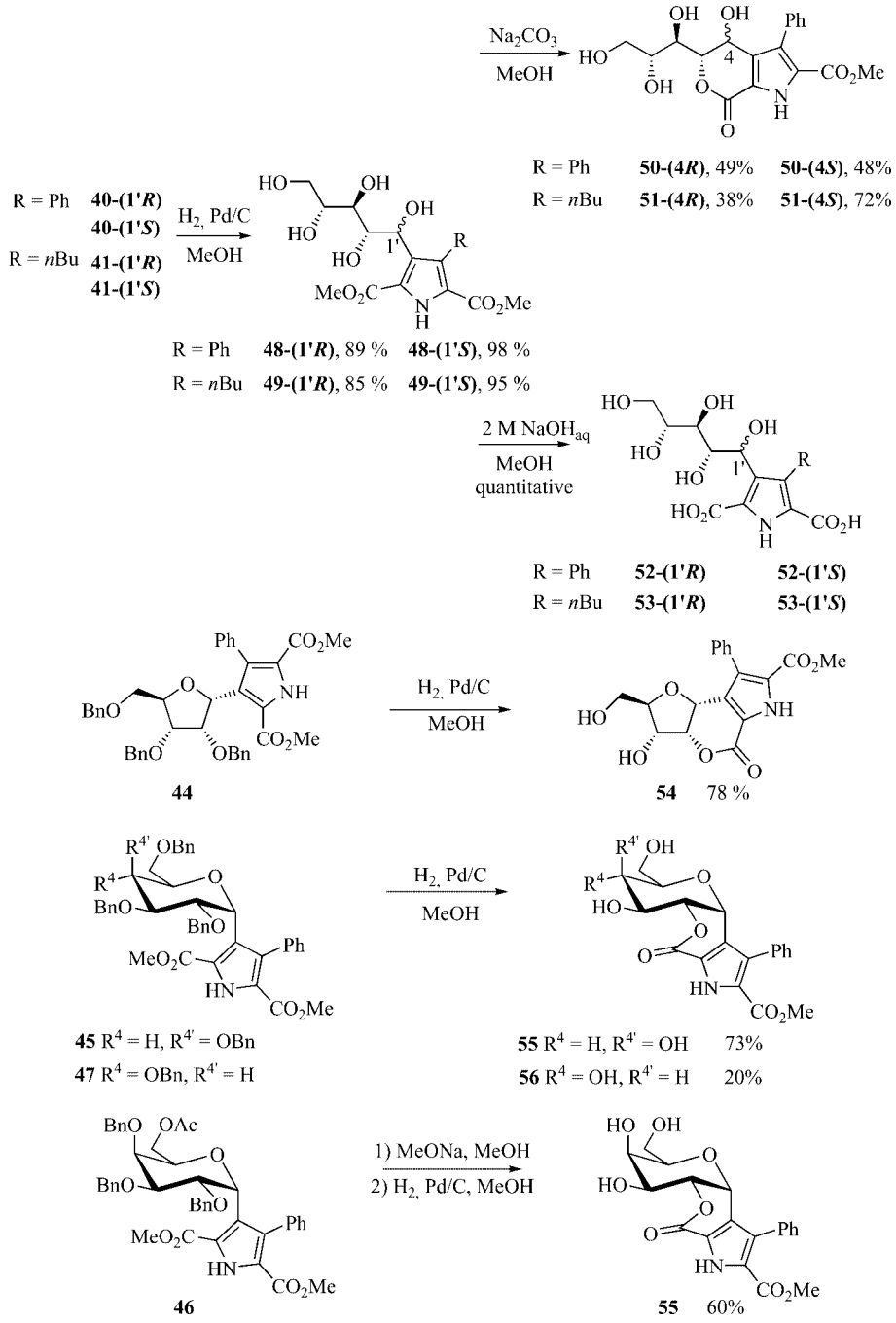
The tetrahydropyrano-pyrroles, as the (*R*,*S*) diastereoisomers, were then synthesized over two general steps from the protected pyrrolo sugars by debenzylation and subsequent

intramolecular transesterification between the hydroxy group at C-2' and one of the ester groups of the pyrrole moiety (Scheme 6).

Thus, debenzylation of pyrroles **40-(1′*R*)**, **40-(1′*S*)**, **41-(1′*R*)**, and **41-(1′*S*)** under hydrogenation conditions (H_2, Pd/C) afforded the corresponding pyrroles **48-(1′*R*)**, **48-(1′*S*)**, **49-(1′*R*)**, and **49-(1′*S*)** in good yields (85–98%).[35] These compounds could not be purified in the pyrrolo diester form as a partial intramolecular lactonization occurred spontaneously on silica gel giving the pyrano-pyrroles **50-(4*R*)**, **50-(4*S*)**, **51-(4*R*)**, and **51-(4*S*)**, respectively, whereas the hydrolysis of pyrroles **48** and **49** by 2 M aqueous NaOH in methanol solution yielded the corresponding diacids **52** and **53** in a quantitative manner.

However, lactonization was fully achieved in a basic medium (Na_2CO_3, MeOH) to provide the pyrano-pyrroles **50-(4*R*)**, **50-(4*S*)**, **51-(4*R*)**, and **51-(4*S*)** in moderate-to-good yields (38–72%). The proposed structure and the stereochemistry of **50-(4*S*)** were assigned in the solid state (Figure 5).[36]

In more constrained structures, such as the ribosyl and pyranosyl series, the deprotection and lactonization events



Scheme 6.

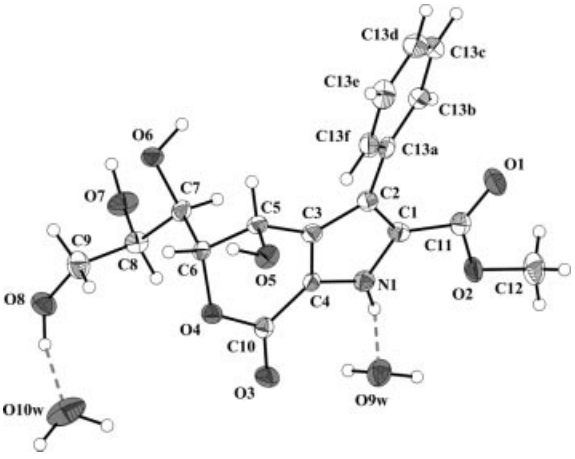


Figure 5. ORTEP diagram of pyrano-pyrone **50-(4*S*)**.

take place successively during the hydrogenation reaction of **44**, **45**, and **47**, leading to the cyclic pyrano-pyrroles **54**, **55**, and **56** spontaneously in 78, 73, and 20% yields, respectively (Scheme 6). The observed yields for the synthesis of pyrano-pyrroles of the glucopyranosyl series are lower than those of the other series. This has not yet been explained, but new conditions are currently being investigated in an effort to improve the results. In the case of pyrrole **46**, a deacetylation step was required before the hydrogenation to provide the pyrone **55** in 60% yield.

Conclusions

We have synthesized seven novel tetrahydropyrano-pyrroles **50-(1′*R*)**, **50-(1′*S*)**, **51-(1′*R*)**, **51-(1′*S*)**, **54**, **55**, and **56** in eight or nine steps from D-ribose, D-galactose, and D-glucose (Figure 5). The key step of the synthesis is the ring contraction of a pyridazine, which was achieved by a Diels–Alder cycloaddition reaction. The biological properties of the linear pyrano-pyrroles were evaluated on KB cells, HIV, HSV, hepatitis C, and on *Leishmania panamensis*, but did not show any significant activity. Biological tests on cyclic pyrano-pyrroles are currently underway. Some analogues of the tetrahydropyrano-pyrroles are presently being synthesized from other furanose and pyranose sugars to study the influence of chain length and of the hydroxy configuration. We also plan to introduce aryl or alkyl substituents onto the terminal part of the osidic skeleton to mimic goniotriol (**2a**) and boronolide (**3a**) side-chains (Figure 6).

In addition, alkyl or aryl substituents will be introduced onto the sugar skeleton, in analogy with goniotriol (**2a**) and boronolide (**3a**). Pyrrole intermediates, such as **46**, which present a selectively different protection of 6-OH, are good candidates to initiate such modifications. This work is currently under investigation in our group and will be reported elsewhere.

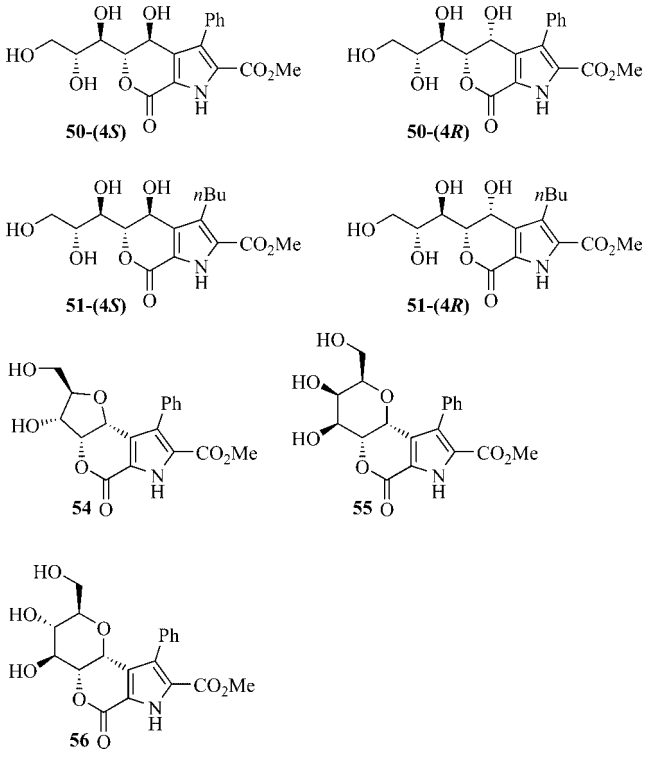


Figure 6. Synthesized polyhydroxy-tetrahydropyrano-pyrroles.

Experimental Section

Solvents were purified and dried by standard methods prior to use. All reactions were carried out under argon. ^{1}H and ^{13}C NMR spectra were recorded with a Bruker AC 400 or AC 300 spectrometer with TMS used as the internal standard in ^{1}H NMR spectra. Chemical shifts (δ) are given in ppm and coupling constants (J) in Hz. All assignments were confirmed with the aid of two-dimensional ^{1}H,^{1}H (COSYGPQF) or ^{1}H,^{13}C (INV4GPQF) or ^{1}H,^{13}C (INV4GPLRNDQF) experiments using standard Bruker pulse programs. All reactions were monitored by TLC on commercially available precoated plates (Kieselgel 60 F_{254}) and the products were visualized with a mostaïne solution [250 mL H_2O, 10.5 g of $(NH_4)_6Mo_7O_{24}{\cdot}4H_2O$, 0.5 g of $Ce(SO_4)_2$, and 15 mL of H_2SO_4]. Kieselgel 60, 230–400 mesh (Merck), was used for column chromatography. Optical rotations were measured at 20 ± 1 °C with a Perkin–Elmer 341 instrument in the indicated solutions whose concentrations are expressed in g/100 mL. Mass spectra were measured by CI with NH_3 on a quad. Hewlett–Packard 5989A instrument. HRMS were measured with a MS/MS ZABSpec TOF spectrometer from Micromass (Positive Electrospray, solvent: MeOH) at the "Centre Régional de Mesures Physiques de l'Ouest", Rennes, France. FTIR spectra were obtained in the 500–4000 cm^{-1} range with a Bruker Vector 22 FT-IR spectrometer using NaCl pellets. For HPLC purification, a KROMASIL semipreparative column was used.

Procedure A – Addition of Acetylene Derivatives to 2,3,5-Tri-*O*-benzyl-D-ribose: Phenylacetylene or hexyne (2.2 equiv.) was added dropwise under argon to a stirred solution of *n*-butyllithium (2.0 equiv., 2.4 M in hexanes) in THF in an ice–salt bath. The solution became dark. The mixture was warmed to 10 °C and turned yellow. Then, 2,3,5-tri-*O*-benzyl-D-ribose (1.0 equiv.) in THF was added dropwise. The mixture was stirred at room temperature for 2 h. Solvent was concentrated under reduced pressure and satu-

rated aqueous N4-HCl solution was added to the resulting residue which was then extracted with EtOAc. The organic layer was dried with Na_2SO_4 and concentrated under reduced pressure.

