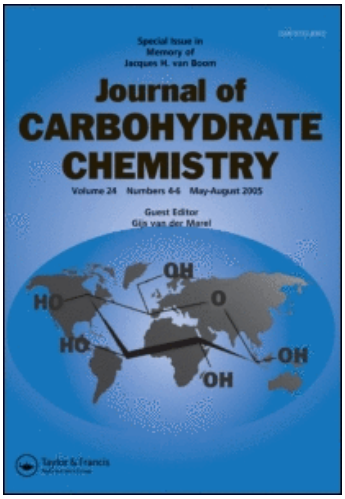

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Versatile Sugar Derivatives for the Synthesis of Potential Degradable Hydrophilic-Hydrophobic Polyurethanes and Polyureas

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Versatile Sugar Derivatives for the Synthesis of Potential Degradable Hydrophilic-Hydrophobic Polyurethanes and Polyureas

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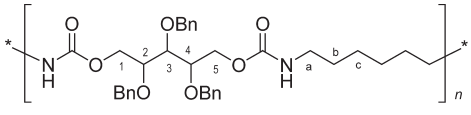
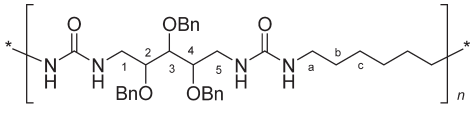
Biodegradable polymers obtained from renewable natural sources are currently receiving increasing attention because they are an alternative to the traditional petroleum-based plastics. In the present communication we describe the synthesis of the diol monomers 2,3,4-tri-*O*-benzyl-L-arabinitol (ABnOH) and 2,3,4-tri-*O*-benzylxylitol (XBnOH), and the diamino monomers 1,5-diamino-1,5-dideoxy-2,3,4-tri-*O*-benzyl-L-arabinitol ($ABnNH_2$) and 1,5-diamino-1,5-dideoxy-2,3,4-tri-*O*-benzylxylitol ($XBnNH_2$), which can be used in the preparation of new potentially biodegradable sugar-based polymers. As an example, we describe the synthesis and characterization of a polyurethane [PU-(ABnOH-HMDI)] and a polyurea [PUR-($ABnNH_2$-HMDI)] by poly addition reaction of ABnOH and $ABnNH_2$ with 1,6-hexamethylene diisocyanate.



PU-(ABnOH-HMDI)



PUR-($ABnNH_2$-HMDI)

Keywords Polyurethanes, Polyureas, Biodegradable polymers, *O*-Benzylalditols, Diaminosugars

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INTRODUCTION

The ever-increasing diversity of industrial activity is responsible for the discharge of compounds that are toxic or difficult to degrade into the environment.[1] Carbohydrates and vegetable oils are considered replacements for some petroleum-based polymer precursors. The use of renewable resources (mainly carbohydrates) in rigid polyurethane and polyurea foams is known to offer several advantages, such as increased strength, improved flame resistance, and enhanced biodegradability.[2,3] A review of the preparation of polyurethanes using natural resources has been provided.[4]

Such polyurethanes are produced as branched and cross-linked materials by combining petroleum-based isocyanate reactants with polyols derived from resources such as plant oils, carbohydrates, wood/lignin, cashew, and cork. Depending on the procedure used to derive them from natural resources, polyols with tunable hydroxyl content can be produced. Bio-based polyurethanes are materials ranging from flexible to rigid, and are thus able to complete with commercially available polyurethanes made from petroleum-based products. Bio-based polyurethane composites are also of interest, since the addition of fibers such as glass or natural lignocellulose (e.g., hemp, jute, flax) may result in improved thermo-mechanical properties. When natural lignocellulose fibers are used, formation of covalent bonds between the fiber and the isocyanate component is possible, with improved interaction between the matrix and the fiber.

Few examples of linear sugar-based polyurethanes are described in the literature. The 2,5-diamino-2,5-dideoxy-1:4,3:6-dianhydrohexitol dihydrochlorides with D-*gluco*, L-*ido*, and D-manno configurations were prepared by Thiem et al. according to known procedures. They developed an initial approach to novel polyurethanes by interfacial polycondensation of these diamino monomers, as well as aliphatic diamines, with the bis(chloroformate) derived from 1,4:3,6-dianhydro-D-sorbitol.[5,6] Catalytic polyaddition of the monomer 2-deoxy-1,4:3,6-dianhydro-2-isocyanato-L-iditol gave the corresponding AB-type polyurethane. A second route required the synthesis of the 2-azido-5-*O*-chloroformyl-1,2-dideoxy-1,4:3,6-dianhydro-L-iditol, which underwent spontaneous polycondensation by catalytic hydrogenation through the 2-amino-5-*O*-chloroformyl derivative.[7] The 2,5-diamino-2,5-dideoxy-1:4,3:6-dianhydrohexitols with D-*gluco*, L-*ido*, and D-*manno* configurations was also transformed into the corresponding diisocyanates by reaction with phosgene.[8] The dithiodiisocyanato derivative was prepared from the diamino-dianhydro-L-*ido*-hexitol and thiophosgene. Polyurethanes and polyureas were synthesized from the D-*gluco*, D-*manno*, and L-*ido* monomers, and poly(thio)urethanes and poly(thio)ureas from the corresponding L-*ido* monomer.[8] Several modified D-glycosylamine and D-glucosamine monomers

were also synthesized by Thiem et al. to carry out catalytic polymerizations leading to polymers with urea and urethane linkages.[9] Garcon et al.[10] have reported the synthesis of two new polyurethanes accomplished by reaction of 1,6-hexamethylene diisocyanate (HMDI) with methyl 2,6-di-*O*-pivaloyl-α-D-glucopyranoside or methyl 4,6-*O*-benzylidene-α-D-glucopyranoside, catalyzed by 1,4-diazabicyclo[2.2.2]octane.

For polyurethane production, Donnelly[11] has carried out the synthesis of copolyurethanes based on mixtures of commercial poly(THF diol)s with glucose. Complex products resulted, which can be represented by mono- or bis(glucoside) structures. From a variety of polyol blends, solid polyurethanes were prepared, which ranged from linear, soluble, weak elastomers to polymers of higher transition temperature and stiffness, low solubility, and low extension under tensile load.[12] These effects are attributable to the rigidity of the glucose unit, which also increases hydrogen bonding and potential for cross-linking. Polymers prepared with the higher levels of the glucoside are able to absorb significant amounts of water, suggesting uses in the biological field.

Polyurethane-polyureas have been prepared using carbohydrates and proteins from biomass.[13] Polyisocyanates (e.g., HMDI) reacted with carbohydrate- and protein-containing biomass (e.g., from baker's yeast) and, optionally, polyols in solution in dimethylsulfoxide (DMSO) or *N*,*N*-dimethyl acetamide (DMA) at $>120^{\circ}C$ to give polyurethane-polyureas that are useful as films, foams, etc. Pectin and related carbohydrates have also been used for the preparation of polyurethane foams.[14]

The synthesis of polyurethane resins derived from polyoxyalkylated arylated carbohydrates was achieved by Prahl and Hart.[15] First, a polyether sugar was prepared by treating an arylated sugar with an alkylene oxide. The polyether was then allowed to react with diisocyanates (such as tolylene diisocyanate) to form polyurethane foams, which have low density, low thermal conditions, and high strength and rigidity.

The preparation and applications of polyurethanes are recorded in many patents and some papers; most of the polyurethanes are used as commodity materials and/or have industrial applications,[16,17] and some of them are biodegradable and/or biocompatible materials.[18–21] Therefore, the biomedical field is one of the areas of greatest interest for their potential applications. The low toxicity, potential biodegradability, biocompatibility,[22] and versatile structures of polyurethanes make them suitable as part of drug administration systems, [23,24] dermatological dressings,[25,26] and hemocompatible materials for catheters (presenting a considerable reduction in their thrombogenic character compared with uncoated polyurethane catheters[27]), and as filters and in biomedical instrumentation and devices.[28–30]