(2*R*,3*R*,4*S*,5*R*)-1,3,4-Tribenzoxy-7-phenylhept-6-yne-2,5-diol [14-(5*R*)] and (2*R*,3*R*,4*S*,5*S*)-1,3,4-Tribenzoxy-7-phenylhept-6-yne-2,5-diol [14-(5*S*)]: These compounds were synthesized according to procedure A from phenylacetylene (3.4 mL, 36.60 mmol), *n*-butyllithium (13.9 mL, 33.30 mmol) in THF (40 mL), and 2,3,5-tri-*O*-benzyl-D-ribose (**13**) (7.0 g, 16.60 mmol) in THF (10 mL). Chromatographic purification on silica gel (petroleum ether/EtOAc, 82.5:17.5) gave compounds **14-(5*R*)** and **14-(5*S*)** (7.59 g, 87%) in a ratio of 1:1. **14-(5*R*)**: Syrup; R_f (petroleum ether/EtOAc, 7:3) = 0.40. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.62 (d, ^3J = 3.3 Hz, 1 H, 2-OH), 3.22 (d, ^3J = 8.1 Hz, 1 H, 5-OH), 3.55 (dd, $J_{1a,1b}$ = 9.8, $J_{1a,2}$ = 3.3 Hz, 1 H, 1a-H), 3.62 (dd, $J_{1b,1a}$ = 9.8, $J_{1b,2}$ = 6.9 Hz, 1 H, 1b-H), 3.90 (dd, $J_{4,3}$ = 6.5, $J_{4,5}$ = 3.6 Hz, 1 H, 4-H), 3.98 (dd, $J_{3,4}$ = 6.5, $J_{3,2}$ = 4.7 Hz, 1 H, 3-H), 4.20 (m, 1 H, 2-H), 4.49 (s, 2 H, CH_2(Bn)), 4.71 (s, 2 H, CH_2(Bn)), 4.74 (d, ^2J = 11.3 Hz, 1 H, CH_2(Bn)), 4.89 (d, ^2J = 11.3 Hz, 1 H, CH_2(Bn)), 4.90 (m, 1 H, 5-H), 7.23–7.46 (m, 20 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 63.0 (C-5), 71.0, 71.1 (C-1, C-2), 73.5, 74.1, 74.2 (3 CH_2(Bn)), 80.2 (C-3), 80.6 (C-4), 86.1, 88.5 (2C_{alkyne}), 122.7 (Cq(Ph)), 128.0–131.8 (CH(Ar)), 137.6–138.0 (Cq(Bn)) ppm. MS (CI^+, NH_3): *m*/*z* = 540 $[M + NH_4]^+$, 523 $[M + H]^+$. IR: $\tilde{\nu}$ = 3457 (OH), 2203 (C≡C) cm^{-1}. $[\alpha]_D^{20}$ = –10.5 (*c* = 0.57, $CHCl_3$). $C_{34}H_{34}O_5 \cdot H_2O$ (540.64): calcd. C 75.53, H 6.71; found C 75.69, H 6.44. **14-(5*S*)**: White needles; m.p. 66 °C; R_f (petroleum ether/EtOAc, 7:3) = 0.32. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.61 (dd, $J_{1a,1b}$ = 9.7, $J_{1a,2}$ = 6.0 Hz, 1 H, 1a-H), 3.69 (dd, $J_{1b,1a}$ = 9.7, $J_{1b,2}$ = 3.2 Hz, 1 H, 1b-H), 4.00 (m, 2 H, 3-H, 4-H), 4.23 (m, 1 H, 2-H), 4.48 (d, ^2J = 11.7 Hz, 1 H, CH_2(Bn)), 4.52 (d, ^2J = 11.2 Hz, 1 H, CH_2(Bn)), 4.54 (d, ^2J = 11.7 Hz, 1 H, CH_2(Bn)), 4.67 (d, ^2J = 11.2 Hz, 1 H, CH_2(Bn)), 4.74 (d, ^2J = 11.8 Hz, 1 H, CH_2(Bn)), 4.86 (d, ^2J = 11.8 Hz, 1 H, CH_2(Bn)), 4.97 (d, $J_{5,4}$ = 5.3 Hz, 1 H, 5-H), 7.21–7.43 (m, 20 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 63.4 (C-5), 69.7 (C-1), 71.1 (C-2), 73.3, 73.4, 73.5 (3 CH_2(Bn)), 79.8, 80.8 (C-3, C-4), 86.4, 88.4 (2C_{alkyne}), 122.7 (Cq(Ph)), 128.0–131.8 (CH(Ar)), 137.8–138.1 (Cq(Bn)) ppm. MS (CI^+, NH_3): *m*/*z* = 540 $[M + NH_4]^+$, 523 $[M + H]^+$. IR: $\tilde{\nu}$ = 3457 (OH), 2203 (C≡C) cm^{-1}. $[\alpha]_D^{20}$ = –6.6 (*c* = 0.95, $CHCl_3$). $C_{34}H_{34}O_5 \cdot 0.5H_2O$ (531.64): calcd. C 76.81, H 6.64; found C 77.12, H 6.46.

(2*R*,3*R*,4*S*,5*R*)-1,3,4-Tribenzoxyundec-6-yne-2,5-diol [15-(5*R*)] and (2*R*,3*R*,4*S*,5*S*)-1,3,4-Tribenzoxyundec-6-yne-2,5-diol [15-(5*S*)]: These compounds were synthesized according to procedure A from hexyne (4.2 mL, 36.70 mmol), *n*-butyllithium (13.9 mL, 33.40 mmol) in THF (40 mL), and 2,3,5-tri-*O*-benzyl-D-ribose (**13**) (7.0 g, 16.70 mmol) in THF (10 mL). Chromatographic purification on silica gel (petroleum ether/EtOAc, 75:25) afforded a mixture of two inseparable isomers **15-(5*R*)** and **15-(5*S*)** (7.1 g, 85%). Only a small amount was purified by semipreparative HPLC (hexanes/EtOAc, 85:15, 2 mL/min) for analyses. **15-(5*R*)**: Syrup; R_f (petroleum ether/EtOAc, 8:2) = 0.16. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.89 (t, $J_{11,10}$ = 7.2 Hz, 3 H, 3×11-H), 1.37–1.53 (m, 4 H, 2×9-H, 2×10-H), 2.25 (td, $J_{8,9}$ = 7.0, $J_{8,10}$ = 1.9 Hz, 2 H, 2×8-H), 2.65 (m, 1 H, 2-OH), 3.06 (d, ^3J = 7.3 Hz, 1 H, 5-OH), 3.54 (dd, $J_{1a,1b}$ = 9.8, $J_{1a,2}$ = 3.2 Hz, 1 H, 1a-H), 3.60 (dd, $J_{1b,1a}$ = 9.8, $J_{1b,2}$ = 6.8 Hz, 1 H, 1b-H), 3.77 (dd, $J_{4,3}$ = 6.1, $J_{4,5}$ = 4.0 Hz, 1 H, 4-H), 3.90 (dd, $J_{3,4}$ = 6.1, $J_{3,2}$ = 5.1 Hz, 1 H, 3-H), 4.15 (m, 1 H, 2-H), 4.49 (s, 2 H, CH_2(Bn)), 4.63–4.71 (m, 4 H, CH_2(Bn), 5-H), 4.83 (d, ^2J = 11.3 Hz, 1 H, CH_2(Bn)), 7.27–7.37 (m, 15 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.7 (C-11), 18.7 (C-8), 22.2 (C-10), 30.8 (C-9), 62.6 (C-5), 71.0 (C-1), 71.1 (C-2), 73.5, 74.0 (3 CH_2(Bn)), 79.3 (C_{alkyne}), 80.1 (C-3), 80.8 (C-4), 87.0 (C_{alkyne}), 128.0–128.6 (CH(Ar)), 137.7–138.0 (Cq(Ar)) ppm. MS (CI^+, NH_3): *m*/*z* = 520 $[M + NH_4]^+$, 503 $[M + H]^+$. IR: $\tilde{\nu}$ = 3456 (OH), 2230 (C≡C) cm^{-1}. $[\alpha]_D^{20}$ = +8.4 (*c* = 1.11, $CHCl_3$). $C_{32}H_{38}O_5 \cdot 0.25H_2O$ (507.14): C 75.79, H 7.65; found C 75.78, H 7.63. **15-(5*S*)**: White needles; m.p. 30 °C; R_f (petroleum ether/EtOAc, 8:2) = 0.11. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, $J_{11,10}$ = 7.2 Hz, 3 H, 3×11-H), 1.35–1.50 (m, 4 H, 2×9-H, 2×10-H), 2.22 (td, $J_{8,9}$ = 7.0, $J_{8,10}$ = 1.9 Hz, 2 H, 2×8-H), 3.60 (dd, $J_{1a,1b}$ = 9.7, $J_{1a,2}$ = 6.2 Hz, 1 H, 1a-H), 3.66 (dd, $J_{1b,1a}$ = 9.7, $J_{1b,2}$ = 3.2 Hz, 1 H, 1b-H), 3.85 (dd, $J_{4,5}$ = 5.3, $J_{4,3}$ = 3.3 Hz, 1 H, 4-H), 3.93 (dd, $J_{3,2}$ = 7.2, $J_{3,4}$ = 3.3 Hz, 1 H, 3-H), 4.20 (ddd, $J_{2,3}$ = 7.2, $J_{2,1a}$ = 6.2, $J_{2,1b}$ = 3.2 Hz, 1 H, 2-H), 4.47–4.75 (m, 6 H, CH_2(Bn), 5-H), 4.81 (d, ^2J = 12.0 Hz, 1 H, CH_2(Bn)), 7.22–7.38 (m, 15 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.7 (C-11), 18.7 (C-8), 22.1 (C-10), 30.8 (C-9), 63.2 (C-5), 69.8 (C-2), 71.1 (C-1), 73.3, 73.3, 73.5 (3 CH_2(Bn)), 79.2 (C_{alkyne}), 79.9 (C-3), 81.0 (C-4), 87.4 (C_{alkyne}), 127.8–128.6 (CH(Ar)), 138.0–138.2 (Cq(Ar)) ppm. MS (CI^+, NH_3): *m*/*z* = 520 $[M + NH_4]^+$, 503 $[M + H]^+$. IR: $\tilde{\nu}$ = 3456 (OH), 2230 (C≡C) cm^{-1}. $[\alpha]_D^{20}$ = +10.6 (*c* = 1.21, $CHCl_3$). $C_{32}H_{38}O_5 \cdot 0.5H_2O$ (511.75): calcd. C 75.12, H 7.68; found C 75.23, H 7.44.

1-(2′,3′,5′-Tri-*O*-benzyl-α-D-ribofuranosyl)-2-phenylacetylene (16α): The diastereoisomer **14-(5*S*)** (1 equiv., 1.5 g, 2.87 mmol) was dissolved in dry pyridine (8 mL) and the resulting solution was heated at 50–60 °C. Tosyl chloride (2 equiv., 820 mg, 4.31 mmol) was added portionwise and the reaction mixture was stirred at this temperature for 3 h. After hydrolysis and extraction with CH_2Cl_2, the organic phase was dried with $MgSO_4$ and concentrated to dryness under reduced pressure. The crude was purified by column chromatography on silica gel (petroleum ether/EtOAc, 95:5) to yield **16α** (753 mg, 52%), which was recrystallized from Et_2O. White needles; m.p. 88–90 °C; R_f (petroleum ether/EtOAc, 8:2) = 0.41. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.57 (dd, $J_{5'a,5'b}$ = 11.1, $J_{5'a,4'}$ = 3.6 Hz, 1 H, 5′a-H), 3.71 (dd, $J_{5'b,5'a}$ = 11.1, $J_{5'b,4'}$ = 3.0 Hz, 1 H, 5′b-H), 4.12 (m, 2 H, 2′-H, 3′-H), 4.34 (m, 1 H, 4′-H), 4.43 (d, ^2J = 12.0 Hz, 1 H, CH_2(Bn)), 4.48 (d, ^2J = 12.3 Hz, 1 H, CH_2(Bn)), 4.57 (d, ^2J = 12.3 Hz, 1 H, CH_2(Bn)), 4.62 (d, ^2J = 11.7 Hz, 1 H, CH_2(Bn)), 4.80 (d, ^2J = 12.0 Hz, 1 H, CH_2(Bn)), 4.95 (d, ^2J = 11.7 Hz, 1 H, CH_2(Bn)), 4.97 (d, $J_{1',2'}$ = 3.0 Hz, 1 H, 1′-H), 7.18–7.48 (m, 20 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 69.6 (C-5′), 71.5 (C-1′), 72.6, 73.2, 73.6 (3 CH_2(Bn)), 78.4 (C-2′, C-3′), 80.3 (C-4′), 85.2, 87.9 (2C_{alkyne}), 122.9 (Cq (Ph)), 127.7–131.9 (CH(Ar)), 138.1–138.3 (Cq(Bn)) ppm. MS (CI^+, NH_3): *m*/*z* = 522 $[M + NH_4]^+$. $[\alpha]_D^{20}$ = +103.0 (*c* = 1.00, $CHCl_3$).

1-(2′,3′,5′-Tri-*O*-benzyl-α-L-lyxofuranosyl)-2-phenylacetylene (17α): This compound was obtained as a byproduct (7%) during the synthesis of **16α**. Syrup; R_f (petroleum ether/EtOAc, 8:2) = 0.46. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.70 (dd, $J_{5'a,5'b}$ = 9.9, $J_{5'a,4'}$ = 3.3 Hz, 1 H, 5′a-H), 3.80 (dd, $J_{5'b,5'a}$ = 9.9, $J_{5'b,4'}$ = 5.9 Hz, 1 H, 5′b-H), 4.20 (m, 2 H, 2′-H, 3′-H), 4.50 (m, 1 H, 4′-H), 4.50 (d, ^2J = 11.9 Hz, 1 H, CH_2(Bn)), 4.60 (m, 2 H, CH_2(Bn)), 4.76 (m, 3 H, CH_2(Bn)), 4.93 (m, 1 H, 1′-H), 7.20–7.55 (m, 20 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 68.9 (C-5′), 70.4 (C-1′), 72.8, 73.6, 73.7 (3 CH_2(Bn)), 77.6 (C-2′ or C-3′), 78.9 (C-4′), 84.5 (C-2′ or C-3′), 86.4, 87.3 (2C_{alkyne}), 122.6 (Cq (Ph)), 127.7–131.9 (CH(Ar)), 137.8–138.3 (Cq(Bn)) ppm. MS (CI^+, NH_3): *m*/*z* = 522 $[M + NH_4]^+$.

Procedure B – Preparation of Glycosyl-α-D-phenylacetylene: A mixture of 1-*O*-acetyl-glycosyl, (phenylethynyl)tributylstannane (2 equiv.), activated 4 Å powdered molecular sieves (same weight as glycosyl), and anhydrous CH_2Cl_2 (4 mL/mmol) was stirred at room temperature for 15 min, and then trimethylsilyl triflate (2 equiv.) was added dropwise. The dark-brown mixture was stirred

at room temperature for an additional 1.5 h, diluted with Et_3N (0.6 mL/mmol) and CH_2Cl_2 (15 mL/mmol), filtered through a pad of Celite, and concentrated. The residue was eluted from a column of silica gel (petroleum ether/EtOAc, 95:5 to 85:15).

1-(2′,3′,4′,6′-Tetra-*O*-benzyl-α-D-galactopyranosyl)-2-phenylacetylene (27): This compound was synthesized according to procedure B from 1-*O*-acetyl-galactosyl **24** (500 mg, 0.86 mmol), (phenylethynyl)tributylstannane (602 μL, 1.72 mmol), molecular sieves (500 mg) and trimethylsilyl triflate (310 μL, 1.72 mmol) in CH_2Cl_2 (4 mL). After work up with Et_3N (0.6 mL) and purification, the galactosylphenylacetylene **27** (262 mg) was obtained (51%). Syrup; R_f (petroleum ether/EtOAc, 8:2) = 0.71. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.57 (m, 2 H, 6′-H), 3.93–3.99 (m, 2 H, 4′-H, 3′-H), 4.15–4.22 (m, 2 H, 5′-H, 2′-H), 4.37 (d, ^2J = 11.6 Hz, 1 H, CH_2(Bn)), 4.48 (d, ^2J = 11.6 Hz, 1 H, CH_2(Bn)), 4.59 (d, ^2J = 11.4 Hz, 1 H, CH_2(Bn)), 4.72–4.78 (m, 3 H, CH_2(Bn)), 4.85 (d, ^2J = 11.9 Hz, 1 H, CH_2(Bn)), 4.95 (d, ^2J = 11.4 Hz, 1 H, CH_2(Bn)), 5.05 (d, $J_{1′,2′}$ = 5.7 Hz, 1 H, 1′-H), 7.00–7.50 (m, 25 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 67.9 (C-1′), 68.8 (C-6′), 72.7 (C-5′), 72.9, 73.1, 73.6 (3 CH_2(Bn)), 74.9 (C-4′ or C-3′), 75.0 (CH_2(Bn)), 75.7 (C-2′), 79.9 (C-3′ or C-4′), 84.4, 88.3 ($2C_{alkyne}$), 122.6 (Cq(Ph)), 123.9–132.1 (CH(Ar)), 137.9, 138.7, 138.8 (Cq(Bn)) ppm. MS (CI$^+$, NH_3): m/z = 642 $[M + NH_4]^+$. $[\alpha]_D^{20}$ = +8.4 (c = 1.10, $CHCl_3$).

1-(6′-*O*-Acetyl-2′,3′,4′-tri-*O*-benzyl-α-D-galactopyranosyl)-2-phenylacetylene (29): This compound was synthesized according to procedure B from 1-*O*-acetyl-galactosyl **28** (389 mg, 0.73 mmol), (phenylethynyl)tributylstannane (510 μL, 1.46 mmol), molecular sieves (400 mg) and trimethylsilyl triflate (264 μL, 1.46 mmol) in CH_2Cl_2 (3 mL). After work up with Et_3N (0.50 mL) and purification, the galactosylphenylacetylene **29** was obtained (235 mg, 52%). Syrup; R_f (petroleum ether/EtOAc, 8:2) = 0.47. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.98 (s, 3 H, Me(OAc)), 3.90 (m, 1 H, 4′-H), 3.95 (dd, $J_{3′,2′}$ = 9.5, $J_{3′,4′}$ = 2.7 Hz, 1 H, 3′-H), 4.13–4.16 (m, 4 H, 2′-H, 5′-H, 6′-H), 4.62 (d, ^2J = 11.5 Hz, 1 H, CH_2(Bn)), 4.76–4.80 (m, 3 H, CH_2(Bn)), 4.82 (d, ^2J = 11.8 Hz, 1 H, CH_2(Bn)), 4.95 (d, ^2J = 11.4 Hz, 1 H, CH_2(Bn)), 5.05 (d, $J_{1′,2′}$ = 5.5 Hz, 1 H, 1′-H), 7.24–7.46 (m, 15 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 21.0 (Me(OAc)), 63.5 (C-6′), 67.8 (C-1′), 72.0 (C-2′ or C-5′), 73.1, 73.5 (2 CH_2(Bn)), 74.6 (C-4′), 74.7 (CH_2(Bn)), 75.9 (C-2′ or C-5′), 79.8 (C-3′), 84.2, 88.5 ($2C_{alkyne}$), 122.6 (Cq(Ph)), 127.7–129.0, 132.1 (CH(Ar)), 138.7, 138.5, 138.3 (Cq(Bn)), 170.8 (CO) ppm. MS (CI$^+$, NH_3): m/z = 576 $[M + NH_4]^+$.

Procedure C − Benzylation: Sodium hydride (2.4 equiv.) was added to a stirred solution of the diol derivative (1 equiv.) in anhydrous THF and a few drops of DMF under argon. After 15 min stirring, benzyl bromide (2.4 equiv.) was added dropwise to the slurry. The reaction mixture was stirred overnight at room temperature. After adding a saturated aqueous NaCl solution, the mixture was extracted with EtOAc. The combined EtOAc fractions were dried with Na_2SO_4 and concentrated in vacuo.

(3*R*,4*S*,5*R*,6*R*)-3,4,5,6,7-Pentabenzoxy-1-phenylhept-1-yne [32-(3*R*)]: This compound was synthesized according to general procedure C. From NaH (385 mg, 9.62 mmol), acetylenic diol **14-(5*R*)** (2.10 g, 4.01 mmol) in a mixture THF (20 mL)/DMF (few drops) and benzyl bromide (1.15 mL, 9.62 mmol), **32-(3*R*)** (2.14 g, 76%) was obtained after flash column chromatography on silica gel (petroleum ether/EtOAc, 95:5). Syrup; R_f (petroleum ether/EtOAc, 9:1) = 0.44. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.70 (dd, $J_{7a,7b}$ = 10.6, $J_{7a,6}$ = 5.5 Hz, 1 H, 7a-H), 3.62 (dd, $J_{7b,7a}$ = 10.6, $J_{7b,6}$ = 3.0 Hz, 1 H, 7b-H), 4.13 (m, 1 H, 4-H), 4.11 (m, 2 H, 6-H, 5-H), 4.44 (d, ^2J = 11.6 Hz, 1 H, CH_2(Bn)), 4.46 (s, 2 H, CH_2(Bn)), 4.57–4.74 (m, 5 H, CH_2(Bn), 3-H), 4.78 (d, ^2J = 11.2 Hz, 1 H, CH_2(Bn)), 4.88 (d, ^2J = 11.8 Hz, 1 H, CH_2(Bn)), 5.02 (d, ^2J = 11.2 Hz, 1 H, CH_2(Bn)), 7.14–7.41 (m, 30 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 70.0 (C-3), 70.9 (C-7), 71.1, 72.7, 73.2, 73.3, 74.9 ($5CH_2$(Bn)), 78.8, 79.0 (C-6, C-5), 81.5 (C-4), 87.0, 87.8 ($2C_{alkyne}$), 122.8 (Cq(Ph)), 127.6–131.8 (CH(Ar)), 138.1–139.0 (Cq(Bn)) ppm. MS (CI$^+$, NH_3): m/z = 720 $[M + NH_4]^+$. IR: $\tilde{\nu}$ = 2223 (C≡C) cm^{-1}. $[\alpha]_D^{20}$ = –53.5 (c = 0.95, $CHCl_3$).

(3*S*,4*S*,5*R*,6*R*)-3,4,5,6,7-Pentabenzoxy-1-phenylhept-1-yne [32-(3*S*)]: This compound was synthesized according to procedure C. From NaH (553 mg, 13.80 mmol), acetylenic diol **14-(5*S*)** (3.01 g, 5.75 mmol) in a mixture THF (30 mL)/DMF (few drops) and benzyl bromide (1.65 mL, 13.80 mmol), **32-(3*S*)** (3.12 g, 77%) was obtained after flash column chromatography on silica gel (petroleum ether/EtOAc, 95:5). Syrup; R_f (petroleum ether/EtOAc, 9:1) = 0.46. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.65–3.75 (m, 2 H, H-7), 3.99–4.08 (m, 3 H, 6-H, 5-H, 4-H), 4.45 (s, 2 H, CH_2(Bn)), 4.53 (d, ^2J = 11.6 Hz, 1 H, CH_2(Bn)), 4.60–4.73 (m, 5 H, CH_2(Bn)), 4.82 (d, $J_{3,4}$ = 4.0 Hz, 1 H, 3-H), 4.90 (d, ^2J = 11.6 Hz, 1 H, CH_2(Bn)), 4.98 (d, ^2J = 11.4 Hz, 1 H, CH_2(Bn)), 7.21–7.44 (m, 30 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 70.7 (C-7), 71.3 (CH_2(Bn)), 71.9 (C-3), 72.6, 73.3, 74.0 (4 CH_2(Bn)), 79.0, 79.4, 80.4 (C-6, C-5, C-4), 86.4, 87.5 ($2C_{alkyne}$), 123.1 (Cq(Ph)), 127.5–132.0 (CH(Ar)), 138.1–139.0 (Cq(Bn)) ppm. MS (CI$^+$, NH_3): m/z = 720 $[M + NH_4]^+$. IR: $\tilde{\nu}$ = 2223 (C≡C) cm^{-1}. $[\alpha]_D^{20}$ = +36.4 (c = 0.91, $CHCl_3$). HRMS: calcd. for $C_{48}H_{47}O_5$ $[M + H]^+$ 703.3424; found 703.3419.

Procedure D − [4+2] Cycloaddition: Dimethyl 1,2,4,5-tetrazine-3,6-dicarboxylate (**12**) (1.1 to 2.2 equiv.) was added to a solution of acetylene derivative (1 equiv.) in freshly distilled toluene and the resulting mixture was stirred under argon at reflux. The solvent was then evaporated under reduced pressure.

Dimethyl (1′*R*,2′*S*,3′*R*,4′*R*)-4-(1′,2′,3′,4′,5′-pentabenzoxypentyl)-5-phenylpyridazine-3,6-dicarboxylate [33-(1′*R*)]: This compound was synthesized according to procedure D. From dimethyl 1,2,4,5-tetrazine-3,6-dicarboxylate (**12**) (906 mg, 4.56 mmol) and alkyne **32-(3*R*)** (1.46 g, 2.08 mmol) in toluene (6 mL), **33-(1′*R*)** (1.00 g, 55%) was obtained after purification by flash chromatography on silica gel (petroleum ether/EtOAc, 80:20). Syrup; R_f (petroleum ether/EtOAc, 7:3) = 0.36. ^{1}H NMR (300 MHz, CD_3OD): δ = 3.37 (dd, $J_{5′a,5′b}$ = 10.2, $J_{5′a,4′}$ = 6.7 Hz, 1 H, 5′a-H), 3.49 (dd, $J_{5′b,5′a}$ = 10.2, $J_{5′b,4′}$ = 3.8 Hz, 1 H, 5′b-H), 3.57 (m, 4 H, OMe, 3′-H), 3.66 (s, 3 H, OMe), 3.89 (m, 2 H, 2′-H, 4′-H), 4.06 (d, ^2J = 11.9 Hz, 1 H, CH_2(Bn)), 4.22 (d, ^2J = 11.5 Hz, 1 H, CH_2(Bn)), 4.32 (d, ^2J = 11.9 Hz, 1 H, CH_2(Bn)), 4.37–4.51 (m, 7 H, CH_2(Bn)), 5.10 (d, $J_{1′,2′}$ = 5.4 Hz, 1 H, 1′-H), 6.79–7.35 (m, 30 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, CD_3OD): δ = 53.3, 53.6 (2 OMe), 71.9 (C-5′), 72.4, 73.8, 74.2, 75.9 ($5CH_2$(Bn)), 79.0 (C-1′, C-3′), 79.8, 81.4 (C-2′,C-4′), 128.4–130.4 (CH(Ar)), 133.3–141.0 (Cq(Bn), Cq(Ph), C-3, C-6), 155.4, 156.7 (C-4, C-5), 166.0, 167.5 (2 CO) ppm. MS (CI$^+$, NH_3): m/z = 873 $[M + H]^+$. IR: $\tilde{\nu}$ = 1744 (C=O) cm^{-1}. $[\alpha]_D^{20}$ = –26.8 (c = 0.95, $CHCl_3$), $C_{54}H_{52}N_2O_9 \cdot 0.25H_2O$ (877.50): calcd. C 73.91, H 6.03, N 3.19; found C 73.86, H 6.05, N 3.15.

Dimethyl (1′*S*,2′*S*,3′*R*,4′*R*)-4-(1′,2′,3′,4′,5′-pentabenzoxypentyl)-5-phenylpyridazine-3,6-dicarboxylate [33-(1′*S*)]: This compound was synthesized according to procedure D. From dimethyl 1,2,4,5-tetrazine-3,6-dicarboxylate (**12**) (1.36 g, 6.88 mmol) and alkyne **32-(3*S*)** (2.20 g, 3.13 mmol) in toluene (9 mL), **33-(1′*S*)** (1.80 g, 66%) was obtained after purification by flash chromatography on silica gel (petroleum ether/EtOAc, 75:25). Syrup; R_f (petroleum ether/EtOAc, 7:3) = 0.41. ^{1}H NMR (300 MHz, CD_3OD): δ = 3.55–3.69 (m, 8 H, OMe, 5′-H), 3.78 (m, 1 H, 4′-H), 3.94 (d, $J_{3′,4′}$ = 4.0 Hz,

1 H, 3′-H), 4.12 (d, ^2J = 10.7 Hz, 1 H, CH_2(Bn)), 4.20–4.40 (m, 8 H, CH_2(Bn)), 4.53 (d, ^2J = 10.8 Hz, 1 H, CH_2(Bn)), 4.62 (d, $J_{2',1'}$ = 9.4 Hz, 1 H, 2′-H), 5.06 (d, $J_{1',2'}$ = 9.4 Hz, 1 H, 1′-H), 6.81–7.33 (m, 30 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, CD_3OD): δ = 53.3, 53.6 (2 OMe), 70.7 (C-5′), 73.0, 74.0, 74.3 (5CH_2(Bn)), 76.4 (C-1′), 79.4 (C-3′, C-4′), 82.1 (C-2′), 128.5–131.8 (CH(Ar)), 133.5–142.4 (Cq(Bn), Cq(Ph), C-3, C-6), 155.3, 155.7 (C-4, C-5), 166.2, 167.7 (2 CO) ppm. MS (CI$^+$, NH_3): *m/z* = 874 [M + H]$^+$. IR: $\tilde{\nu}$ = 1744 (C=O) cm^{-1}. $[\alpha]_D^{20}$ = –30.4 (*c* = 0.91, $CHCl_3$). HRMS: calcd. for $C_{54}H_{53}N_2O_9$ [M + H]$^+$ 873.3751; found 873.3719.