RESULTS AND DISCUSSION

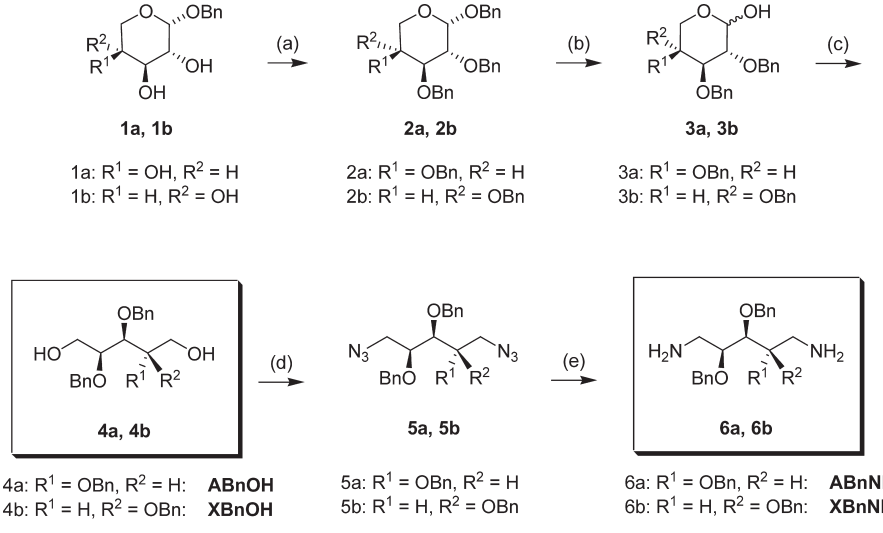
Synthesis and Characterization of the Monomers

The synthesis of the diol monomers 2,3,4-tri-*O*-benzyl-L-arabinitol (ABnOH, **4a**) and 2,3,4-tri-*O*-benzylxylitol (XBnOH, **4b**) and diamino monomers 1,5-diamino-1,5-dideoxy-2,3,4-tri-*O*-benzyl-L-arabinitol ($ABnNH_2$, **6a**) and 1,5-diamino-1,5-dideoxy-2,3,4-tri-*O*-benzylxylitol ($XBnNH_2$, **6b**) was accomplished following the synthetic Scheme 1.

The ^1H NMR and ^{13}C NMR spectra of the different compounds and polymers (polyurethanes and polyureas) were elucidated with the aid of other NMR experiments, such as COSY, DEPT, heteronuclear correlation, etc.

In the present study, the naturally occurring aldopentoses L-arabinose and D-xylose have been selected for several reasons. Firstly, they are natural, cheap, commercially available carbohydrates. Secondly, the reduction of their hemiacetal derivatives **3a** and **3b** will lead to the diols **4a** and **4b**, respectively, which differ only in the absolute configuration on one stereocenter. This particular feature could have important consequences in the physical properties (crystallinity, solubility, stiffness, degradability, etc.) of their polymeric-based materials synthesized.

There have been some attempts at using copolyurethanes and/or polyureas as drug delivery systems, for encapsulating or embedding pharmaceuticals.[31] In every case, the drug is anchored to the polymer by physical interactions. In the present work, we have chosen benzyl ethers as protecting groups in the carbohydrate-based monomers, in order to be orthogonally cleaved later.



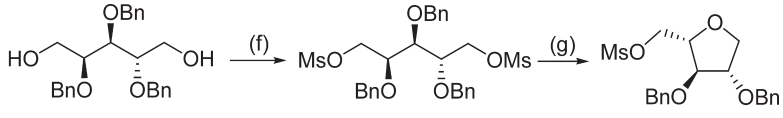
Scheme 1: (a): NaH, BnBr, DMF, rt; (b) HCl 4M-acetonitrile, 16:10 v/v, 80°C; (c) LiAlH4, THF, rt; (d) Ph_3P, DEAD, DPPA, THF, rt; (e) H_2 2 p.s.i., C/Pd 10%, CH_3OH, rt.

Therefore, the synthesized polyurethanes and polyureas could become amphiphilic materials after hydrogenolysis, which would give them some special properties. It is noteworthy that the presence of free hydroxyl groups in the polymeric chains would allow the chemical anchoring of pharmacological compounds of interest for therapeutic applications.

The preparation of benzyl-β,L-arabinopyranoside (**1a**) and benzyl-α,D-xylopyranoside (**1b**) from the naturally occurring L-arabinose and D-xylose has previously been described in detail.[26] The protection of the hydroxyl groups of **1a** and **1b** was carried out using sodium hydride and benzyl bromide in dry *N*,*N*-dimethylformamide (DMF), to generate the tetra-*O*-benzyl derivative **2a** and **2b** in excellent yields (>85%). The preparation of the hemiacetals **3a** and **3b** was achieved in acid media (acetonitrile-hydrochloric acid mixtures) at 80°C. The hydrolysis of the benzyl acetals **2a** and **2b** requires their solubilization in the reaction mixture. Hence, the use of acetonitrile as a cosolvent was crucial in this step. The reduction of **3a** and **3b** with a 1-M solution of $LiAlH_4$ in THF was accomplished in less than 2 h, at rt, with almost quantitative yields for the diol monomers 2,3,4-tri-*O*-benzyl-L-arabinitol (ABnOH, **4a**) and 2,3,4-tri-*O*-benzylxylitol (XBnOH, **4b**). As expected, small differences in their structures led to different physical properties. Thus, for example, the diol **4a** was isolated as a white solid and the diol **4b** as an uncolored oil at rt.

The transformation of the diol **4a** into the diamine monomer **6a** was attempted first using the classical methodology.[32] The procedure (Sch. 2) involves the synthesis of the dimesyl derivative **7** (mesyl chloride, TEA, dichloromethane, from 0°C to rt) and subsequent displacement of the mesyl groups with azide ion to give the compound **5a**. The synthesis of **7** was achieved in good yield (78%), but the subsequent displacement was not successful. The main product of the reaction was the tetrahydrofuran derivative **8**, in 44% overall yield. The diazide derivative **5a** was also isolated as a secondary product. Compound **8** can be of interest in various applications. For example, its template has been incorporated in the structure of some substituted sulfonylaminopyrimidines (*rac*-5-isopropyl-*N*-[5-(2-methoxyphenoxy)-2-(4-pyridyl)-6-(tetrahydrofuran-2-ylmethoxy)-4-pyrimidinyl]-2-pyridinesulfonamide) for use as active ingredients in pharmaceutical compounds, especially endothelin receptor antagonists.[33]

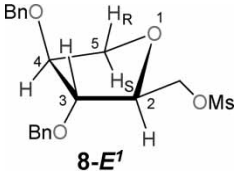
For the formation of the tetrahydrofuran derivative **8**, it was necessary to eliminate the benzyl and mesylate groups, by attack of the *O*-benzyl group on C-4 to C-1. This was not surprising, as this type of elimination product has



4a **7** **8**

Scheme 2: (f): MsCl, TEA, CH_2Cl_2, 0–20°C; (g): NaN_3, CH_3CN-H_2O 10:1, 80°C.

Table 1: Coupling constants ($J_{H,H}$) and torsion angles ($\phi_{H,H}$) for **8**-E^1.

Compound	H,H	$J_{H,H}$[a]	$\phi_{H,H}$[b]	$\phi_{H,H}$[c]	$\phi_{H,H}$[d]
	2,3	3.3	117	129	157
	3,4	4.5	233	222	240
	$4,5_R$	1.3	87	87	83
	$4,5_S$	4.5	−49	−35	−37

8-E^1

[a]Measured directly from the spectrum.
[b]Calculated from the Durette and Horton equation.[34]
[c]Calculated from the Altona equation.[35]
[d]Taken from models of the ideal conformation.[36]

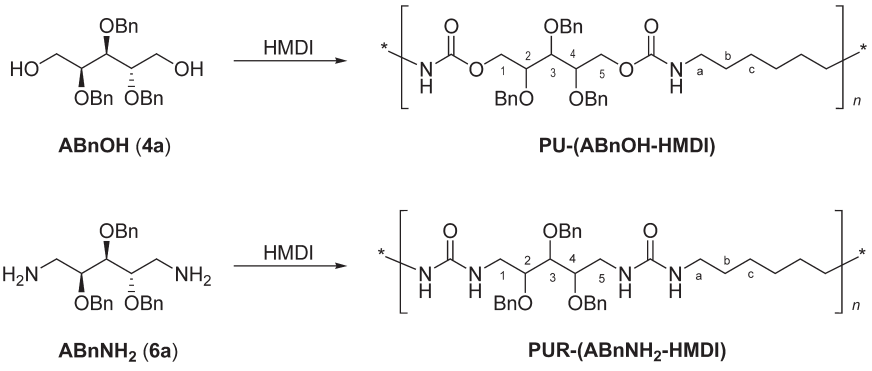
already been reported by our group,[32] where the cleaved groups were a methyl and a mesylate moiety. We obtained the *all-trans* derivative **8**, in the preferential E^1 conformation. This structure was deduced on the basis of the torsion angles calculated from the coupling constants in agreement with modified Karplus equations (Table 1).[34–36] The fact that the only tetrahydrofuran-based product isolated in this reaction was the compound **8** suggests that the cyclization mechanism is regioselective, in agreement with earlier observations.[32,37]

Alternatively, the diazido derivatives **5a** and **5b** have been prepared from the diols ABnOH (**4a**) and XBnOH (**4b**), in one step, by reaction with triphenylphosphine, diethylazodicarboxylate (DEAD), and diphenylphosphoryl azide (DPPA) in THF, at rt, with excellent yields (96% and 89%, respectively). The formation of cyclic compounds was totally prevented by this method. The reduction of the azide groups for the synthesis of the diamines $ABnNH_2$ (**6a**) and $XBnNH_2$ (**6b**) was selectively carried out by hydrogenolysis in the presence of the benzyl groups (H_2, 2 p.s.i., Pd/C, 10%), without side reactions, with almost quantitative yields (>92%).