(7*R*,8*S*,9*R*,10*R*)-7,8,9,10,11-Pentabenzoxyundec-5-yne [34-(7*R*)] and (7*S*,8*S*,9*R*,10*R*)-7,8,9,10,11-Pentabenzoxyundec-5-yne [34-(7*S*)]: These compounds were synthesized according to procedure C from NaH (259 mg, 6.47 mmol), a mixture of acetylenic diol **15-(7*R*)** and **15-(7*S*)** (1.35 g, 2.70 mmol) in a mixture of THF (17 mL)/DMF (few drops) and benzyl bromide (770 μL, 6.47 mmol). Chromatographic purification on silica gel (petroleum ether/EtOAc, 95:5) afforded a mixture of two inseparable isomers **34-(7*R*)** and **34-(7*S*)** (1.14 g, 62%). Only a small amount was purified by semipreparative HPLC (hexanes/EtOAc, 95:5, 2 mL/min) for analyses. **34-(7*R*)**: syrup; R_f (petroleum ether/EtOAc, 95:5) = 0.27. ^{1}H NMR (300 MHz, CD_3OD): δ = 0.87 (t, ^3J = 7.1 Hz, 3 H, 3×1-H), 1.34–1.51 (m, 4 H, 2×2-H, 2×3-H), 2.23 (td, ^3J = 6.7, ^5J = 1.9 Hz, 2 H, 2×4-H), 3.65 (dd, $J_{11a,11b}$ = 10.7, $J_{11a,10}$ = 5.7 Hz, 1 H, 11a-H), 3.77 (dd, $J_{11b,11a}$ = 10.7, $J_{11b,10}$ = 3.1 Hz, 1 H, 11b-H), 3.86 (t, ^3J = 4.9 Hz, 1 H, 8-H), 4.00 (m, 1 H, 10-H), 4.06 (t, ^3J = 4.9 Hz, 1 H, 9-H), 4.39–4.47 (m, 5 H, H-7, CH_2(Bn)), 4.53 (d, ^2J = 11.7 Hz, 1 H, CH_2(Bn)), 4.55 (d, ^2J = 11.4 Hz, 1 H, CH_2(Bn)), 4.62 (d, ^2J = 11.7 Hz, 1 H, CH_2(Bn)), 4.68 (d, ^2J = 11.2 Hz, 1 H, CH_2(Bn)), 4.73 (d, ^2J = 11.7 Hz, 1 H, CH_2(Bn)), 4.88 (d, ^2J = 11.2 Hz, 1 H, CH_2(Bn)), 7.15–7.33 (m, 25 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, CD_3OD): δ = 14.0 (C-1), 19.2 (C-4), 23.0, 31.8 (C-2, C-3), 71.2 (C-7), 71.4, 71.7 (C-11, CH_2(Bn)), 73.3, 74.0, 74.2, 75.8 (4 CH_2(Bn)), 78.4 (C_{alkyne}), 79.8, 79.9 (C-9, C-10), 82.9 (C-8), 89.7 (C_{alkyne}), 128.6–129.3 (CH(Ar)), 139.4–140.0 (Cq(Ar)) ppm. MS (CI$^+$, NH_3): *m/z* = 700 [M + NH_4]$^+$. IR: $\tilde{\nu}$ = 2225 (C≡C) cm^{-1}. $[\alpha]_D^{20}$ = –31.6 (*c* = 0.75, $CHCl_3$), $C_{46}H_{50}O_5$·0.25H_2O (687.39): C 80.38, H 7.40; found C 80.47, H 7.34. **34-(7*S*)**: Syrup; R_f (petroleum ether/EtOAc, 95:5) = 0.29. ^{1}H NMR (400 MHz, CD_3OD): δ = 0.89 (t, ^3J = 7.0 Hz, 3 H, 3×1-H), 1.42–1.51 (m, 4 H, 2×2-H, 2×3-H), 2.27 (td, ^3J = 6.5, ^5J = 1.8 Hz, 2 H, 2×4-H), 3.64 (dd, $J_{11a,11b}$ = 10.7, $J_{11a,10}$ = 6.3 Hz, 1 H, 11a-H), 3.73 (dd, $J_{11b,11a}$ = 10.7, $J_{11b,10}$ = 3.5 Hz, 1 H, 11b-H), 3.87 (dd, $J_{8,9}$ = 6.1, $J_{8,7}$ = 4.0 Hz, 1 H, 8-H), 3.93 (dd, $J_{9,8}$ = 6.1, $J_{9,10}$ = 3.4 Hz, 1 H, 9-H), 4.03 (m, 1 H, 10-H), 4.40 (s, 2 H, CH_2(Bn)), 4.45 (d, ^2J = 11.7 Hz, 1 H, CH_2(Bn)), 4.53 (dt, $J_{7,4}$ = 2.1, $J_{7,8}$ = 4.0 Hz, 1 H, 7-H), 4.55–4.64 (m, 5 H, CH_2(Bn)), 4.76 (d, ^2J = 11.7 Hz, 1 H, CH_2(Bn)), 4.85 (d, ^2J = 11.4 Hz, 1 H, CH_2(Bn)), 7.18–7.30 (m, 25 H, H(Ar)) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 13.9 (C-1), 19.2 (C-4), 22.9, 31.9 (C-2, C-3), 71.5 (C-11), 71.8 (CH_2(Bn)), 72.4 (C-7), 73.4, 74.1, 74.7, 74.9 (5CH_2(Bn)), 77.1 (C_{alkyne}), 80.1 (C-10), 80.3 (C-9), 81.8 (C-8), 89.3 (C_{alkyne}), 128.4–129.3 (CH(Ar)), 139.4–140.0 (Cq(Ar)) ppm. MS (CI$^+$, NH_3): *m/z* = 700 [M + NH_4]$^+$. IR: $\tilde{\nu}$ = 2225 (C≡C) cm^{-1}. $[\alpha]_D^{20}$ = +35.5 (*c* = 0.16, $CHCl_3$).

Dimethyl (1′*R*,2′*S*,3′*R*,4′*R*)-5-Butyl-4-(1′,2′,3′,4′,5′-pentabenzoxypentyl)pyridazine-3,6-dicarboxylate [35-(1′*R*)] and Dimethyl (1′*S*,2′*S*,3′*R*,4′*R*)-5-Butyl-4-(1′,2′,3′,4′,5′-pentabenzoxypentyl)pyridazine-3,6-dicarboxylate [35-(1′*S*)]: These compounds were synthesized according to procedure D from dimethyl 1,2,4,5-tetrazine-3,6-dicarboxylate (**12**) (1.82 g, 9.18 mmol) and a mixture of alkyne **34-(7*R*)** and **34-(7*S*)** (2.85 g, 4.17 mmol, ratio 7*R*/7*S*, 52:48) in toluene (11 mL) to give a mixture of **35-(1′*R*)** and **35-(1′*S*)** (1.64 g, 46%, ratio, 68:32). The mixture was purified by semipreparative HPLC (hexanes/EtOAc, 85:15, 2 mL/min). **35-(1′*R*)**: white needles; m.p. 66 °C; R_f (petroleum ether/EtOAc, 75:25) = 0.32. ^{1}H NMR (300 MHz, CD_3OD): δ = 0.59 (t, ^3J = 6.8 Hz, 3 H, H_δ(Bu)), 0.86 (m, 3 H, 2H_γ(Bu), H_β(Bu)), 1.10 (m, 1 H, H_β(Bu)), 2.31 (m, 1 H, H_α(Bu)), 3.00 (m, 1 H, H_α(Bu)), 3.34 (m, 1 H, 2′-H), 3.56 (m, 1 H, 5′-H), 3.66 (s, 3 H, OMe), 3.74 (m, 1 H, 5′-H), 3.88 (m, 1 H, 4′-H), 3.95 (s, 3 H, OMe), 4.15–4.63 (m, 8 H, CH_2(Bn)), 4.71 (m, 1 H, 3′-H), 4.78–4.97 (m, 2 H, CH_2(Bn)), 5.20 (d, $J_{1',2'}$ = 8.4 Hz, 1 H, 1′-H), 6.81 (m, 2 H, H(Ar)), 7.13–7.44 (m, 23 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, CD_3OD): δ = 14.2 (C_δ(Bu)), 23.8 (C_γ(Bu)), 29.0 (C_α(Bu)), 33.7 (C_β(Bu)), 53.5, 53.7 (2 OMe), 69.4 (C-5′), 71.9, 74.1 (4 CH_2(Bn)), 75.4 (C-3′), 77.2 (CH_2(Bn)), 79.1 (C-1′), 80.3 (C-4′), 83.5 (C-2′), 128.7–129.9 (CH(Ar)), 138.3–143.8 (Cq(Bn), C-3, C-6), 155.5, 156.3 (C-4, C-5), 166.3, 168.1 (2 CO) ppm. MS (CI$^+$, NH_3): *m/z* = 853 [M]$^+$. IR: $\tilde{\nu}$ = 1740 (C=O) cm^{-1}. $[\alpha]_D^{20}$ = –52.5 (*c* = 0.36, $CHCl_3$), $C_{52}H_{56}N_2O_9$·0.5H_2O (862.01): C 72.45, H 6.66, N 3.25; found C 72.61, H 6.48, N 3.04. **35-(1′*S*)**: Syrup; R_f (petroleum ether/EtOAc, 75:25) = 0.28. ^{1}H NMR (400 MHz, CD_3OD): δ = 0.67 (t, ^3J = 7.0 Hz, 3 H, H_δ(Bu)), 0.98 (m, 2 H, H_γ(Bu)), 1.14 (m, 1 H, H_β(Bu)), 1.27 (m, 1 H, H_β(Bu)), 2.58 (m, 1 H, H_α(Bu)), 2.92 (m, 1 H, H_α(Bu)), 3.54 (s, 3 H, OMe), 3.72 (dd, $J_{5'a,5'b}$ = 10.6, $J_{5'a,4'}$ = 3.8 Hz, 1 H, 5′a-H), 3.83 (dd, $J_{5'b,5'a}$ = 10.6, $J_{5'b,4'}$ = 1.8 Hz, 1 H, 5′b-H), 4.00 (m, 4 H, OMe, 4′-H), 4.09 (d, ^2J = 11.2 Hz, 1 H, CH_2(Bn)), 4.23 (m, 3 H, CH_2(Bn), 3′-H), 4.51 (m, 4 H, CH_2(Bn), 2′-H), 4.64 (m, 1 H, CH_2(Bn)), 4.77 (m, 1 H, CH_2(Bn)), 5.24 (d, $J_{1',2'}$ = 9.4 Hz, 1 H, 1′-H), 6.78 (m, 2 H, H(Ar)), 7.08–7.32 (m, 23 H, H(Ar)) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 14.2 (C_δ(Bu)), 23.8 (C_γ(Bu)), 29.1 (C_α(Bu)), 33.1 (C_β(Bu)), 53.4, 53.7 (2 OMe), 70.0 (C-5′), 72.7, 74.4, 74.7 (5CH_2(Bn)), 76.3 (C-1′), 79.1 (C-3′), 79.5 (C-4′), 82.3 (C-2′), 128.5–129.8 (CH(Ar)), 138.0–144.2 (Cq(Bn), C-3, C-6), 155.1, 155.3 (C-4, C-5), 166.7, 167.9 (2 CO) ppm. MS (CI$^+$, NH_3): *m/z* = 853 [M]$^+$. IR: $\tilde{\nu}$ = 1740 (C=O) cm^{-1}. $[\alpha]_D^{20}$ = +49.0 (*c* = 0.28, $CHCl_3$). $C_{52}H_{56}N_2O_9$·0.5H_2O (862.01): C 72.45, H 6.66, N 3.25; found C 72.57, H 6.51, N 3.09.

Dimethyl 5-Phenyl-4-(2′,3′,5′-tri-*O*-benzyl-α-D-ribofuranosyl)pyridazine-3,6-dicarboxylate (36): This compound was synthesized according to procedure D. From dimethyl 1,2,4,5-tetrazine-3,6-dicarboxylate (**12**) (652 mg, 3.30 mmol) and acetylene derivative **16**α (757 mg, 1.50 mmol) in toluene (4 mL), **36** (493 mg, 49%) was obtained after purification by flash column chromatography on silica gel (petroleum ether/EtOAc, 8:2 to 1:1). Pale yellow solid; m.p. 140–141 °C; R_f (petroleum ether/EtOAc, 7:3) = 0.25. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.43–3.58 (m, 2 H, 5′-H), 3.61 (s, 3 H, OMe), 3.69 (m, 1 H, 2′-H), 3.87 (m, 1 H, 4′-H), 3.92 (s, 3 H, OMe), 3.95 (m, 1 H, 3′-H), 4.14 (d, ^2J = 12.2 Hz, 1 H, CH_2(Bn)), 4.38–4.53 (m, 4 H, CH_2(Bn)), 4.75 (d, ^2J = 12.2 Hz, 1 H, CH_2(Bn)), 4.29 (d, $J_{1',2'}$ = 2.6 Hz, 1 H, 1′-H), 6.87–7.37 (m, 20 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 52.7, 52.9 (2 OMe), 60.4 (C-5′), 73.2, 73.4 (3 CH_2(Bn)), 78.3 (C-2′ or C-4′), 79.0 (C-1′), 79.1 (C-4′ or C-2′), 80.2 (C-3′), 127.4–128.9 (CH(Ar)), 132.9–138.0 (Cq(Bn), Cq(Ph), C-3, C-6), 153.2, 154.3 (C-4, C-5), 164.8, 165.8 (2 CO) ppm. MS (CI$^+$, NH_3): *m/z* = 675 [M + H]$^+$. IR: $\tilde{\nu}$ = 1739 (CO) cm^{-1}. $[\alpha]_D^{20}$ = –58.9 (*c* = 1.00, $CHCl_3$).

Dimethyl 4-(2′,3′,4′,6′-Tetra-*O*-benzyl-α-D-galactopyranosyl)-5-phenylpyridazine-3,6-dicarboxylate (37): This compound was synthesized according to procedure D. From dimethyl 1,2,4,5-tetrazine-3,6-dicarboxylate (**12**) (138 mg, 0.69 mmol) and acetylene derivative **27** (216 mg, 0.35 mmol) in toluene (4 mL), **37** (119 mg, 46%) was obtained after purification by flash column chromatography on silica gel (petroleum ether/EtOAc, 8:2 to 1:1). Yellow syrup; R_f (petroleum ether/EtOAc, 7:3) = 0.26. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.03 (m, 1 H, 2′-H), 3.61 (m, 1 H, 3′-H), 3.65 (s, 3 H, OMe), 3.77 (dd, $J_{6'a,5'}$ = 2.4, $J_{6'a,6'b}$ = 12.2 Hz, 1 H,

6′a-H), 3.81–3.89 (m, 3 H, 6′b-H, CH_2(Bn)), 3.98 (s, 3 H, OMe), 4.03–4.10 (m, 3 H, 4′-H, CH_2(Bn)), 4.35–4.47 (m, 3 H, 5′-H, CH_2(Bn)), 4.50 (d, ^2J = 12.6 Hz, 1 H, CH_2(Bn)), 4.60 (d, ^2J = 12.6 Hz, 1 H, CH_2(Bn)), 5.12 (d, $J_{1′,2′}$ = 1.6 Hz, 1 H, 1′-H), 5.94 (d, ^3J = 6.7 Hz, 1 H, H(Ar)), 6.69–7.34 (m, 24 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 52.8 (2 OMe), 64.8 (C-6′), 66.7 (C-1′), 71.6, 71.9, 72.4 (4 CH_2(Bn)), 72.7 (C-3′, C-4′), 74.0 (C-2′), 76.6 (C-5′), 127.3–129.0 (CH(Ar), Cq(Ph)), 132.4–138.7 (Cq(Bn), C-3, C-6), 152.7, 155.7 (C-4, C-5), 165.0, 166.2 (2 CO) ppm. MS (CI$^+$, NH_3): *m*/*z* = 795 [M + H]$^+$. IR: $\tilde{\nu}$ = 1746 (CO) cm^{-1}. $[\alpha]_D^{20}$ = –65.4 (*c* = 1.00, $CHCl_3$).

Dimethyl 4-(6′-*O*-Acetyl-2′,3′,4′-tri-*O*-benzyl-α-D-galactopyranosyl)-5-phenylpyridazine-3,6-dicarboxylate (38): This compound was synthesized according to procedure D. From dimethyl 1,2,4,5-tetrazine-3,6-dicarboxylate (**12**) (117 mg, 0.59 mmol) and acetylene derivative **29** (310 mg, 0.54 mmol) in toluene (3 mL), **38** (180 mg, 45%) was obtained after purification by flash column chromatography on silica gel (petroleum ether/EtOAc, 8:2 to 1:1). Syrup; R_f (petroleum ether/EtOAc, 7:3) = 0.27. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.96 (s, 3 H, Me(OAc)), 3.06 (m, 1 H, 2′-H), 3.57 (m, 1 H, 3′-H), 3.57 (s, 3 H, OMe), 3.86 (m, 1 H, 6′a-H), 3.86 (s, 3 H, OMe), 3.90–3.99 (m, 4 H, 4′-H, CH_2(Bn)), 4.18 (m, 1 H, 5′-H), 4.26 (d, ^2J = 12.7 Hz, 1 H, CH_2(Bn)), 4.39 (m, 2 H, CH_2(Bn)), 5.10 (dd, $J_{6′b,6′a}$ = 12.8, $J_{6′b,5′}$ = 10.5 Hz, 1 H, 6′b-H,), 5.47 (br. s, 1 H, 1′-H), 5.90 (d, ^3J = 7.3 Hz, 1 H, H(Ar)), 6.68 (d, ^3J = 6.9 Hz, 2 H, H(Ar)), 6.87 (m, 2 H, H(Ar)), 7.13–7.32 (m, 14 H, H(Ar)), 7.47 (m, 1 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 21.0 (Me(OAc)), 52.5, 52.8 (2 OMe), 59.3 (C-6′), 66.3 (C-1′), 71.3 (C-3′), 71.6, 71.9 (3 CH_2(Bn)), 72.5 (C-4′), 73.3 (C-2′), 74.8 (C-5′), 127.5–129.2 (CH(Ar), Cq(Ph)), 132.5, 135.4 (C-3, C-6), 137.4–137.9 (Cq(Bn)), 155.6, 152.9 (C-4, C-5), 166.3, 164.9 (2 CO-(CO_2Me)), 171.3 (CO(OAc)) ppm. MS (CI$^+$, NH_3): *m*/*z* = 747 [M + H]$^+$. $[\alpha]_D^{20}$ = –96.0 (*c* = 1.00, $CHCl_3$).

Dimethyl 4-(2′,3′,4′,6′-Tetra-*O*-benzyl-α-D-glucopyranosyl)-5-phenylpyridazine-3,6-dicarboxylate (39): This compound was synthesized according to procedure D. From dimethyl 1,2,4,5-tetrazine-3,6-dicarboxylate (**12**) (139 mg, 0.70 mmol) and acetylene derivative **21** (200 mg, 0.32 mmol) in toluene (4 mL), **39** (127 mg, 50%) was obtained after purification by flash column chromatography on silica gel (petroleum ether/EtOAc, 8:2 to 1:1). Yellow solid; m.p. 158–160 °C; R_f (petroleum ether/EtOAc, 8:2) = 0.10. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.24 (m, 1 H, 2′-H), 3.44 (m, 1 H, 6′a-H), 3.57 (s, 3 H, OMe), 3.62 (m, 2 H, 6′b-H, 3′-H), 3.78 (m, 1 H, 4′-H), 3.82 (s, 3 H, OMe), 4.04 (m, 4 H, 5′-H, CH_2(Bn)), 4.37–4.52 (m, 5 H, CH_2(Bn)), 5.17 (d, $J_{1′,2′}$ = 1.7 Hz, 1 H, 1′-H), 5.78 (d, ^3J = 7.1 Hz, 1 H, H(Ar)), 6.78 (m, 2 H, H(Ar)), 7.00–7.25 (m, 22 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 52.8 (2 OMe), 66.6 (C-6′), 70.5 (C-1′), 70.6, 70.8 (2 CH_2(Bn)), 72.6 (C-5′), 73.2, 73.7 (2 CH_2(Bn)), 74.2 (C-2′), 77.3 (C-4′), 79.8 (C-3′), 127.8–129.8 (CH(Ar), Cq(Ph)), 132.6–138.2 (Cq(Bn), C-3, C-6), 153.2, 155.3 (C-4, C-5), 166.1, 164.8 (2 CO) ppm. MS (CI$^+$, NH_3): *m*/*z* = 795 [M + H]$^+$. $[\alpha]_D^{20}$ = –76.1 (*c* = 1.00, $CHCl_3$).

Procedure E – Ring Contraction: Zinc dust (20 equiv.) was added to a refluxing solution of pyridazine (1 equiv.) in glacial acetic acid. After being stirred for 30 min, the reaction mixture was cooled, filtered through a pad of Celite, and concentrated under reduced pressure. The crude oil was purified by flash chromatography on silica gel.

Dimethyl (1′*R*,2′*S*,3′*R*,4′*R*)-3-(1′,2′,3′,4′,5′-Pentabenzoxypentyl)-4-phenyl-1*H*-pyrrole-2,5-dicarboxylate [40-(1′*R*)]: This compound was synthesized according to procedure E. From pyridazine **33-(1′*R*)** (1.29 g, 1.48 mmol) and zinc dust (1.94 g, 29.60 mmol) in acetic acid (17 mL), **40-(1′*R*)** (535 mg, 46%) was obtained after purification by flash column chromatography on silica gel (petroleum ether/EtOAc, 80:20). Syrup; R_f (petroleum ether/EtOAc, 7:3) = 0.50. ^{1}H NMR (400 MHz, C_6D_6, 320 K): δ = 3.25 (s, 3 H, OMe), 3.34 (s, 3 H, OMe), 3.84–3.89 (m, 2 H, 3′-H, 5′a-H), 4.03 (dd, $J_{5′b,5′a}$ = 10.9, $J_{5′b,4′}$ = 2.1 Hz, 1 H, 5′b-H), 4.19–4.24 (m, 3 H, 2′-H, 4′-H, CH_2(Bn)), 4.35 (d, ^2J = 12.1 Hz, 1 H, CH_2(Bn)), 4.39 (d, ^2J = 12.1 Hz, 1 H, CH_2(Bn)), 4.57–4.66 (m, 5 H, CH_2(Bn)), 4.72 (d, ^2J = 12.1 Hz, 1 H, CH_2(Bn)), 4.82 (d, ^2J = 11.3 Hz, 1 H, CH_2(Bn)), 5.79 (d, $J_{1′,2′}$ = 8.6 Hz, 1 H, 1′-H), 7.05–7.32 (m, 30 H, H(Ar)), 9.47 (br. s, 1 H, NH) ppm. ^{13}C NMR (100 MHz, C_6D_6, 320 K): δ = 51.7, 51.9 (2 OMe), 72.6 (CH_2(Bn)), 72.9 (C-5′), 73.4, 73.7, 74.1, 76.4 (4 CH_2(Bn)), 78.2 (C-1′), 81.2 (C-4′), 82.3 (C-3′), 82.5 (C-2′), 123.7, 123.8 (C-2, C-5), 133.0, 135.1 (C-3, C-4), 127.9–132.6 (CH(Ar), Cq(Ph)), 140.2–140.8 (Cq(Bn)), 161.2 (2 CO) ppm. IR: $\tilde{\nu}$ = 3282 (NH), 1716 (C=O) cm^{-1}. $[\alpha]_D^{20}$ = +13.6 (*c* = 1.38, $CHCl_3$).

Dimethyl (1′*S*,2′*S*,3′*R*,4′*R*)-3-(1′,2′,3′,4′,5′-Pentabenzoxypentyl)-4-phenyl-1*H*-pyrrole-2,5-dicarboxylate [40-(1′*S*)]: This compound was synthesized according to procedure E. Pyridazine **33-(1′*S*)** (1.13 g, 1.29 mmol) and zinc (1.70 g, 25.90 mmol) in acetic acid (15 mL) afforded **40-(1′*S*)** (661 mg, 60%) after purification by flash column chromatography on silica gel (petroleum ether/EtOAc, 80:20). Syrup; R_f (petroleum ether/EtOAc, 8:2) = 0.19. ^{1}H NMR (400 MHz, C_6D_6, 328 K): δ = 3.27 (s, 3 H, OMe), 3.39 (s, 3 H, OMe), 3.83 (dd, $J_{5′a,5′b}$ = 10.6, $J_{5′a,4′}$ = 5.3 Hz, 1 H, 5′a-H), 3.92 (dd, $J_{5′b,5′a}$ = 10.6, $J_{5′b,4′}$ = 1.5 Hz, 1 H, 5′b-H), 4.22 (m, 1 H, 4′-H), 4.32–4.46 (m, 5 H, 3′-H, CH_2(Bn)), 4.53–4.68 (m, 6 H, 2′-H, CH_2(Bn)), 4.77 (d, ^2J = 11.5 Hz, 1 H, CH_2(Bn)), 5.56 (d, $J_{1′,2′}$ = 7.9 Hz, 1 H, 1′-H), 7.01–7.44 (m, 30 H, H(Ar)), 9.62 (br. s, 1 H, NH) ppm. ^{13}C NMR (100 MHz, C_6D_6, 328 K): δ = 51.0, 51.3 (2 OMe), 71.6 (CH_2(Bn)), 71.9 (C-5′), 72.6, 73.5, 73.7, 73.8 (4 CH_2(Bn)), 74.3 (C-1′), 79.6 (C-4′), 80.5 (C-3′), 81.3 (C-2′), 122.3, 123.8 (C-2, C-5), 130.0, 134.6 (C-3, C-4), 127.2–131.7 (CH(Ar), Cq(Ph)), 139.5–140.5 (Cq(Bn)), 160.5–160.8 (2 CO) ppm. MS (CI$^+$, NH_3): *m*/*z* (%) = 877 [M + NH_4]$^+$. IR: $\tilde{\nu}$ = 3444 (NH), 1707 (C=O) cm^{-1}. $[\alpha]_{546}^{20}$ = +23.0 (*c* = 0.27, $CHCl_3$). HRMS: calcd. for $C_{54}H_{54}NO_9$ [M + H]$^+$ 860.3799; found 860.3760.

Dimethyl (1′*R*,2′*S*,3′*R*,4′*R*)-4-Butyl-3-(1′,2′,3′,4′,5′-pentabenzoxypentyl)-1*H*-pyrrole-2,5-dicarboxylate [41-(1′*R*)]: This compound was synthesized according to procedure E. From pyridazine **35-(1′*R*)** (1.06 g, 1.24 mmol) and zinc dust (1.62 g, 24.90 mmol) in acetic acid (14 mL), **41-(1′*R*)** (713 mg, 68%) was obtained after purification by flash column chromatography on silica gel (petroleum ether/EtOAc, 80:20). Syrup; R_f (petroleum ether/EtOAc, 7:3) = 0.54. ^{1}H NMR (400 MHz, C_6D_6, 328 K): δ = 0.89 (t, ^3J = 7.2 Hz, 3 H, H_δ(Bu)), 1.41 (m, 2 H, H_γ(Bu)), 1.70 (m, 2 H, H_β(Bu)), 3.12 (m, 2 H, H_α(Bu)), 3.37 (s, 3 H, OMe), 3.46 (s, 3 H, OMe), 3.84 (dd, $J_{5′a,5′b}$ = 10.5, $J_{5′a,4′}$ = 5.6 Hz, 1 H, 5′a-H), 4.01–4.06 (m, 2 H, 3′-H, 5′b-H), 4.16 (m, 1 H, 4′-H), 4.35–4.47 (m, 3 H, CH_2(Bn)), 4.55–4.68 (m, 5 H, CH_2(Bn), 2′-H), 4.77 (d, ^2J = 11.6 Hz, 1 H, CH_2(Bn)), 4.85–5.00 (m, 2 H, CH_2(Bn)), 5.82 (d, $J_{1′,2′}$ = 7.9 Hz, 1 H, 1′-H), 7.06–7.42 (m, 25 H, H(Ar)), 9.32 (br. s, 1 H, NH) ppm. ^{13}C NMR (100 MHz, C_6D_6, 328 K): δ = 13.9 (C_δ(Bu)), 23.6 (C_γ(Bu)), 26.3 (C_α(Bu)), 33.8 (C_β(Bu)), 50.9, 51.2 (2 OMe), 72.2 (C-5′), 72.3, 73.0, 73.3, 73.7, 75.8 (5CH_2(Bn)), 77.5 (C-1′), 80.6 (C-4′), 81.2 (C-3′), 83.7 (C-2′), 122.8, 122.9 (C-2, C-5), 134.8 (C-3 or C-4), 127.3–128.5 (C-3 or C-4, CH(Ar)), 139.6–140.2 (Cq(Bn)), 160.6, 160.8 (2 CO) ppm. MS (CI$^+$, NH_3): *m*/*z* (%) = 857 [M + NH_4]$^+$. IR: $\tilde{\nu}$ = 3449 (NH), 1710 (C=O) cm^{-1}. $[\alpha]_{578}^{20}$ = +10.9 (*c* = 0.41, $CHCl_3$).

Dimethyl (1′*S*,2′*S*,3′*R*,4′*R*)-4-Butyl-3-(1′,2′,3′,4′,5′-pentabenzoxypentyl)-1*H*-pyrrole-2,5-dicarboxylate [41-(1′*S*)]: This compound

was synthesized according to procedure E. Pyridazine **35-(1′*S*)** (478 mg, 0.56 mmol) and zinc (733 mg, 11.21 mmol) in acetic acid (6 mL), afforded **41-(1′*S*)** (309 mg, 60%) after purification by flash column chromatography on silica gel (petroleum ether/EtOAc, 80:20). Syrup; R_f (petroleum ether/EtOAc, 7:3) = 0.45. ^{1}H NMR (400 MHz, C_6D_6, 328 K): δ = 0.89 (t, ^3J = 7.3 Hz, 3 H, H_δ(Bu)), 1.41 (m, 2 H, H_γ(Bu)), 1.70 (m, 2 H, H_β(Bu)), 2.88–3.16 (m, 2 H, H_α(Bu)), 3.39 (s, 3 H, OMe), 3.47 (s, 3 H, OMe), 3.93 (dd, $J_{5'a,5'b}$ = 10.7, $J_{5'a,4'}$ = 5.6 Hz, 1 H, 5′a-H), 4.05 (dd, $J_{5'b,5'a}$ = 10.7, $J_{5'b,4'}$ = 1.9 Hz, 1 H, 5′b-H), 4.29 (d, ^2J = 11.7 Hz, 1 H, CH_2(Bn)), 4.40–4.47 (m, 4 H, CH_2(Bn), 3′-H, 4′-H), 4.54–4.61 (m, 4 H, CH_2(Bn), 2′-H), 4.76–4.88 (m, 3 H, CH_2(Bn)), 5.03 (d, ^2J = 11.7 Hz, 1 H, CH_2(Bn)), 5.82 (d, $J_{1',2'}$ = 9.1 Hz, 1 H, 1′-H), 6.99–7.43 (m, 25 H, H(Ar)), 9.37 (br. s, 1 H, NH) ppm. ^{13}C NMR (100 MHz, C_6D_6, 328 K): δ = 14.0 (C_δ(Bu)), 23.6 (C_γ(Bu)), 25.9 (C_α(Bu)), 34.0 (C_β(Bu)), 50.9, 51.1 (2 OMe), 71.9, 72.1 (CH_2(Bn), C-5′), 72.7, 73.7, 73.8, 74.1 (4 CH_2(Bn)), 74.7 (C-1′), 79.9, 80.7 (C-3′, C-4′), 82.0 (C-2′), 122.2, 123.9 (C-2, C-5), 129.0, 134.5 (C-3, C-4), 127.4–128.5 (CH(Ar)), 139.2–140.3 (Cq(Bn)), 160.7 (2 CO) ppm. MS (CI$^+$, NH_3): *m*/*z* = 857 [M + NH_4]$^+$. IR: $\tilde{\nu}$ = 3451 (NH), 1713, 1697 (C=O) cm^{-1}. $[\alpha]_{365}^{20}$ = –23.3 (*c* = 0.64, $CHCl_3$). $C_{52}H_{57}NO_9 \cdot 0.5H_2O$ (849.02): C 73.56, H 6.89, N 1.65; found C 73.73, H 6.76, N 1.29.