Synthesis and Characterization of the Polymers

The polymerization reactions were almost quantitative. The polyurethane (PU-ABnOH-HMDI) synthesized from 1,6-hexamethylene diisocyanate and 2,3,4-tri-*O*-benzyl-L-arabinitol was a white solid. The polyurea (PUR-$ABnNH_2$-HMDI) synthesized from the same diisocyanate was obtained as a pale yellow solid. As the sugar monomer lacks a C_2 symmetry axis, the resultant polymers are nonregioregular (Scheme 3).[38]

The polyurethane presented a weight average molecular weight (M_W) of 52,100. This value is of the order of those obtained by us from *O*-methyl-protected xylitol, L-arabinitol, and threitol,[39] and markedly higher than those of other sugar-based polyurethanes reported in the literature.[5–10] The



Scheme 3

M_w of the polyurea (4100) was lower than that of the polyurethane, probably due to the insolubility of the former in the reaction solvent.

The chromatograms from GPC show monomodal curves in every case, and hence, the polymerization process courses uniformly throughout the reaction time and without side reactions. The reactions were allowed to proceed for a short period of time—2 h for polyurethane and 1 h for polyurea—and the unreacted terminal isocyanate groups were deactivated by the addition of *tert*-butanol or 1-decaneamine, respectively, preventing undesirable cross-linked reactions involving the isocyanate group.[40–42] As a consequence, the polyurethane is soluble in common organic solvents such as chloroform or THF. In contrast, the polyurea—showing a greater tendency to form hydrogen bonds with its own or other polymer chains—presents reduced solubility in organic solvents, being only slightly soluble in *N*-methylpyrrolidone and dimethylsulfoxide.

When the NMR characterization of the polymeric materials was carried out, it was observed that the peaks of the ^{1}H NMR spectra were broad and the multiplicity was not always well resolved (Fig. 1).

Due to the presence of the N-H group in the backbone of the polymer chain, these materials have a high tendency to bond to protic solvents. For this reason, despite the long drying periods employed, some of the samples contain a residual amount of solvent ($<$2.9% w/w).

The thermal analysis of the new polyurethane showed that it was very stable to thermal degradation, having a decomposition onset temperature with a 10% weight loss (T_d 10%) of 319°C. The new polymer tended to be more stable to thermal degradation than its methoxylated counterpart.[39] The degradation under nitrogen atmosphere proceeded in two steps—one with the main weight loss at 360°C (weight loss $>$96%), and the second at 456°C, with a weight loss of less than 2%.

The DSC studies of PU-ABnOH-HMDI showed a low T_g (36°C), and a post annealing T_m of 81°C (Table 2). This semi-crystalline behavior contrasts with that of the analogous methoxylated polymer (PU-AMeOH-HMDI), which

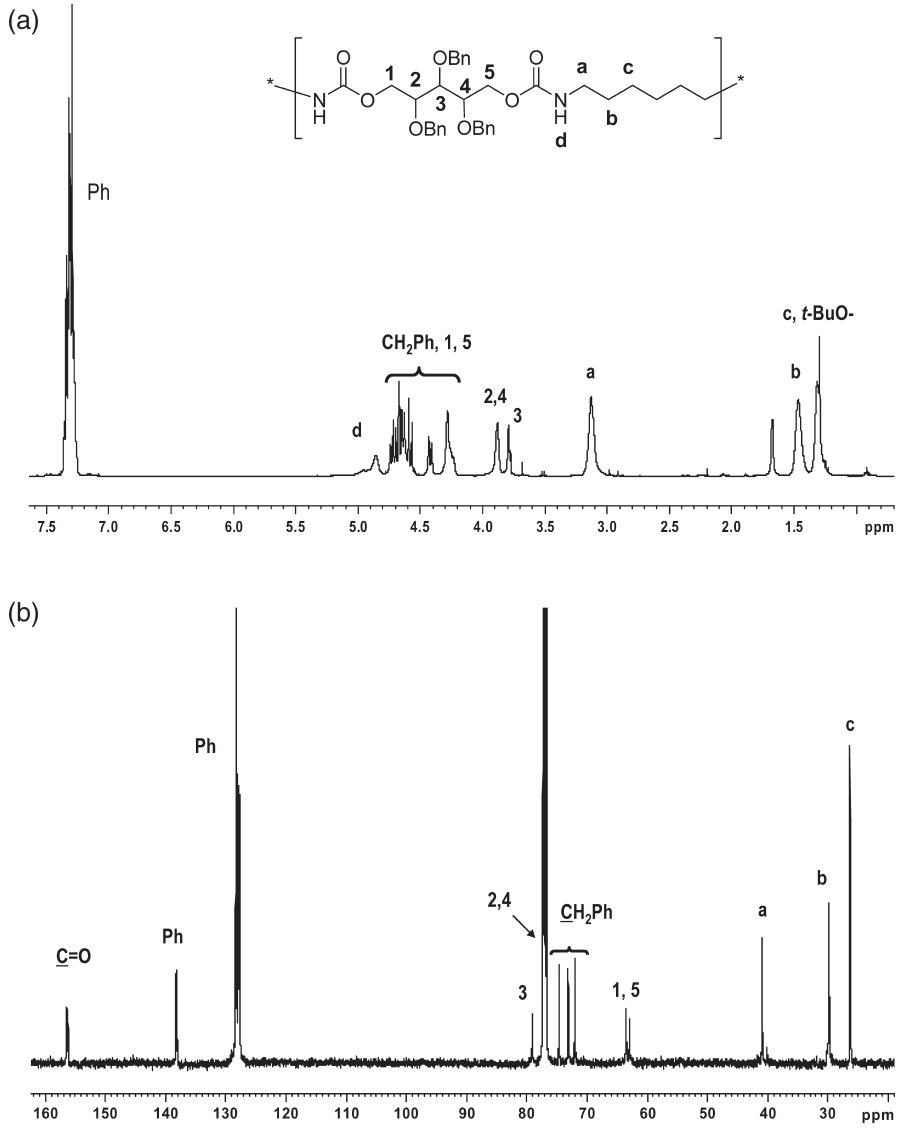


Figure 1: NMR spectra of polyurethane PU-ABnOH-HMDI in $CDCl_3$. A: ^1H NMR spectrum; B: ^{13}C NMR spectrum.

turned out to be amorphous.[39] The polyurea PUR-ABnNH_2-HMDI showed more crystallinity than the polyurethane. It presented a higher melting point (178°C) and higher melting enthalpy (61 J/g). Its thermal degradation took place via a very different pathway to that of the polyurethane, showing thermal decomposition in several steps (Table 2).

Some attempts have been made at debenzylation of the polyurethane. We obtained a high degree of deprotection (67%) by a general hydrogenation

Table 2: Thermal properties and molecular weights of the described polymers.

	DSC					TGA			GPC	
Polymer	**Tm[a] (°C)**	**ΔHm[a] (J/g)**	**Tg[b] (°C)**	**Tm[c] (°C)**	**ΔHm[c] (J/g)**	**Td_{on}[d] (°C)**	**T[e] (°C)**	**ΔW[f] (%)**	**Mw[g] (g/mol)**	**Mn[g] (g/mol)**
PU-(ABnOH-HMDI)	69	12	36	81	8	319	**360**/456	96/2	59100	29200
PUR-(ABnNH$_2$-HMDI)	175	59	108	178	61	253	**292**/352/437	45/41/1	4100	3800

[a]Measured in the first heating cycle.
[b]Measured in the second heating cycle, after rapid cooling to rt.
[c]Measured after annealing for 1.5 h at 10°C above Tg.
[d]Onset decomposition temperature (10% of weight lost).
[e]Decomposition temperatures measured at the peaks of the derivative curves; major peak in bold.
[f]Weight lost at the respective decomposition step.
[g]Determined by GPC against polystyrene standards, with NMP as mobile phase.

procedure (C/Pd 10%, as catalyst, under hydrogen atmosphere [40 p.s.i.] at rt). The key point was the solubilization of the polymeric material, in order to allow the approach of the catalyst to the reaction centers in the polymers. The best results were obtained with 8:4:1 mixtures of chloroform-THF-trifluoroacetic acid. The degree of debenzylation was determined by ^{1}H NMR.