Dimethyl (1′*R*,2′*S*,3′*R*,4′*R*)-3-(2′,3′,5′-Tribenzoxy-1′,4′-dihydroxypentyl)-4-phenyl-1*H*-pyrrole-2,5-dicarboxylate [42-(1′*R*)]: This compound was obtained as a byproduct (<10%) during the synthesis of **40-(1′*R*)**. Syrup; R_f (petroleum ether/EtOAc, 7:3) = 0.13. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 3.31 (m, 1 H, 3′-H), 3.41 (d, $J_{5',4'}$ = 5.2 Hz, 2 H, 5′-H), 3.69 (s, 3 H, OMe), 3.85 (s, 3 H, OMe), 3.92 (t, ^3J = 6.4 Hz, 1 H, 2′-H), 4.07 (m, 1 H, 4′-H), 4.32–4.39 (m, 3 H, CH_2(Bn)), 4.50–4.52 (m, 3 H, CH_2(Bn)), 5.43 (d, $J_{1',2'}$ = 6.4 Hz, 1 H, 1′-H), 7.12–7.35 (m, 20 H, H(Ar)), 9.83 (br. s, 1 H, NH) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 51.8, 52.1 (2 OMe), 70.2 (C-5′), 71.9, 72.1, 73.4 (3 CH_2(Bn)), 77.6 (C-1′), 77.8 (C-3′), 79.4 (C-2′), 81.1 (C-4′), 121.8, 122.8 (C-2, C-5), 132.7, 133.2 (C-3, C-4), 127.1–131.3 (CH(Ar), Cq(Ph)), 138.1–138.4 (Cq(Bn)), 160.5 (2 CO) ppm. MS (CI$^+$, NH_3): *m*/*z* = 679 [M + H – H_2O]$^+$. IR: $\tilde{\nu}$ = 3436 (NH), 3285 (OH), 1725, 1711 (C=O) cm^{-1}. $[\alpha]_{365}^{20}$ = +15.3 (*c* = 0.61, $CHCl_3$).

Dimethyl (1′*R*,2′*S*,3′*R*,4′*R*)-4-Butyl-3-(2′,3′,5′-tribenzoxy-1′,4′-dihydroxypentyl)-1*H*-pyrrole-2,5-dicarboxylate [43-(1′*R*)]: This compound was obtained as a byproduct (<10%) during the synthesis of **41-(1′*R*)**. Solid; m.p. 83–85 °C; R_f (petroleum ether/EtOAc, 7:3) = 0.26. ^{1}H NMR (400 MHz, C_6D_6, 328 K): δ = 0.94 (t, ^3J = 7.3 Hz, 3 H, H_δ(Bu)), 1.40 (m, 2 H, H_γ(Bu)), 1.60–1.86 (m, 2 H, H_β(Bu)), 2.95 (m, 1 H, H_α(Bu)), 3.13 (m, 1 H, H_α(Bu)), 3.36 (s, 3 H, OMe), 3.43 (s, 3 H, OMe), 3.70 (dd, $J_{5'a,5'b}$ = 10.4, $J_{5'a,4'}$ = 4.7 Hz, 1 H, 5′a-H), 3.77 (dd, $J_{5'b,5'a}$ = 10.4, $J_{5'b,4'}$ = 5.0 Hz, 1 H, 5′b-H), 4.25 (m, 1 H, 3′-H), 4.36–4.48 (m, 5 H, CH_2(Bn), 2′-H, 4′-H), 4.53 (d, ^2J = 11.5 Hz, 1 H, CH_2(Bn)), 4.64 (d, ^2J = 12.0 Hz, 1 H, CH_2(Bn)), 4.74 (d, ^2J = 12.0 Hz, 1 H, CH_2(Bn)), 5.86 (d, $J_{1',2'}$ = 7.8 Hz, 1 H, 1′-H), 7.03–7.39 (m, 15 H, H(Ar)), 9.33 (br. s, 1 H, NH) ppm. ^{13}C NMR (100 MHz, C_6D_6, 328 K): δ = 14.1 (C_δ(Bu)), 23.3 (C_γ(Bu)), 25.4 (C_α(Bu)), 34.5 (C_β(Bu)), 50.9, 51.2 (2 OMe), 71.3 (C-5′), 72.7, 72.8, 73.8 (3 CH_2(Bn)), 77.1 (C-1′), 79.2 (C-3′), 82.7 (C-2′), 83.0 (C-4′), 122.1, 123.0 (C-2, C-5), 134.3 (C-3 or C-4), 127.4–128.6 (C-3 or C-4, CH(Ar)), 139.3–139.5 (Cq(Bn)), 160.4, 160.6 (2 CO) ppm. MS (CI$^+$, NH_3): *m*/*z* = 642 [M + H – H_2O]$^+$. IR: $\tilde{\nu}$ = 3267 (NH + OH), 1711, 1687 (C=O) cm^{-1}. $[\alpha]_{365}^{20}$ = +28.0 (*c* = 0.49, $CHCl_3$).

Dimethyl 4-Phenyl-3-(2′,3′,5′-tri-*O*-benzyl-α-D-ribofuranosyl)-1*H*-pyrrole-2,5-dicarboxylate (44): This compound was synthesized according to procedure E from pyridazine **36** (188 mg, 0.28 mmol) and zinc dust (362 mg, 5.58 mmol) in glacial acetic acid (3 mL). Chromatographic purification on silica gel (petroleum ether/EtOAc, 8:2) gave compound **44** (184 mg, 56%). Syrup; R_f (petroleum ether/EtOAc, 7:3) = 0.53. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.31 (m, 2 H, 5′-H), 3.42 (m, 1 H, 4′-H), 3.65 (s, 3 H, OMe), 3.81 (s, 3 H, OMe), 4.22–4.31 (dd, $J_{3',2'}$ = 9.7, $J_{3',4'}$ = 4.1 Hz, 1 H, 3′-H), 4.22–4.31 (m, 3 H, CH_2(Bn), 2′-H), 4.36–4.40 (m, 2 H, CH_2(Bn)), 4.47–4.55 (m, 2 H, CH_2(Bn)), 5.66 (d, $J_{1',2'}$ = 5.7 Hz, 1 H, 1′-H), 7.01 (m, 2 H, H(Ar)), 7.18–7.32 (m, 18 H, H(Ar)), 9.64 (br. s, 1 H, NH) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 51.8, 51.9 (2 OMe), 70.0 (C-5′), 72.8, 73.1, 73.4 (3 CH_2(Bn)), 77.3 (C-2′), 77.9 (C-4′), 78.4 (C-1′), 79.5 (C-3′), 120.3, 122.3 (C-2, C-5), 128.9, 132.9, 134.9 (C-3, C-4, Cq(Ph)), 126.6–132.9 (CH(Ar)), 138.0–138.3 (Cq(Bn)), 160.4, 160.9 (2 CO) ppm. MS (CI$^+$, NH_3): *m*/*z* (%) = 662 [M + H]$^+$.

Dimethyl 3-(2′,3′,4′,6′-Tetra-*O*-benzyl-α-D-galactopyranosyl)-4-phenyl-1*H*-pyrrole-2,5-dicarboxylate (45): This compound was synthesized according to procedure E from pyridazine **37** (188 mg, 0.24 mmol) and zinc dust (196 mg, 3.00 mmol) in glacial acetic acid (2 mL). Chromatographic purification on silica gel (petroleum ether/EtOAc, 7:2) gave compound **45** (129 mg, 70%). Yellow syrup; (petroleum ether/EtOAc, 7:3) = 0.47. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.56 (s, 3 H, OMe), 3.61 (s, 3 H, OMe), 3.61 (m, 2 H, 6′-H), 3.66 (m, 2 H, 2′-H, 3′-H), 3.80 (m, 1 H, 4′-H), 3.88 (m, 1 H, 5′-H), 4.06 (d, ^2J = 12.1 Hz, 1 H, CH_2(Bn)), 4.23 (d, ^2J = 12.1 Hz, 1 H, CH_2(Bn)), 4.32 (d, ^2J = 11.5 Hz, 1 H, CH_2(Bn)), 4.36 (d, ^2J = 11.5 Hz, 1 H, CH_2(Bn)), 4.40 (s, 2 H, CH_2(Bn)), 4.48 (s, 2 H, CH_2(Bn)), 5.40 (d, $J_{1',2'}$ = 1.3 Hz, 1 H, 1′-H), 6.83–7.27 (m, 25 H, H(Ar)), 9.50 (s, 1 H, NH) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 51.0 (2 OMe), 65.6 (C-6′), 66.7 (C-1′), 71.8, 72.3, 72.7, 72.9 (4 CH_2(Bn)), 73.5 (C-4′), 74.8 (C-5′), 75.5, 77.2 (C-2′, C-3′), 120.8, 121.9 (C-2, C-5), 126.4–130.5 (CH(Ar), Cq(Ph)), 133.0, 135.2 (C-3, C-4), 138.1–138.8 (Cq(Bn)), 161.0–162.0 (2 CO) ppm. MS (CI$^+$, NH_3): *m*/*z* = 782 [M + H]$^+$. $[\alpha]_D^{20}$ = –19.7 (*c* = 0.5, $CHCl_3$).

Dimethyl 3-(6′-*O*-Acetyl-2′,3′,4′tri-*O*-benzyl-α-D-galactopyranosyl)-4-phenyl-1*H*-pyrrole-2,5-dicarboxylate (46): This compound was synthesized according to procedure E from pyridazine **38** (146 mg, 0.19 mmol) and zinc dust (254 mg, 3.90 mmol) in glacial acetic acid (1.5 mL). Chromatographic purification on silica gel (petroleum ether/EtOAc, 6:4) gave compound **46** (81 mg, 57%). Syrup; R_f (petroleum ether/EtOAc, 8:2) = 0.41. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.92 (s, 3 H, Me(OAc)), 3.59 (s, 3 H, OMe), 3.61 (s, 3 H, OMe), 3.67 (m, 2 H, 2′-H, 4′-H or 3′-H), 3.79 (m, 2 H, 5′-H, 4′-H or 3′-H), 4.03 (d, ^2J = 12.1 Hz, 1 H, CH_2(Bn)), 4.17 (m, 2 H, CH_2(Bn), 6′a-H), 4.37 (d, ^2J = 11.7 Hz, 1 H, CH_2(Bn)), 4.43 (d, ^2J = 11.7 Hz, 1 H, CH_2(Bn)), 4.51 (s, 2 H, CH_2(Bn)), 4.65 (dd, $J_{6'b,6'a}$ = 12.8, $J_{6'b,5'}$ = 8.8 Hz, 1 H, 6′b-H), 5.48 (d, $J_{1',2'}$ = 1.8 Hz, 1 H, 1′-H), 6.82 (m, 2 H, H(Ar)), 7.01–7.27 (m, 18 H, H(Ar)), 9.55 (s, 1 H, NH) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 21.2 (Me(OAc)), 51.8 (2 OMe), 60.7 (C-6′), 66.2 (C-1′), 71.5, 72.8, 78.8 (3 CH_2(Bn)), 73.1 (C-4′), 73.2 (C-3′), 74.2 (C-2′), 76.5 (C-5′), 120.8, 121.8 (C-2, C-5), 126.4–130.4 (CH(Ar), Cq(Ph)), 132.8, 135.2 (C-3, C-4), 137.9, 138.4, 138.5 (Cq(Bn)), 160.4, 160.8 (2 CO-(CO_2Me)), 171.2 (CO(OAc)) ppm. MS (CI$^+$, NH_3): *m*/*z* = 734 [M + H]$^+$.

Dimethyl 3-(2′,3′,4′,6′-Tetra-*O*-benzyl-α-D-glucopyranosyl)-4-phenyl-1*H*-pyrrole-2,5-dicarboxylate (47): This compound was synthesized according to procedure E from pyridazine **39** (60 mg, 0.07 mmol) and zinc dust (100 mg, 1.51 mmol) in glacial acetic acid (1 mL). Chromatographic purification on silica gel (petroleum ether/EtOAc, 7:3) gave compound **47** (16 mg, 27%). Syrup; R_f (petroleum ether/EtOAc, 8:2) = 0.27. ^{1}H NMR (300 MHz, $CDCl_3$): δ

= 2.50 (dd, $J_{6'a,6'b}$ = 10.8, $J_{6'a,5'}$ = 2.1 Hz, 1 H, 6′a-H), 3.20 (dd, $J_{6'b,6'a}$ = 10.8, $J_{6'b,5'}$ = 2.1 Hz, 1 H, 6′b-H), 3.45 (m, 1 H, 5′-H), 3.56 (s, 3 H, OMe), 3.59 (s, 3 H, OMe), 3.70 (m, 1 H, 3′-H), 3.79 (m, 1 H, 4′-H), 3.90 (m, 1 H, 2′-H), 4.33–4.60 (m, 8 H, CH_2(Bn)), 5.56 (d, $J_{1',2'}$ = 3.0 Hz, 1 H, 1′-H), 6.91–7.16 (m, 25 H, H(Ar)), 9.61 (s, 1 H, NH) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 52.9 (2 OMe), 60.0 (C-6′), 70.2 (C-1′), 71.3, 71.9 (2 CH_2(Bn)), 72.3 (C-5′), 72.8, 73.4 (2 CH_2(Bn)), 77.3 (C-2′), 78.2 (C-4′), 80.9 (C-3′), 120.1, 122.2 (C-2, C-5), 126.4–130.2 (CH(Ar), Cq(Ph)), 132.6, 135.7 (C-3, C-4), 137.7–138.6 (Cq(Bn)), 160.4, 160.9 (2 CO) ppm. MS (CI^+, NH_3): m/z = 782 $[M + H]^+$.