We can conclude that the new *O*-benzyl-alditols and -diamino-alditols are suitable monomers for the preparation of new potentially biodegradable polyurethanes and polyureas, as well as other polymers such as polyesters or polyamides. As the *O*-protecting groups are removable by hydrogenolysis, the new polymers can be transformed into partially or fully hydroxylated polymers with a controlled balance between their hydrophilic and hydrophobic properties.

EXPERIMENTAL

General Methods

Common reagents and solvents were purchased from Aldrich Chemical Co. and used as received. Solvents were dried and purified, when necessary, by appropriate standard procedures. Benzyl-β,L-arabinopyranoside (**1a**) and benzyl α,D-xylopyranoside (**1b**) were prepared from the naturally occurring L-arabinose and D-xylose by the classical Fischer and Beensch glycoside synthesis.[43]

Optical rotations were measured in a Perkin-Elmer 341 polarimeter $20 \pm 5^{\circ}$C (1 dm cell). Elemental analyses were determined in the Microanalyses Laboratories of the CITIUS Service, in the Universidad de Sevilla. IR spectra (films or KBr discs) were recorded with a JASCO FT/IR-410 spectrometer. NMR spectra were recorded at 300 K on either a Bruker Advance AV-500 or a Bruker AMX-500. Chemical shifts (δ) are reported as parts per million downfield from Me_4Si. Mass spectra were obtained using a Kratos MS80RFA instrument. Gel permeation chromatography (GPC) analyses were performed using a Waters apparatus equipped with a Waters 2414 refractive index detector and two Styragel® HR columns (7.8×300 mm) linked in series, thermostatted at 60°C, using *N*-methylpyrrolidone (NMP) as the mobile phase, at a flow rate of 0.5 mL/min^{-1}. Molecular weights were estimated against polystyrene standards. The thermal behavior of the polyurethanes and polyureas was examined by DSC, using a Perkin-Elmer DSC-7 calibrated with indium. DSC data were obtained from samples of 4 to 6 mg at heating/cooling rates of 10°C/min^{-1} under a nitrogen flow. The glass transition temperatures were determined at a heating rate of 20°C min^{-1} from rapidly melt-quenched polymer samples. Thermogravimetric analyses (TGAs) were performed under nitrogen atmosphere (flow rate 100 mL/min^{-1}) with a Universal V4.3A TA Instrument at a heating rate of 10°C/min^{-1}.

The polymerization reactions were performed using standard Schlenk techniques, in absence of humidity, under inert atmosphere. All glassware was heated overnight at 80°C before use, and was further heated under vacuum to eliminate the surface moisture after assembly. The diol monomer (Sch. 1) 2,3,4-tri-*O*-benzyl-L-arabinitol (ABnOH, **4a**) and diamino monomer 1,5-diamino-1,5-dideoxy-2,3,4-tri-*O*-benzyl-L-arabinitol ($ABnNH_2$, **6a**), were dried under high vacuum for at least 3 d. 1,6-Hexamethylene diisocyanate (HMDI) was stored at 4°C and handled under inert atmosphere. Anhydrous tetrahydrofuran (THF) and *N,N*-dimethylacetamide (DMA) polymerization solvents were further dried in order to eliminate residual water. THF was refluxed in the presence of sodium, with benzophenone as indicator, and was freshly distilled prior to use. DMA was vacuum distilled, and stored over molecular sieve in a desiccator for not more than a week before use. The other reactants and reagents for the polymerizations were stored in a desiccator under inert atmosphere until required.

Benzyl 2,3,4-tri-*O*-benzyl-β-L-arabinopyranoside (2a)

To sodium hydride (60% w/w) (0.96 g, 24 mmol) washed with dry pentane (20 mL × 3) under argon atmosphere, a solution of **1a** (1.44 g, 6 mmol) in dry DMF (15 mL) was added dropwise with stirring at 0°C. The mixture was stirred at this temperature for 1 h, and then benzyl bromide (2.7 mL, 21.6 mmol) was added, and stirring was continued at rt overnight. Methanol (2 mL) was added dropwise, and the mixture was stirred for 1 h. The reaction mixture was evaporated to dryness and the residue was then dissolved with a mixture of $CHCl_3$ (50 mL) and aq $NaHCO_3$ satd solution (20 mL). The organic phase was washed with brine (10 mL) and then water (20 mL), dried (anhydrous $MgSO_4$), and concentrated. The yellowish residue was purified by column chromatography (1:8 *tert*-butylmethyl ether-hexane, Rf = 0.21) to give the title compound as a white solid (2.8 g, 92%); m.p. 61.4–62.5°; $[\alpha]_D + 131$ (*c* 1.0, dichloromethane); IR (cm^{-1}): 3062, 3029 (Ph), 1096 (C-O-CH_2Ph) 738, 696 (Ph); ^{1}H NMR ($CDCl_3$, 200 MHz): δ (ppm) 7.35 (m, 20H, 4 Ph), 4.93 (d, 1H, H-1, $J_{1,2} = 3.2$ Hz), 4.79 (1H, d, C$\underline{H}_A$H$_B$-O-Ph, $J_{HA,HB} = 11.9$ Hz), 4.77 (1H, d, C$\underline{H}_C$H$_D$-O-Ph, $J_{HC,HD} = 11.8$ Hz), 4.75 (1H, d, C$\underline{H}_E$H$_F$-O-Ph, $J_{HE,HF} = 12.4$ Hz), 4.73 (2H, s, C$\underline{H}_G\underline{H}_H$-O-Ph), 4.66 (1H, d, CH$_C\underline{H}_D$-O-Ph), 4.61 (1H, d, CH$_A\underline{H}_B$-O-Ph), 4.57 (1H, d, CH$_E\underline{H}_F$-O-Ph), 4.04 (1H, dd, H-2, $J_{2,3} = 9.7$ Hz), 3.95 (1H, dd, H-3, $J_{3,4} = 2.9$ Hz), 3.80 (1H, m, H-4), 3.70 (2H, d, H-5A, H-5B, $J_{4,5A} = J_{4,5B} = 1.99$ Hz); ^{13}C NMR ($CDCl_3$, 50 MHz): δ (ppm) 138.74, 138.65, 138.28, 137.36 (4C, Ph), 128.27, 127.84, 127.72, 127.55 (20C, Ph), 96.54 (C-1), 77.28 (C-3), 76.34 (C-2), 73.85 (C-4), 73.29, 72.69, 71.62, 68.92 (4C, O$\underline{C}H_2$Ph) 60.41 (C-5); MS (CI): m/z 510 $(M)^+$, 509 $(M-1)^+$, 419 $(M-CH_2Ph)^+$, 403 $(M-OCH_2Ph)^+$, 181 $(PhCH_2CHPh)^+$, 91 $(PhCH_2)^+$.

Anal. Calcd for $C_{33}H_{34}O_5$: C, 77.62; H, 6.71. Found: C, 77.47; H, 6.53.

Benzyl 2,3,4-tri-*O*-benzyl-α-D-xylopyranoside (2b)

This was obtained from **1b** as an oil (85% yield), following the procedure described above for **2a**. $[\alpha]_D + 59^\circ$ (*c* 1.7, dichloromethane); IR (cm^{-1}): 3063, 3028 (Ph), 1074 (C-O-CH_2Ph) 734, 696 (Ph); ^{1}H NMR ($CDCl_3$, 500 MHz): δ (ppm) 7.32 (m, 20H, 4 Ph), 4.97 (1H, d, C$\underline{H}_A$H$_B$-O-Ph, $J_{HA,HB} = 11.0$ Hz), 4.90 (1H, d, CH$_A$$\underline{H}_B$-O-Ph), 4.79 (1H, d, H-1, $J_{1,2} = 3.6$ Hz), 4.78 (1H, d, CH$_C$H$_D$-O-Ph, $J_{HC,HD} =$ 10.5 Hz), 4.76 (1H, d, CH$_C$$\underline{H}_D$-O-Ph), 4.71 (1H, d, C$\underline{H}_EH_F$-O-Ph, $J_{HE,HF} =$ 11.9 Hz), 4.66 (1H, d, CH$_E$$\underline{H}_F$-O-Ph), 4.58 (1H, d, C$\underline{H}_GH_I$-O-Ph, $J_{HG,HI} = 12.1$ Hz), 4.54 (1H, d, CH$_G$$\underline{H}_I$-O-Ph), 4.00 (dd, 1H, H-3, $J_{2,3} = 9.6$ Hz, $J_{3,4} = 8.0$ H,), 3.65 (2H, m, H-5A/5B), 3.60 (1H, m, H-4), 3.48 (1H, dd, H-2); ^{13}C NMR ($CDCl_3$, 50 MHz): δ (ppm) 139.01, 138.40, 138.31, 137.23 (4C, Ph), 128.46, 128.42, 128.40, 128.33, 128.25, 127.99, 127.94, 127.86, 127.84, 127.81, 127.78, 127.76, 127.69, 127.60, 127.57, 127.52 (20C, Ph), 95.45 (C-1), 81.49 (C-3), 79.77 (C-2), 78.20 (C-4), 75.76, 73.54, 73.13, 68.74 (4C, O$\underline{C}$H$_2$Ph) 60.21 (C-5); MS (CI): m/z 509 $(M-1)^+$, 419 $(M-CH_2Ph)^+$, 403 $(M-OCH_2Ph)^+$, 181 $(PhCH_2CHPh)^+$, 91 $(PhCH_2)^+$.