Procedure F − Debenzylation of Pyrroles: A solution of benzylated pyrrole in MeOH was hydrogenated at room temperature over Pd/C (100% w/w) for 1 h under a slight overpressure of hydrogen. The mixture was then filtered trough a bed of Celite and the solvent was removed under reduced pressure.

Dimethyl (1′*R*,2′*S*,3′*R*,4′*R*)-3-(1′,2′,3′,4′,5′-Pentahydroxypentyl)-4-phenyl-1*H*-pyrrole-2,5-dicarboxylate [48-(1′*R*)]: This compound was synthesized according to procedure F. From pyrrole **40-(1′*R*)** (454 mg, 0.54 mmol) and Pd/C (450 mg) in MeOH (5 mL), **48-(1′*R*)** (188 mg, 89%) was obtained. White solid; m.p. 94 °C; R_f (dichloromethane/MeOH, 85:15) = 0.49. ^{1}H NMR (400 MHz, CD_3OD): δ = 3.46 (dd, $J_{5'a,5'b}$ = 11.7, $J_{5'a,4'}$ = 6.0 Hz, 1 H, 5′a-H), 3.52–3.59 (m, 2 H, 5′b-H, 3′-H), 3.65 (s, 4 H, OMe, 4′-H), 3.92 (s, 3 H, OMe), 4.13 (t, ^3J = 6.9 Hz, 1 H, 2′-H), 5.06 (d, $J_{1',2'}$ = 6.9 Hz, 1 H, 1′-H), 7.32–7.38 (m, 5 H, H(Ph)) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 51.9, 52.4 (2 OMe), 63.8 (C-5′), 72.4 (C-3′), 75.2 (C-2′), 79.6 (C-1′), 86.2 (C-4′), 123.5, 124.3 (C-2, C-5), 134.0 135.3 (C-3, C-4), 128.2–132.2 (CH(Ph), Cq(Ph)), 162.3 (2 CO) ppm. MS (CI^+, NH_3): m/z (%) = 392 $[M + H – H_2O]^+$. IR: $\tilde{\nu}$ = 3427 (NH + OH), 1709 (C=O) cm^{-1}. $[\alpha]_D^{20}$ = –12.3 (c = 1.50, MeOH)

Dimethyl (1′*S*,2′*S*,3′*R*,4′*R*)-3-(1′,2′,3′,4′,5′-Pentahydroxypentyl)-4-phenyl-1*H*-pyrrole-2,5-dicarboxylate [48-(1′*S*)]: This compound was synthesized according to procedure F. From pyrrole **40-(1′*S*)** (300 mg, 0.35 mmol) and Pd/C (300 mg) in MeOH (3 mL), **48-(1′*S*)** (140 mg, 98%) was obtained. White solid; m.p. 86 °C; R_f (dichloromethane/MeOH, 85:15) = 0.60. ^{1}H NMR (400 MHz, CD_3OD): δ = 3.57 (dd, $J_{5'a,5'b}$ = 11.2, $J_{5'a,4'}$ = 5.8 Hz, 1 H, 5′a-H), 3.64 (s, 3 H, OMe), 3.68 (dd, $J_{5'b,5'a}$ = 11.2, $J_{5'b,4'}$ = 3.4 Hz, 1 H, 5′b-H), 3.74–3.82 (m, 2 H, 3′-H, 4′-H), 3.95 (s, 3 H, OMe), 4.03 (dd, $J_{2',1'}$ = 8.9, $J_{2',3'}$ = 5.0 Hz, 1 H, 2′-H), 4.86 (d, $J_{1',2'}$ = 8.9 Hz, 1 H, 1′-H), 7.26–7.38 (m, 5 H, H(Ph)) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 51.9, 52.8 (2 OMe), 64.2 (C-5′), 69.6 (C-1′), 73.9 (C-4′), 75.0 (C-2′), 75.8 (C-3′), 123.2, 123.4 (C-2, C-5), 132.7, 133.7, 135.1 (C-3, C-4, Cq(Ph)), 128.2–132.0 (CH(Ph)), 162.3, 163.7 (2 CO) ppm. MS (CI^+, NH_3): m/z = 410 $[M + H]^+$. IR: $\tilde{\nu}$ = 3353 (NH + OH), 1685 (C=O) cm^{-1}. $[\alpha]_{436}^{20}$ = –12.3 (c = 2.14, MeOH).

Dimethyl (1′*R*,2′*S*,3′*R*,4′*R*)-4-Butyl-3-(1′,2′,3′,4′,5′-pentahydroxypentyl)-1*H*-pyrrole-2,5-dicarboxylate [49-(1′*R*)]: This compound was synthesized according to procedure F. From pyrrole **41-(1′*R*)** (735 mg, 0.88 mmol) and Pd/C (740 mg) in MeOH (7 mL), **49-(1′*R*)** (290 mg, 85%) was obtained. Syrup; R_f (dichloromethane/MeOH, 85:15) = 0.52. ^{1}H NMR (400 MHz, CD_3OD): δ = 0.94 (t, ^3J = 7.3 Hz, 3 H, H_δ(Bu)), 1.36–1.45 (m, 2 H, H_γ(Bu)), 1.47–1.56 (m, 2 H, H_β(Bu)), 2.74 (m, 1 H, H_α(Bu)), 2.87 (m, 1 H, H_α(Bu)), 3.64–3.69 (m, 2 H, 2′-H, 5′a-H), 3.74–3.83 (m, 3 H, 3′-H, 4′-H, 5′b-H), 3.87 (s, 3 H, OMe), 3.92 (s, 3 H, OMe), 5.26 (d, $J_{1',2'}$ = 2.8 Hz, 1 H, 1′-H) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 14.2 (C_δ(Bu)), 23.7 (C_γ(Bu)), 25.4 (C_α(Bu)), 34.5 (C_β(Bu)), 52.0, 52.9 (2 OMe), 64.3 (C-5′), 68.4 (C-1′), 73.3 (C-3′), 74.2 (C-4′), 77.7 (C-2′), 123.0, 123.2 (C-2, C-5), 132.4, 132.5 (C-3, C-4), 162.3, 164.0 (2 CO) ppm. IR: $\tilde{\nu}$ = 3416 (NH + OH), 1692 (C=O) cm^{-1}. $[\alpha]_D^{20}$ = +8.2 (c = 1.50, MeOH). HRMS: calcd. for $C_{17}H_{28}NO_9$ $[M + H]^+$ 390.1743; found 390.1764.

Dimethyl (1′*S*,2′*S*,3′*R*,4′*R*)-4-Butyl-3-(1′,2′,3′,4′,5′-pentahydroxypentyl)-1*H*-pyrrole-2,5-dicarboxylate [49-(1′*S*)]: This compound was synthesized according to procedure F. From pyrrole **41-(1′*S*)** (309 mg, 0.37 mmol) and Pd/C (310 mg) in MeOH (3 mL), **49-(1′*S*)** (136 mg, 95%) was obtained. Syrup; R_f (dichloromethane/MeOH, 86:14) = 0.47. ^{1}H NMR (300 MHz, CD_3OD): δ = 0.95 (t, 3 H, H_δ(Bu), ^3J = 7.2), 1.34–1.62 (m, 4 H, H_β(Bu), H_γ(Bu)), 2.77–2.95 (m, 2 H, H_α(Bu)), 3.66 (dd, $J_{5'a,5'b}$ = 11.2, $J_{5'a,4'}$ = 6.1 Hz, 1 H, 5′a-H), 3.78–3.84 (m, 2 H, 3′-H, 5′b-H), 3.87 (s, 3 H, OMe), 3.91–3.96 (m, 4 H, 4′-H, OMe), 4.02 (dd, $J_{2',1'}$ = 8.1, $J_{2',3'}$ = 5.5 Hz, 1 H, 2′-H), 5.15 (d, $J_{1',2'}$ = 8.1 Hz, 1 H, 1′-H) ppm. ^{13}C NMR (75 MHz, CD_3OD): δ = 14.3 (C_δ(Bu)), 23.9 (C_γ(Bu)), 25.6 (C_α(Bu)), 34.7 (C_β(Bu)), 52.0, 52.7 (2 OMe), 64.1 (C-5′), 69.5 (C-1′), 73.8 (C-4′), 75.3 (C-3′), 76.0 (C-2′), 123.0, 123.1 (C-2, C-5), 132.3, 134.4 (C-3, C-4), 162.5, 163.9 (2 CO) ppm. IR: $\tilde{\nu}$ = 3350 (NH + OH), 1686 (C=O) cm^{-1}. $[\alpha]_{436}^{20}$ = –31.0 (c = 1.35, MeOH).

Procedure G − Lactonization: Na_2CO_3 (1 equiv.) was added to a solution of pyrrole (1 equiv.) in MeOH. The mixture was stirred for 1 h at room temperature and filtered trough a pad of Celite. After concentration, the crude was purified by preparative TLC (CH_2Cl_2/MeOH, 88:12).

Methyl (4*R*,5*S*,1′*R*,2′*R*)-4-Hydroxy-7-oxo-3-phenyl-5-(1′,2′,3′-trihydroxypropyl)-1,4,5,7-tetrahydropyrano[3,4-*b*]pyrrole-2-carboxylate [50-(4*R*)]: This compound was synthesized according to procedure G. From pyrrole **48-(1′*R*)** (90 mg, 0.22 mmol) in MeOH (3 mL), **50-(4*R*)** (41 mg, 49%) was obtained. White solid; m.p. 125 °C; R_f (dichloromethane/MeOH, 85:15) = 0.39. ^{1}H NMR (400 MHz, CD_3OD): δ = 3.72 (dd, $J_{3'a,3'b}$ = 11.5, $J_{3'a,2'}$ = 6.5 Hz, 1 H, 3′a-H), 3.77 (s, 3 H, OMe), 3.81 (dd, $J_{3'b,3'a}$ = 11.5, $J_{3'b,2'}$ = 3.9 Hz, 1 H, 3′b-H), 3.95 (m, 1 H, 2′-H), 4.17 (dd, $J_{1',5}$ = 7.7, $J_{1',2'}$ = 4.7 Hz, 1 H, 1′-H), 4.59 (dd, $J_{5,1'}$ = 7.7, $J_{5,4}$ = 1.9 Hz, 1 H, 5-H), 4.79 (d, $J_{4,5}$ = 1.9 Hz, 1 H, 4-H), 7.31–7.53 (m, 5 H, H(Ph)) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 52.1 (OMe), 60.9 (C-4), 64.0 (C-3′), 72.1 (C-1′), 73.8 (C-2′), 84.3 (C-5), 122.1, 125.8 (C-2, C-5), 129.8, 131.9, 133.9 (C-3, C-4, Cq(Ph)), 128.5–131.3 (CH(Ph)), 160.7, 162.4 (2 CO) ppm. IR: $\tilde{\nu}$ = 3420 (NH + OH), 1720 (C=O) cm^{-1}. $[\alpha]_D^{20}$ = –31.3 (c = 2.05, MeOH). HRMS: calcd. for $C_{18}H_{20}NO_8$ $[M + H]^+$ 378.1189; found 378.1174.

Methyl (4*S*,5*S*,1′*R*,2′*R*)-4-Hydroxy-7-oxo-3-phenyl-5-(1′,2′,3′-trihydroxypropyl)-1,4,5,7-tetrahydropyrano[3,4-*b*]pyrrole-2-carboxylate [50-(4*S*)]: This compound was synthesized according to procedure G. From pyrrole **48-(1′*S*)** (400 mg, 0.98 mmol) in MeOH (5 mL), **50-(4*S*)** (178 mg, 48%) was obtained after purification by preparative TLC. White needles; m.p. 142 °C; R_f (dichloromethane/MeOH, 85:15) = 0.46. ^{1}H NMR (400 MHz, CD_3OD): δ = 3.63–3.75 (m, 7 H, 1′-H, 2′-H, 3′-H, OMe), 4.83 (dd, $J_{5,1'}$ = 7.5, $J_{5,4}$ = 1.6 Hz, 1 H, 5-H), 4.99 (d, $J_{4,5}$ = 1.6 Hz, 1 H, 4-H), 7.32–7.53 (m, 5 H, H(Ph)) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 52.1 (OMe), 61.2 (C-4), 64.1 (C-3′), 73.2 (C-1′), 73.9 (C-2′), 89.1 (C-5), 121.8, 125.5 (C-2, C-5), 129.9, 132.1, 134.0 (C-3, C-4, Cq(Ph)), 128.2–131.3 (CH(Ph)), 159.9, 162.4 (2 CO) ppm. IR: $\tilde{\nu}$ = 3439 (NH + OH), 1727, 1700 (2 C=O) cm^{-1}. $[\alpha]_D^{20}$ = +53.2 (c = 1.68, MeOH). HRMS: calcd. for $C_{18}H_{19}NO_8Na$ $[M + Na]^+$ 400.1008; found 400.1009.

Methyl (4*R*,5*S*,1′*R*,2′*R*)-3-Butyl-4-hydroxy-7-oxo-5-(1′,2′,3′-trihydroxypropyl)-1,4,5,7-tetrahydropyrano[3,4-*b*]pyrrole-2-carboxylate [51-(4*R*)]: This compound was synthesized according to procedure G. From pyrrole **49-(1′*R*)** (197 mg, 0.51 mmol) in MeOH (2 mL), **51-(4*R*)** (69 mg, 38%) was obtained after purification by preparative TLC. Syrup; R_f (dichloromethane/MeOH, 88:12) = 0.28. ^{1}H NMR (400 MHz, CD_3OD): δ = 0.94 (t, ^3J = 7.3 Hz, 3 H, H_δ(Bu)),

1.40 (m, 2 H, H_γ(Bu)), 1.50–1.67 (m, 2 H, H_β(Bu)), 2.85 (m, 2 H, H_α(Bu)), 3.74 (dd, $J_{3'a,3'b}$ = 11.5, $J_{3'a,2'}$ = 6.6 Hz, 1 H, 3′a-H), 3.83 (dd, $J_{3'b,3'a}$ = 11.5, $J_{3'b,2'}$ = 4.0 Hz, 1 H, 3′b-H), 3.87 (s, 3 H, OMe), 4.00 (m, 1 H, 2′-H), 4.19 (dd, $J_{1',5}$ = 7.9, $J_{1',2'}$ = 4.6 Hz, 1 H, 1′-H), 4.56 (dd, $J_{5,1'}$ = 7.9, $J_{5,4}$ = 2.1 Hz, 1 H, 5-H), 5.00 (d, $J_{4,5}$ = 2.1 Hz, 1 H, 4-H) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 14.2 (C_δ(Bu)), 23.7 (C_γ(Bu)), 25.3 (C_α(Bu)), 34.3 (C_β(Bu)), 52.1 (OMe), 60.7 (C-4), 63.9 (C-3′), 72.1 (C-1′), 73.8 (C-2′), 84.1 (C-5), 121.5, 126.2 (C-2, C-5), 130.8, 131.8 (C-3, C-4), 160.7, 162.5 (2 CO) ppm. IR: $\tilde{\nu}$ = 3491 (NH + OH), 1715 (C=O) cm^{-1}. $[\alpha]_D^{20}$ = +21.2 (c = 1.65, MeOH). HRMS: calcd. for $C_{16}H_{24}NO_8$ $[M + H]^+$ 358.1502; found 358.1490.