HRMS: Theoretical molecular weight for $C_{33}H_{33}O_5$ $(M-1)^+$ 421.247639, experimental molecular weight: 421.249118.

2,3,4-Tri-*O*-benzyl-α,β-L-arabinopyranose (3a)

A solution of **2a** (1.68 g, 3.3 mmol) in a mixture of 4 M HCl-acetonitrile 16:10 (13 mL) was heated at 80°C for 22 h. The mixture was concentrated to dryness and extracted with CH_2Cl_2 (50 mL). The extracts were washed with aq $NaHCO_3$ satd solution (10 mL × 3), dried (anhydrous $MgSO_4$), and concentrated to dryness. The residue was purified by column chromatography (1:1 tert-butylmethyl ether-hexane, Rf = 0.14) to give the title compound as a white solid (1.1 g, 80%); m.p. 84.1–84.8°; $[\alpha]_D + 69$ (*c* 0.99, dichloromethane); IR (cm^{-1}): 3364 (OH), 3032 (Ph), 1098 (C-O-CH_2Ph) 741, 697 (Ph); ^{1}H NMR ($CDCl_3$, 500 MHz): δ (ppm) α,β anomers in 43:56 ratio; 7.31 (m, 30H, 3 Ph, α and β anomers), 5.17 (dd, 1H, H-1β, $J_{1,2} = 2.0$ Hz, $J_{1,OH} = 5.2$ Hz,), 4.87 (dd, 1H, H-1α, $J_{1,2} = 10.0$ Hz, $J_{1,OH} = 2.1$ Hz,), 4.80–4.52 (m, 12H, 3 C$\underline{H}_2$Ph, α and β anomers), 4.04 (1H, dd, H-5Aβ, $J_{4,5A} = 8.7$ Hz, $J_{5A,5B} = 11.4$ Hz), 3.92–3.76 (7H, m, H-2β/3α/3β/4α/4β/5Aα/5Bα), 3.67–3.63 (2H, m, H-5Bβ/2α), 3.06 (1H, d, OHβ); ^{13}C NMR ($CDCl_3$, 125 MHz): δ (ppm) 138.40, 138.21, 138.12, 137.88, 137.69, 137.45 (6C, Ph, α and β anomers), 128.52, 128.47, 128.45, 128.39, 128.06, 128.00, 127.96, 127.93, 127.82, 127.78, 127.69, 127.65 (30C, Ph α and β anomers), 93.46 (C-1α), 92.09 (C-1β), 76.76 (C-2β), 76.20 (C-2α), 76.09 (C-3α), 75.43 (C-3β), 73.81, 73.62 (2C, O$\underline{C}$H$_2$Ph, α and/or β anomers), 73.01 (C-4α), 72.83, 72.70 (2C, O$\underline{C}$H$_2$Ph, α and/or β anomers), 72.09 (C-4β), 61.00 (C-5β), 58.24 (C-5α); MS (CI): m/z 403 $(M-OH)^+$, 329 $(M-CH_2Ph)^+$, 253 $(M-CH_2Ph-Ph + H)^+$, 181 $(PhCH_2CHPh)^+$, 107 $(PhCH_2O)^+$,

91 $(PhCH_2)^+$. MS (CI): m/z 253 $(M\text{-}CH_2Ph\text{-}Ph + H)^+$, 181 $(PhCH_2CHPh)^+$, 91 $(PhCH_2)^+$.

Anal. Calcd for $C_{26}H_{28}O_5$: C, 74.26; H, 6.71. Found: C, 74.06; H, 6.75.

2,3,4-Tri-*O*-benzyl-α,β-D-xylopyranose (3b)

This was obtained from **2b** as a white solid (85% yield), following the procedure described above for **2a**; m.p. 131.2–131.6°C; $[\alpha]_D + 18.4$ (*c* 0.38, dichloromethane); IR (cm^{-1}): 3409 (OH), 3088, 3064, 3030 (Ph), 1074 (C-O-CH_2Ph) 735, 695 (Ph); ^{1}H NMR ($CDCl_3$, 500 MHz): δ (ppm) α and β anomers in 77:23 ratio; 7.31 (m, 30H, 3 Ph α and β anomers), 5.12 (d, 1H, H-1α, $J_{1,2} = 3.5$ Hz), 4.90–4.62 (m, 13H, H-1β, 3 C$\underline{H}_2$Ph from α and β anomers), 3.96 (1H, dd, H-5β, $J = 4.5$ Hz, $J = 11.5$ Hz), 3.87 (1H, t, H-3a, $J_{2,3} = J_{3,4} = 8.5$ Hz), 3.81 (1H, t, H-5Aα, $J_{5A,5B} = J_{5A,4} = 11$ Hz), 3.67 (1H, dd, H-5Bβ, $J_{4,5B} = 5.0$ Hz), 3.62 (1H, m, H-3β), 3.59–3.53 (2H, m, H-4α/4 β), 3.49 (1H, dd, H-2α, $J_{2,3} = 3.5$ Hz, $J_{3,4} = 9$ Hz), 3.31 (1H, m, H-2β); ^{13}C NMR ($CDCl_3$, 125 MHz): δ (ppm) 138.64, 138.49, 138.33, 138.23, 138.08, 137.81 (6C, Ph, a and β anomers), 128.50, 128.43, 128.37, 128.07, 128.03, 127.98, 127.86, 127.79, 127.76, 127.65 (30C, Ph α and β anomers), 97.74 (C-1β), 91.48 (C-1α), 83.17 (C-3β), 82.31 (C-2β), 80.46 (C-3α), 79.47 (C-2α), 77.54, 77.47 (C-4α/β), 75.47, 74.75, 73.44, 73.25, 73.19 (6C, O$\underline{C}H_2$Ph, α and β anomers), 63.73 (C-5β), 60.40 (C-5α); MS (CI): m/z 403 $(M\text{-}OH)^+$, 329 $(M\text{-}CH_2Ph)^+$, 253 $(M\text{-}CH_2Ph\text{-}Ph + H)^+$, 181 $(PhCH_2CHPh)^+$, 107 $(PhCH_2O)^+$, 91 $(PhCH_2)^+$.

HRMS: Theoretical molecular weight for $C_{26}H_{27}O_4$ $(M\text{-}OH)^+$ 403.190935, experimental molecular weight: 403.189944.

2,3,4-Tri-*O*-benzyl-L-arabinitol (4a, ABnOH)

A solution of **3a** (1.21 g, 2.86 mmol) in dry THF (5 mL) was cooled in an ice bath for 15 min under argon atmosphere, and then a 1.0-M solution of $LiAlH_4$ in THF (2.86 mL, 2.86 mmol) was added dropwise. The reaction proceeded in inert atmosphere. The reaction mixture was stirred for 2 h at rt until the reaction had finished. Aq Na_2SO_4 satd solution (0.86 mL) was added and the mixture was stirred for 15 min and then diluted with CH_2Cl_2 (20 mL). The aluminum salts were filtered off, and the solution was evaporated under vacuum to dryness. The white solid was purified by column chromatography (1:1 *tert*-butylmethyl ether-hexane, $R_f = 0.09$) to give the title compound as a white solid (1.17 g, 96%); m.p. 75.7–76.8°; $[\alpha]_D + 7.4°$ (*c* 0.96, dichloromethane); IR (cm^{-1}): 3421 (OH), 3064, 3033 (Ph), 1064 (C-O-CH_2Ph) 734, 697 (Ph); ^{1}HNMR ($CDCl_3$, 500 MHz): δ (ppm) 7.38 (m, 15H, 3 Ph), 4.79 (1H, d, C$\underline{H}_A$H$_B$-O-Ph, $J_{HA,HB} = 11.5$ Hz), 4.72 (1H, d, CH$_A\underline{H}_B$-O-Ph), 4.69 (1H, d, C$\underline{H}_C$H$_D$-O-Ph, $J_{HC,HD} = 12.0$ Hz), 4.64 (1H, d, C$\underline{H}_E$H$_F$-O-Ph, $J_{HE,HF} =$ 11.5 Hz), 4.62 (1H, d, CH$_E\underline{H}_F$-O-Ph), 4.56 (1H, d, CH$_C\underline{H}_D$-O-Ph), 3.94–3.72

(7H, m, H-1A, H-1B, H-2, H-3, H-4, H-5A, H-5B), 2.38 (1H, t, OH, $J = 6.4$ Hz), 2.25 (1H, dd, OH, $J = 7.0$; $J = 4.8$ Hz); ^{13}C NMR ($CDCl_3$, 125 MHz): δ (ppm) 138.11, 137.98, 137.92 (3C, Ph), 128.53, 128.51, 128.50, 128.29, 127.98, 127.97, 127.91, 127.89, 127.83 (15C, Ph), 79.44, 79.26, 79.02 (C-2, C-3, C-4), 74.27, 72.71, 72.07 (3C, O$\underline{C}H_2$Ph) 61.38, 60.79 (C-1, C-5); MS (CI): m/z 423 $(M + 1)^+$, 331 $(M\text{-}CH_2Ph)^+$, 271 $(C_{17}H_{19}O_3)^+$ 181 $(PhCH_2CHPh)^+$, 91 $(PhCH_2)^+$.

Anal. Calcd for $C_{26}H_{30}O_5$: C, 73.91; H, 7.16. Found: C, 73.67; H, 7.50.

2,3,4-Tri-*O*-benzylxylitol (4b, XBnOH)

This was obtained from **3b** as an oil (92% yield), following the procedure described above for **4a**. IR (cm^{-1}): 3434 (OH), 3062, 3031 (Ph), 1063 (C-O-CH_2Ph) 737, 698 (Ph); ^{1}H NMR ($CDCl_3$, 500 MHz): δ (ppm) 7.33 (m, 15H, 3 Ph), 4.72 (2H, s, C$\underline{H}_2$-O-Ph in C-3), 4.65 (2H, d, C$\underline{H}_A$H$_B$-O-Ph, $J_{HA,HB} = 11.5$ Hz), 4.64 (2H, d, CH$_A\underline{H}_B$-O-Ph), 3.81 (1H, t, H-3, $J_{3,4} = J_{2,3} = 5.5$ Hz), 3.80 (2H, dd, H-1A/H-5A, $J_{1A,2} = J_{5A,4} = 4.5$ Hz), 3.74 (2H, dd, H-2/H-4, $J_{1B,2} = J_{5B,4} = 9.8$ Hz), 3.65 (2H, dd, H-1B/H-5B), 2.18 (2H, sa, OH-1/OH-2); ^{13}C NMR ($CDCl_3$, 125 MHz): δ (ppm) 137.95, 137.89 (3C, Ph), 128.51, 128.46, 128.36, 128.03, 127.93 (15C, Ph), 79.39 (C-3), 79.04 (C-2, C-4), 74.57 (1C, O$\underline{C}H_2$Ph in C-3), 72.80 (2C, O$\underline{C}H_2$Ph in C-2/C-4) 61.56 (C-1, C-5); MS (CI): m/z 423 $(M + 1)^+$, 331 $(M\text{-}CH_2Ph)^+$, 271 $(C_{17}H_{19}O_3)^+$ 181 $(PhCH_2CHPh)^+$, 91 $(PhCH_2)^+$.

HRMS: Theoretical molecular weight for $C_{26}H_{31}O_5$ $(M + 1)^+$ 423.217149, experimental molecular weight: 423.215830.

1,5-Diazido-1,5-dideoxy-2,3,4-tri-*O*-benzyl-L-arabinitol (5a)

To a solution of triphenylphosphine (3.05 g, 11.64 mmol, 2.2 equiv) in dry THF (13 mL) at 0°C, a commercial 40% solution of diethylazodicarboxylate (DEAD) in toluene (5.3 mL, 11.6 mmol, 2.2 equiv) was added dropwise, and the mixture was stirred for 5 min prior to the sequential dropwise addition of diphenylphosphoryl azide (DPPA) (2.4 mL, 11.1 mmol, 2.1 equiv) and a solution of 1.12 g of **4a** (2.64 mmol) in THF (13 mL). The reaction solution was stirred for 3 h and then concentrated to dryness. The residue was purified by column chromatography (1:3 dichloromethane-hexane, Rf = 0.13) to give the title compound as a colorless oil (1.19 g, 96%); $[\alpha]_D + 4^\circ$ (c 0.61, dichloromethane); IR (cm^{-1}): 3062, 3031 (Ph), 2100 (N_3), 1073 (C-O-CH_2Ph) 737, 697 (Ph); ^{1}H NMR ($CDCl_3$, 500 MHz): δ (ppm) 7.35 (m, 15H, 3 Ph), 4.74 (1H, d, C$\underline{H}_A$H$_B$-O-Ph, $J_{HA,HB} = 11.6$ Hz), 4.69 (1H, d, C$\underline{H}_C$H$_D$-O-Ph, $J_{HC,HD} = 11.6$ Hz), 4.66 (1H, d, C$\underline{H}_E$H$_F$-O-Ph, $J_{HE,HF} = 11.5$ Hz,), 4.66 (1H, d, CH$_A\underline{H}_B$-O-Ph), 4.57 (1H, d, CH$_E\underline{H}_F$-O-Ph,) 4.49 (1H, d, CH$_C$H$_D$-O-Ph), 3.79 (3H, m, H-2/H-3/H-4), 3.63 (1H, dd, H1A, $J_{1A,IB} = 13.3$ Hz, $J_{1A,2} = 2.8$ Hz), 3.51 (1H, dd, H1B, $J_{1B,2} = 5.0$ Hz), 3.47 (1H, dd, H5A, $J_{5A,5B} = 12.6$ Hz, $J_{5A,4} = 6.1$ Hz), 3.42 (1H, dd, H5B, $J_{5B,4} = 5.1$ Hz); ^{13}C NMR ($CDCl_3$,

125 MHz): δ (ppm) 137.76, 137.53 (3C, Ph), 128.52, 128.50, 128.46, 128.15, 128.04, 127.99 (15C, Ph), 78.77, 78.19, 78.16 (C-2/C-3/C-4), 74.57, 73.35, 72.41 (3C, O$\underline{C}H_2$Ph), 51.68, 50.92 (C-1, C-5); MS (CI): m/z 445 $(M - N_2 + 1)^+$, 417 $(M - 2N_2 + 1)^+$, 181 ($PhCH_2CHPh$), 91 $(PhCH_2)^+$.

Anal. Calcd for $C_{26}H_{28}N_6O_3$: C, 66.09; H, 5.97; N, 17.78. Found: C, 65.97; H, 5.70; N, 17.43.

1,5-Diazido-1,5-dideoxy-2,3,4-tri-*O*-benzylxylitol (5b)

This was obtained from **4b** as an oil (89% yield), following the procedure described above for **5a**. IR (cm^{-1}): 3077, 3031 (Ph), 2099 (N_3), 1076 (C-O-CH_2Ph) 736, 698 (Ph); ^{1}H NMR ($CDCl_3$, 500 MHz): δ (ppm) 7.34 (m, 15H, 3 Ph), 4.70 (2H, d, C$\underline{H}_A$H$_B$-O-Ph, C$\underline{H}_C$H$_D$-O-Ph, $J_{HA,HB} = J_{HC,HD} = 11.50$ Hz), 4.67 (2H, s, C$\underline{H}_E\underline{H}_F$-O-Ph), 4.62 (2H, d, CH$_A\underline{H}_B$-O-Ph, CH$_C\underline{H}_D$-O-Ph), 3.74 (2H, m, H2/H4), 3.69 (1H, t, H3, $J_{2,3} = J_{3,4} = 5.0$ Hz), 3.44 (2H, dd, H1A/5A, $J_{1A,IB} = J_{5A,5B} = 12.5$ Hz, $J_{1A,2} = J_{5A,4} = 4.5$ Hz) 3.34 (2H, dd, H1B/5B, $J_{1B,2} = J_{5B,4} = 6.5$ Hz); ^{13}C NMR ($CDCl_3$, 125 MHz): δ (ppm) 137.73, 137.62 (3C, Ph), 128.53, 128.50, 128.40, 128.20, 128.08, 128.03 (15C, Ph), 77.74 (C-2/C-4), 77.63 (C-3), 74.63, 73.21 (3C, O$\underline{C}H_2$Ph) 51.33 (C-1, C-5); MS (CI): m/z 445 $(M - N_2 + 1)^+$, 417 $(M - 2N_2 + 1)^+$, 181 $(PhCH_2CHPh)^+$, 91 $(PhCH_2)^+$.

Anal. Calcd for $C_{26}H_{28}N_6O_3$: C, 66.09; H, 5.97; N, 17.78. Found: C, 65.94; H, 5.61; N, 17.78.