Methyl (4*S*,5*S*,1′*R*,2′*R*)-3-Butyl-4-hydroxy-7-oxo-5-(1′,2′,3′-trihydroxypropyl)-1,4,5,7-tetrahydropyrano[3,4-*b*]pyrrole-2-carboxylate [51-(4*S*)]: This compound was synthesized according to procedure G. From pyrrole **49-(1′*S*)** (110 mg, 0.28 mmol) in MeOH (2 mL), **51-(4*S*)** (73 mg, 72%) was obtained after purification by preparative TLC. Syrup; R_f (dichloromethane/MeOH, 86:14) = 0.37. ^{1}H NMR (400 MHz, CD_3OD): δ = 0.95 (t, ^3J = 7.3 Hz, 3 H, H_δ(Bu)), 1.40 (m, 2 H, H_γ(Bu)), 1.56–1.62 (m, 2 H, H_β(Bu)), 2.86 (t, ^3J = 7.8 Hz, 2 H, H_α(Bu)), 3.68–3.88 (m, 7 H, 1′-H, 2′-H, 3′-H, OMe), 4.79 (dd, $J_{5,1'}$ = 6.6, $J_{5,4}$ = 3.0 Hz, 1 H, 5-H), 5.20 (d, $J_{4,5}$ = 3.0 Hz, 1 H, 4-H) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 14.2 (C_δ(Bu)), 23.7 (C_γ(Bu)), 25.4 (C_α(Bu)), 34.2 (C_β(Bu)), 52.0 (OMe), 61.6 (C-4), 64.2 (C-3′), 73.2 (C-1′), 73.7 (C-2′), 88.8 (C-5), 121.1, 126.2 (C-2, C-5), 130.3, 131.7 (C-3, C-4), 160.2, 162.7 (2 CO) ppm. IR: $\tilde{\nu}$ = 3357 (NH + OH), 1714 (C=O) cm^{-1}. $[\alpha]_D^{20}$ = +16.0 (c = 1.00, MeOH). HRMS: calcd. for $C_{16}H_{23}NO_8Na$ $[M + Na]^+$ 380.1321; found 380.1325.

General Procedure H − Debenzylation Followed by Saponification of the Ester Groups: A solution of benzylated pyrrole in MeOH in the presence of Pd/C (100% w/w) under H_2 was allowed to stir for 1 h at room temperature. The suspension was filtered through a pad of Celite and the filtrate was evaporated. Aqueous NaOH (0.5 mL, 2 M) was immediately added to the crude debenzylated pyrrole intermediate dissolved in THF (2 mL). After total hydrolysis as monitored by TLC, acidic resin (Dowex 50W*8) was added to neutralize the mixture. Filtration through a pad of Celite and concentration under vacuum gave the diacid. No suitable purification methods were found (silica gel, neutral alumina, reversed phase).

(1′*R*,2′*S*,3′*R*,4′*R*)-3-(1′,2′,3′,4′,5′-Pentahydroxypentyl)-4-phenyl-1*H*-pyrrole-2,5-dicarboxylic Acid [52-(1′*R*)]: This compound was synthesized according to the general procedure H. From pyrrole diester **40-(1′*R*)** (92 mg, 0.105 mmol) in MeOH (3 mL), **52-(1′*R*)** (60 mg) was obtained. Syrup. ^{1}H NMR (300 MHz, CD_3OD): δ = 3.32 (dd, $J_{5'a,5'b}$ = 11.9, $J_{5'a,4'}$ = 4.5 Hz, 1 H, 5′a-H), 3.42 (dd, $J_{5'b,5'a}$ = 11.9, $J_{5'b,4'}$ = 3.4 Hz, 1 H, 5′b-H), 3.55–3.64 (m, 2 H, 3′-H, 4′-H), 4.21 (dd, $J_{2',1'}$ = 7.5, $J_{2',3'}$ = 6.3 Hz, 1 H, 2′-H), 5.09 (d, $J_{1',2'}$ = 7.5 Hz, 1 H, 1′-H), 7.09–7.29 (m, 5 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, CD_3OD): δ = 63.7 (C-5′), 72.5, 86.1 (C-3′, C-4′), 75.8 (C-2′), 80.0 (C-1′), 123.1, 130.0, 138.0 (4 $C_{pyrrole}$), 127.0–132.7 (CH(Ph), Cq(Ph)), 169.1 (2 CO) ppm. IR: $\tilde{\nu}$ = 3350 (NH + OH) cm^{-1}.

(1′*S*,2′*S*,3′*R*,4′*R*)-3-(1′,2′,3′,4′,5′-Pentahydroxypentyl)-4-phenyl-1*H*-pyrrole-2,5-dicarboxylic Acid [52-(1′*S*)]: This compound was synthesized according to the general procedure H. From pyrrole diester **40-(1′*S*)** (155 mg, 0.178 mmol) in MeOH (3 mL), **52-(1′*S*)** (70 mg) was obtained. Syrup. ^{1}H NMR (300 MHz, CD_3OD): δ = 3.51 (dd, $J_{5'a,5'b}$ = 11.1, $J_{5'a,4'}$ = 5.8 Hz, 1 H, 5′a-H), 3.67 (dd, $J_{5'b,5'a}$ = 11.1, $J_{5'b,4'}$ = 3.8 Hz, 1 H, 5′b-H), 3.71–3.80 (m, 2 H, 3′-H, 4′-H), 3.97 (dd, $J_{2',1'}$ = 8.2, $J_{2',3'}$ = 5.1 Hz, 1 H, 2′-H), 4.80 (d, $J_{1',2'}$ = 8.2 Hz, 1 H, 1′-H), 7.28–7.40 (m, 5 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, CD_3OD): δ = 64.0 (C-5′), 69.5 (C-1′), 73.8–75.3 (C-3′, C-4′), 75.7 (C-2′), 123.4, 123.9, 133.4, 135.2 (4 $C_{pyrrole}$), 128.1–132.1 (CH(Ar), Cq(Ph)), 163.3, 164.9 (2 CO) ppm. IR: $\tilde{\nu}$ = 3350 (NH + OH) cm^{-1}.

(1′*R*,2′*S*,3′*R*,4′*R*)-3-Butyl-4-(1′,2′,3′,4′,5′-pentahydroxypentyl)-1*H*-pyrrole-2,5-dicarboxylic Acid [53-(1′*R*)]: This compound was synthesized according to the general procedure H. From pyrrole diester **41-(1′*R*)** (50 mg, 0.060 mmol) in MeOH (3 mL), **53-(1′*R*)** (18 mg) was obtained. Syrup. ^{1}H NMR (300 MHz, CD_3OD): δ = 0.94 (t, ^3J = 7.3 Hz, 3 H, H_δ(Bu)), 1.27–1.63 (m, 4 H, H_γ(Bu), H_β(Bu)), 2.72–2.96 (m, 2 H, H_α(Bu)), 3.69–3.89 (m, 3 H, 4′-H, 5′-H), 4.12 (m, 1 H, 3′-H), 4.31 (m, 1 H, 2′-H), 5.14 (d, $J_{1',2'}$ = 7.7 Hz, 1 H, 1′-H) ppm. ^{13}C NMR (75 MHz, CD_3OD): δ = 14.3 (C_δ(Bu)), 23.9 (C_γ(Bu)), 25.6 (C_α(Bu)), 35.2 (C_β(Bu)), 63.7 (C-5′), 72.5 (C-3′), 76.2 (C-2′), 79.3 (C-1′), 87.0 (C-4′), 120.8, 127.4, 134.7 (4 $C_{pyrrole}$), 163.4, 163.7 (2 CO) ppm. IR: $\tilde{\nu}$ = 3421 (NH + OH), 1678 (C=O) cm^{-1}.

(1′*S*,2′*S*,3′*R*,4′*R*)-3-Butyl-4-(1′,2′,3′,4′,5′-pentahydroxypentyl)-1*H*-pyrrole-2,5-dicarboxylic Acid [53-(1′*S*)]: This compound was synthesized according to the general procedure H. From pyrrole diester **41-(1′*S*)** (40 mg, 0.048 mmol) in MeOH (3 mL), **53-(1′*S*)** (11 mg) was obtained. Syrup. ^{1}H NMR (400 MHz, CD_3OD): δ = 0.93 (t, ^3J = 7.2 Hz, 3 H, H_δ(Bu)), 1.39 (m, 2 H, H_γ(Bu)), 1.55 (m, 2 H, H_β(Bu)), 2.74 (m, 1 H, H_α(Bu)), 2.91 (m, 1 H, H_α(Bu)), 3.68 (dd, $J_{5'a,5'b}$ = 11.1, $J_{5'a,4'}$ = 6.0 Hz, 1 H, 5′a-H), 3.77 (m, 2 H, 3′-H, 5′b-H), 3.91 (m, 1 H, 4′-H), 3.98 (t, ^3J = 6.3 Hz, 1 H, 2′-H), 4.89 (d, $J_{1',2'}$ = 6.9 Hz, 1 H, 1′-H) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 14.4 (C_δ(Bu)), 23.9 (C_γ(Bu)), 25.4 (C_α(Bu)), 34.8 (C_β(Bu)), 64.1 (C-5′), 70.1 (C-1′), 74.2 (C-4′), 75.2 (C-3′), 77.9 (C-2′), 120.6, 128.4, 133.8 (4 $C_{pyrrole}$), 164.5 (2 CO) ppm. IR: $\tilde{\nu}$ = 3421 (NH + OH), 1678 (C=O) cm^{-1}.

(2*R*,3*R*,3a*R*,8b*R*)-7-Methoxycarbonyl-3-hydroxy-2-(hydroxymethyl)-5-oxo-8-phenyl-2,3,3a,5,6,8b-hexahydrofuro[2′,3′:5,6]pyrano[3,4-*b*]pyrrole 54: This compound was synthesized according to procedure F. From pyrrole **44** (86 mg, 0.13 mmol) and Pd/C (110 mg) in methanol (2.5 mL), **54** (39 mg, 78%) was obtained. Syrup; R_f (EtOAc) = 0.41. ^{1}H NMR (400 MHz, CD_3OD): δ = 3.65 (m, 1 H, 5′a-H), 3.76 (s, 3 H, OMe), 3.79 (m, 1 H, 5′b-H), 3.91 (m, 1 H, 4′-H), 4.39 (m, 1 H, 3′-H), 4.92 (m, 1 H, 1′-H), 4.99 (m, 1 H, 2′-H), 7.39–7.17 (m, 5 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 52.2 (OMe), 62.7 (C-5′), 69.2 (C-1′), 73.8 (C-3′), 84.1 (C-4′), 84.9 (C-2′), 121.6, 125.7 (C-2, C-5), 127.6, 130.8, 133.5 (C-3, C-4, Cq(Ph)), 127.6–131.6 (CH(Ar)), 159.2, 162.1 (2 CO) ppm. MS (EI): m/z = 359 $[M]^+$.

(2*R*,3*R*,4*S*,4a*R*,9b*R*)-8-Methoxycarbonyl-3,4-dihydroxy-2-(hydroxymethyl)-6-oxo-9-phenyl-2,3,4,4a,7,9b-hexahydro-2*H*-pyrano[2′,3′:5,6]pyrano[3,4-*b*]pyrrole (55): This compound was synthesized according to procedure F. From pyrrole **45** (52 mg, 0.07 mmol) and Pd/C (50 mg) in methanol (2 mL), **55** (19 mg, 73%) was obtained. White solid; m.p. 145–146 °C; R_f (EtOAc) = 0.49. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.47 (m, 1 H, 6′a-H), 3.59 (dd, $J_{6'b,5'}$ = 5.1, $J_{6'b,6'a}$ = 11.5 Hz, 1 H, 6′b-H), 3.70 (m, 1 H, 5′-H), 3.77 (s, 3 H, OMe), 3.98 (dd, $J_{3',4'}$ = 3.4, $J_{3',2'}$ = 6.1 Hz, 1 H, 3′-H), 4.05 (t, $J_{4',3'}$ = 3.4 Hz, 1 H, 4′-H), 4.60 (dd, $J_{1',2'}$ = 3.6, $J_{2',3'}$ = 6.1 Hz, 1 H, 2′-H), 5.19 (d, $J_{1',2'}$ = 3.6 Hz, 1 H, 1′-H), 7.20–7.40 (m, 5 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 50.8 (OMe), 58.6 (C-6′), 61.6 (C-1′), 66.9 (C-4′), 69.4 (C-3′), 75.6 (C-5′), 81.7 (C-2′), 120.7–132.2 (CH(Ar), 4 $C_{pyrrole}$), 158.3, 160.8 (2 CO) ppm. MS (CI^+, NH_3): m/z = 407 $[M + NH_4]^+$. $[\alpha]_D^{20}$ = +42.0 (c = 0.23, MeOH).

Methyl (2*R*,3*S*,4*S*,4a*R*,9b*R*)-3,4-Dihydroxy-2-(hydroxymethyl)-6-oxo-9-phenyl-2,3,4,4a,7,9b-hexahydro-2*H*-pyrano[2′,3′:5,6]pyrano-[3,4-*b*]pyrrole-8-carboxylate (56): This compound was synthesized according to procedure F. From pyrrole **47** (50 mg, 0.06 mmol) and Pd/C (20%, 50 mg) in methanol (2 mL), **56** (5 mg, 20%) was obtained. Syrup; R_f (EtOAc) = 0.35. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.71 (dd, $J_{6'a,6'b}$ = 11.5, $J_{6'a,5}$ = 2.5 Hz, 1 H, 6′a-H), 3.03 (m, 1 H, 5′-H), 3.36 (m, 1 H, 6′b-H), 3.48 (t, $J_{4',5'} = J_{4',3'}$ = 8.9 Hz, 1 H, 4′-H), 3.74 (s, 3 H, OMe), 3.76 (m, 1 H, 3′-H), 4.42 (dd, $J_{2',3'}$ = 8.4, $J_{2',1'}$ = 6.0 Hz, 1 H, 2′-H), 5.61 (d, $J_{1',2'}$ = 6.0 Hz, 1 H, 1′-H), 7.26–7.40 (m, 5 H, H(Ar)) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 50.8 (OMe), 59.6 (C-6′), 66.6 (C-1′), 68.8 (C-4′), 73.2 (C-3′), 74.8 (C-5′), 81.7 (C-2′), 120.7–132.2 (CH(Ar), 4 $C_{pyrrole}$), 157.8, 160.7 (2 CO) ppm.

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