1,5-Diamino-1,5-dideoxy-2,3,4-tri-*O*-benzyl-L-arabinitol (6a, ABnNH$_2$)

A solution of **5b** (0.80 g, 1.693 mmol) in methanol (9 mL) was stirred with 10% Pd/C (80 mg) for 2 h at rt under hydrogen atmosphere at 0.5 bar pressure. The mixture was then diluted with methanol, and the catalyst was filtered off through diatomaceous earth and concentrated, giving the title product as a pure oil (0.66 g, 92% yield). IR (cm^{-1}): 3373, 3278 (NH_2), 3030 (Ph), 1071 (C-O-CH_2Ph) 743, 698 (Ph); ^{1}H NMR ($CDCl_3$, 500 MHz): δ (ppm) 7.28 (m, 15H, 3 Ph), 4.72 (1H, d, C$\underline{H}_A$H$_B$-O-Ph, $J_{HA,HB} = 11.5$ Hz), 4.67 (1H, d, CH$_A\underline{H}_B$-O-Ph), 4.64 (1H, d, C$\underline{H}_C$H$_D$-O-Ph, $J_{HC,HD} = 11.5$ Hz), 4.59 (1H, d, CH$_C\underline{H}_D$-O-Ph), 4.53 (1H, d, C$\underline{H}_E$H$_F$-O-Ph, $J_{HE,HF} = 15.5$ Hz), 4.51 (1H, d, CH$_E\underline{H}_F$-O-Ph), 3.84 (1H, dd, H-3, $J = 4.1$ Hz, $J = 5.2$ Hz), 3.64 (1H, m, H-2), 3.59 (1H, m, H-4), 3.03 (1H, dd, H-1A, $J_{1A,2} = 6.0$ Hz, $J_{1A,1B} = 13.8$ Hz), 2.99 (1H, dd, H-1B, $J_{1B,2} = 4.2$ Hz), 2.93 (1H, dd, H-5A, $J_{5A,4} = 4.6$ Hz, $J_{5A,5B} = 13.2$ Hz), 2.82 (1H, dd, H-5B, $J_{5B,2} = 6.4$ Hz), 1.95 (4H, s, NH_2); ^{13}C NMR ($CDCl_3$, 125 MHz): δ (ppm) 138.14, 138.08, 137.87, (3C, Ph), 129.33, 128.47, 128.44, 128.40, 128.02, 127.96, 127.90, 127.84, 127.80 (15C, Ph), 79.69 (C-4), 79.26 (C-2), 78.87 (C-3), 74.15, 73.42, 71.92 (3C, O$\underline{C}H_2$Ph) 41.51 (C-1), 40.72 (C-2); MS (CI): m/z 421 $(M + 1)^+$, 91 $(PhCH_2)^+$.

HRMS: Theoretical molecular weight for $C_{26}H_{33}N_2O_3$ $(M + 1)^+$ 421.249118, experimental molecular weight: 421.248401.

1,5-Diamino-1,5-dideoxy-2,3,4-tri-*O*-benzylxylitol (6b, XBnNH$_2$)

This was obtained from **5b** as an oil (97% yield), following the procedure described above for **6a**. IR (cm^{-1}): 3331 (NH_2), 3030 (Ph), 1068 (C-O-CH_2Ph) 735, 697 (Ph); ^{1}H NMR ($CDCl_3$, 500 MHz): δ (ppm) 7.34 (m, 15H, 3 Ph), 4.76 (2H, s, C$\underline{H}_2$-O-Ph), 4.68 (2H, d, C$\underline{H}_A$H$_B$-O-Ph/C$\underline{H}_C$H$_D$-O-Ph, $J_{HA,HB} = J_{HC,HD} = 11.5$ Hz), 4.63 (2H, d, CH$_A\underline{H}_B$-O-Ph, CH$_C\underline{H}_D$-O-Ph), 3.73 (1H, t, H-3, $J_{2,3} = J_{3,4} = 5.5$ Hz), 3.60 (2H, m, H2/4), 2.92 (2H, dd, H-1A/5A, $J_{1A,2} = J_{5A,4} = 4.5$ Hz, $J_{1A,1B} = J_{5A,5B} = 13.3$ Hz,), 2.78 (2H, dd, H-1B/5B, $J_{1B,2} = J_{5B,4} = 6.1$ Hz,), 1.73 (4H, s, NH_2); ^{13}C NMR ($CDCl_3$, 125 MHz): δ (ppm) 138.44, 138.37, (3C, Ph), 128.46, 128.04, 127.86, 127.79, (15C, Ph), 80.91 (C-2, C-4), 78.77 (C-3), 74.37, 73.03 (3C, O$\underline{C}H_2$Ph) 41.88 (C-1,C-5).

HRMS: Theoretical molecular weight for $C_{26}H_{33}N_2O_3$ $(M + 1)^+$ 421.249118, experimental molecular weight: 421.247639.

1,5-Dideoxy-1,5-dimesyl-2,3,4-tri-*O*-benzyl-L-arabinitol (7)

A solution of mesyl chloride (0.39 mL, 5 mmol, 1.25 equiv) in dry dichloromethane (1.5 mL) was added dropwise to a cold solution (0°C) of 0.85 g of 2,3,4-tri-*O*-benzyl-L-arabinitol (**4a**, ABnOH, 2 mmol) and triethylamine (0.7 mL, 5 mmol, 1.25 equiv) in dry dichloromethane (5 mL), under argon atmosphere. The reaction was allowed to warm up to rt and was monitored by thin layer chromatography (TLC, *tert*-butylmethyl ether). The starting material was consumed in 90 min. The reaction mixture was diluted with water (5 mL), and the aqueous phase was extracted with CH_2Cl_2 (3 × 10 mL). The combined organic layers were washed first with aq 4 M HCl solution (10 mL) and then with aq $NaHCO_3$ sat solution (10 mL), dried (anhydrous $MgSO_4$), and concentrated under vacuum. The residue was purified by column chromatography (1:1 *tert*-butylmethyl ether-hexane, $R_f = 0.08$) to give the title compound as a colorless oil (0.90 g, 78%). $[\alpha]_D + 1.7°$ (*c* 1.85, dichloromethane); IR (cm^{-1}): 3065, 3036 (Ph), 1356, 1175 (OSO_2CH_3), 1085 (C-O-CH_2Ph) 736, 701 (Ph); ^{1}H NMR ($CDCl_3$, 500 MHz): δ (ppm) 7.34 (15H, m, 3 Ph), 4.73 (1H, d, C$\underline{H}_A$H$_B$-O-Ph, $J_{HA,HB} = 11.4$ Hz), 4.65 (1H, d, CH$_A\underline{H}_B$-O-Ph), 4.70 (1H, d, C$\underline{H}_C$H$_D$-O-Ph, $J_{HC,HD} = 11.7$ Hz), 4.57 (1H, d, CH$_C\underline{H}_D$-O-Ph), 4.68 (1H, d, C$\underline{H}_E$H$_F$-O-Ph, $J_{HE,HF} = 15.3$ Hz), 4.49 (1H, d, CH$_E\underline{H}_F$-O-Ph), 4.37 (1H, d, H1 A, $J_{1A,2} = 1.0$ Hz), 4.36 (1H, d, H1B, $J_{1B,2} = 1.8$ Hz), 4.02–3.92 (2H, m, H-2/H-4), 3.80 (1H, dd, H-3, $J_{2,3} = 4.1$ Hz, $J_{3,4} = 5.5$ Hz), 4.62 (1H, dd, H-5A, $J_{5A,5B} = 11.4$ Hz, $J_{5A,4} = 2.9$ Hz), 4.41 (1H, dd, $J_{5B,4} = 5.3$ Hz), 2.93 (3H, s, CH_3SO_{3-}), 2.91 (3H, s, CH_3SO_{3-}); ^{13}C NMR ($CDCl_3$, 125 MHz): δ (ppm)

137.43, 137.35, 137.32 (3C, Ph), 128.93, 128.58, 128.55, 128.24, 128.14, 128.07, 128.04, 127.83 (15C, Ph), 77.48, 77.36, 77.03 (C-2/C-3/C-4), 74.35, 73.65, 72.85 (3C, O$\underline{C}H_2$Ph), 69.01, 68.76 (C-1/C-5), 37.47, 37.30 (2$\underline{C}H_3SO_{3^-}$). MS (CI): m/z 181 $(PhCH_2CHPh)^+$, 91 $(PhCH_2)^+$.

Anal. Calcd for $C_{28}H_{34}O_9S_2$: C, 58.11; H, 5.92; S, 11.08. Found: C, 58.51; H, 6.04; S, 10.95.

((2*S*,3*S*,4*S*)-3,4-bis(benzyloxy)-tetrahydrofuran-2-yl)methyl methanesulfonate (8)

To a solution of the dimesyl arabinitol derivative **7** (0.70 g, 1.21 mmol) in a mixture of acetonitrile-water 10:1 (11 mL) was added sodium azide (0.20 g, 3.02 mmol), and the solution was heated at 80°C for 18 h. The reaction was followed by TLC, and a main product was detected ($R_f = 0.33$ in *tert*-butylmethyl ether-hexane 2:1). The mixture was evaporated and then dissolved in a mixture of dichloromethane-water 2:1 (60 mL). The organic layer was dried (anhydrous Na_2SO_4) and the solvents were evaporated. The residue was purified by column chromatography (1:1 *tert*-butylmethyl ether-hexane, $R_f = 0.1$) to give the title compound as a white solid (0.21 g, 44%), m.p. 79.9–80.4°C. $[\alpha]_D$ −33° (*c* 1.28, dichloromethane); IR (cm^{-1}): 3031 (Ph), 1356, 1175 (OSO_2CH_3), 1097 (C-O-CH_2Ph) 742, 699 (Ph); ^{1}H NMR ($CDCl_3$, 500 MHz): δ (ppm) 7.34 (10H, m, 2 Ph), 4.60 (2H, s, C$\underline{H}_2$-O-Ph), 4.54 (2H, d, C$\underline{H}_2$-O-Ph, $J = 1.8$ Hz), 4.36 (1H, dd, H-1′A, $J_{1'A,1'B} = 11.0$ Hz; $J_{1'A,2} = 5.1$ Hz), 4.33 (1H, dd, H-1′B, $J_{1'B,2} = 5.9$ Hz), 4.16 (1H, ddd, H-2, $J_{2,3} = 3.3$ Hz), 4.12 (1H, dt, H-4, $J_{4,5A} = 1.3$ Hz, $J_{3,4} = J_{4,5B} = 4.5$ Hz), 4.08 (1H, bd, H-5A, $J_{5A,5B} = 10.1$ Hz), 4.03–3.90 (2H, m, H-3/5B), 3.02 (3H, s, $CH_3SO_{3^-}$); ^{13}C NMR ($CDCl_3$, 125 MHz): δ (ppm) 137.44, 137.29 (2C, Ph), 128.61, 128.59, 128.11, 128.03, 127.84, 127.82 (10C, Ph), 83.59 (C-2), 82.60 (C-4), 81.40 (C-3), 72.06, 72.00, 71.48 (C-5, 2 O$\underline{C}H_2$Ph), 69.04 (C-1), 37.67 ($\underline{C}H_3SO^{3-}$). MS (CI): m/z 391 $(M\text{-}1)^+$, 301 $(M\text{-}PhCH_2)^+$, 285 $(M\text{-}PhCH_2O)^+$, 271 $(M\text{-}PhCH_2O\text{-}CH_3)^+$, 181 $(PhCH_2CHPh)^+$, 91 $(PhCH_2)^+$.

HRMS: Theoretical molecular weight for $C_{20}H_{25}O_6S$ $(M\text{-}1)^+$ 391.121536, experimental molecular weight: 391.122398.

Polyurethane PU-(ABnOH-HMDI)

In a typical procedure, the carbohydrate-based diol 2,3,4-tri-*O*-benzyl-L-arabinitol (**4a**, ABnOH) (0.21 g, 0.5 mmol) was charged in a round-bottom flask with an inlet of Ar/vacuum. The system was treated with three cycles of vacuum-argon before the addition, via cannula, of dried THF (2 mL). The mixture was stirred to homogenization, and the diisocyanate (HMDI, 82 μL, 0.5 mmol) was added under argon atmosphere, followed by the catalyst (dibutyltin dilaurate, one drop). The polymerization solution was stirred for 3 h under argon atmosphere, at rt. *Tert*-

butanol (1 mL) was added, the mixture was stirred for 30 min, and the solution was added dropwise into cold diethyl ether (150 mL), where the polymer PU-(ABnOH-HMDI) precipitated. The polyurethane was purified by redissolution in a small volume of chloroform (2 mL), and reprecipitation into diethyl ether. The pure polymer (white solid) was dried under vacuum for 2 d and stored in a desiccator (0.28 g, 95% yield). $[\alpha]_D$ -0.03° (*c* 1.0, dichloromethane); M_w 52100; M_n 29200; M_w/M_n 1.8; *DP* 49. IR: ν (cm^{-1}) 3334 (N-H), 3056, 3031 (C-H ar), 1703 (C═O urethane), 1536 (N-H urethane), 1097 (C-O-CH_2Ph), 739, 699 (ar). ^{1}H NMR ($CDCl_3$, 500 MHz): δ (ppm) 7.31 (m, 15H, 3 Ph), 4.86 (bs, 2H, N-H), 4.79–4.17 (m, 10H, H-1/H5/3CH_2Ph), 3.88 (bs, 2H, H-2/H4), 3.79 (m, 1H, H-3), 3.13 (bs, 4H, CH_2-a), 1.47 (bs, 4H, CH_2-b), 1.31 (bs, 4H, CH_2-c); ^{13}C NMR ($CDCl_3$, 125 MHz): δ (ppm) 156.37, 156.20 (C═O), 138.38, 138.14, 138.07 (3C, Ph), 128.34, 128.17, 127.96, 127.89, 127.74, 127.66 (15C, Ph), 79.06 (C-3), 77.28, 77.03 (C-2/C4), 74.65, 73.13, 72.06 (3OCH_2Ph), 63.52, 62.98 (C-1/C5), 40.91 (CH_2-a), 29.85 (CH_2-b), and 26.34 (CH_2-c).

Anal. Calcd. for $(C_{34}H_{42}N_2O_7) \cdot (H_2O)_{0.5}$: C, 68.09; H, 7.23; N, 4.67. Found: C, 68.05; H, 7.34; N, 4.95.

Polyurea PUR-(ABnNH$_2$-HMDI)

In a typical procedure, the carbohydrate-based diamine 1,6-diamino-1,6-dideoxy-2,3,4-tri-*O*-benzyl-L-arabinitol (**6a**, ABnNH_2) (145 mg, 0.345 mmol) was charged in a round-bottom flask with an inlet of Ar/vacuum. The system was treated with three cycles of vacuum-argon before the addition, via cannula, of dried *N*,*N*-dimethylacetamide (DMA) (2 mL). The mixture was stirred to homogenization, the di-isocyanate (HMDI, 82 μL, 0.5 mmol) was added under argon atmosphere, and the mixture was stirred at rt for 30 min. The catalyst was then added (dibutyltin dilaurate, one drop), and stirring was continued for a further 30 min under argon atmosphere, at rt. 1-Decaneamine (0.5 mL) was added, the mixture was stirred for 30 min, and the reaction mixture was dropped into cold *tert*-butylmethyl ether (^{t}BME) (200 mL), where the polymer PUR-(XBnNH_2-HMDI) precipitated. The polyurea was purified by several washes with ^{t}BME. The pure polymer (pale yellow solid) was dried under vacuum for 2 d and stored in a desiccator (0.2 g, 98% yield). $[\alpha]_D$ $+0.01^\circ$ (*c* 1.0, sulfuric acid). M_w 4100; M_n 3800; M_w/M_n 1.1. IR: ν (cm^{-1}) 3333 (N-H), 3054, 3029 (C-H ar), 1619 (C═O urea), 1077 (C-O-CH_2Ph), 735, 697 (ar). ^{1}H NMR (DMSO-d_6 500 MHz): δ (ppm) 7.32 (sa, 15H, 3 Ph), 5.86 (sa, 4H, N-H), 4.60 (sa, 6H, 3CH_2Ph), 3.72 (sa, 2H, H-2/H-4) 3.59 (sa, 1H, H-3), 3.41 (sa, 2H, H-1A/H-5A), 3.20 (sa, 2H, H-1B/H-5B), 2.96 (sa, 4H, CH_2-a), 1.34 (sa, 4H, CH_2-b), 1.25 (sa, 4H, CH_2-c); ^{13}C NMR (DMSO-d_6, 125 MHz): δ (ppm) 158.62 (C═O), 139.16 (3C, Ph), 128.58, 128.36, 128.12, 127.79 (15C, Ph), 79.64 (C-2/C4), 78.89 (C-3), 74.06, 72.40 (3OCH_2Ph), 39.87 (CH_2-a), 39.66 (C-1/C5), 30.53 (CH_2-b), and 22.56 (CH_2-c).

Anal. Calcd. for ($C_{34}H_{42}N_2O_7$): C, 69.36; H, 7.53; N, 9.52. Found: C, 69.72; H, 8.05; N, 10.12.

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