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New polyfunctional dendritic linear hybrids from terminal amine polyether oligomers (Jeffamine®): synthesis and characterization

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Abstract—New dendritic polyether oligomers were synthesized from three different Jeffamines® and characterized. This class of polyfunctional oligomers, bearing on their surface methylester, carboxylic acid, nitrile or amine groups, could be interesting modifying agents to change the properties of materials. The optimization of the iterative synthetic methods, through Michael addition, hydrolysis or hydrogenation, gave first and second generation dendritic structures in good yields.

It is well known that the incorporation of a predominantly poly(oxyethylene) (POE) or poly(oxypropylene) (POP) backbone within different materials can change and improve their properties, such as hydrophilicity/hydrophobicity ratio,[1] biocompatibility,[2] and kinetic parameters of solid-phase reactions.[3] Additionally, it has been demonstrated that branched Jeffamines®, polyether oligomers of different molecular weight terminated at each end with an amine group, contribute to improved such properties as conductivity[4] and tenacity.[5,6] Therefore, Jeffamines®, are extensively used as modifiers of organic and inorganic compounds. For example, Jeffamines® were used as hydrophilic spacer arms in electrodes through reaction to form an amide linkage,[7] and as chelating agents for agricultural applications.[8] Other applications are in the synthesis of hydrophilic polymers such as graft, segmented copolymers or crosslinked products by using either Jeffamine® mono or diamine.[1,9]

The synthesis and design of highly branched molecules thus creates a special class of compounds that possesses unusual properties that are rarely observed in random and coiled polymers.[10,11]

Since the advantages of dendritic effects are well known,[12] the dendrimerization of materials is today a convenient method to obtain a new type of hybrid polymers, which is being widely developed.[13–15] In light of the increasing interest in these modified agents, we report here the synthesis and characterization of new hybrid molecules bearing nitrile, methylester or amine functional groups from the dendrimerization of Jeffamines®. These structures could have new and interesting applications, such as grafting or crosslinking agents, or macromonomers for the preparation of new materials with specific characteristics, such as amphilicity, tenacity, functionality, etc. Arm end groups can be added in a specific manner to obtain either identical end groups or specific moieties at specific arms to produce targeted interaction sites.

The pathway for the synthesis of the dendritic products from Jeffamine® (4,7,10-trioxa-1,13-tridecanediamine) **1** is shown in Figure 1. This amine core was treated with an excess (50%) of acrylonitrile to generate the yellowish oil tetranitrile **2** (96% yield),[17] confirmed by the appearance of the typical IR band of the nitrile group at 2248 cm^{-1} and the appearance of ^{13}C NMR resonance peaks at δ 17.34 and 119.06 corresponding to CH_2CN and *C*N, respectively. Tetraamine **3** was synthesized by catalytic hydrogenation of **2** using PtO_2 activated with 37% aqueous HCl. The product, purified (95% yield)[18] and characterized by FTIR and NMR spectroscopy, gave the typical ^{13}C NMR signals at δ 37.80 and 24.71 assigned to the α- and β-aminomethylene groups,

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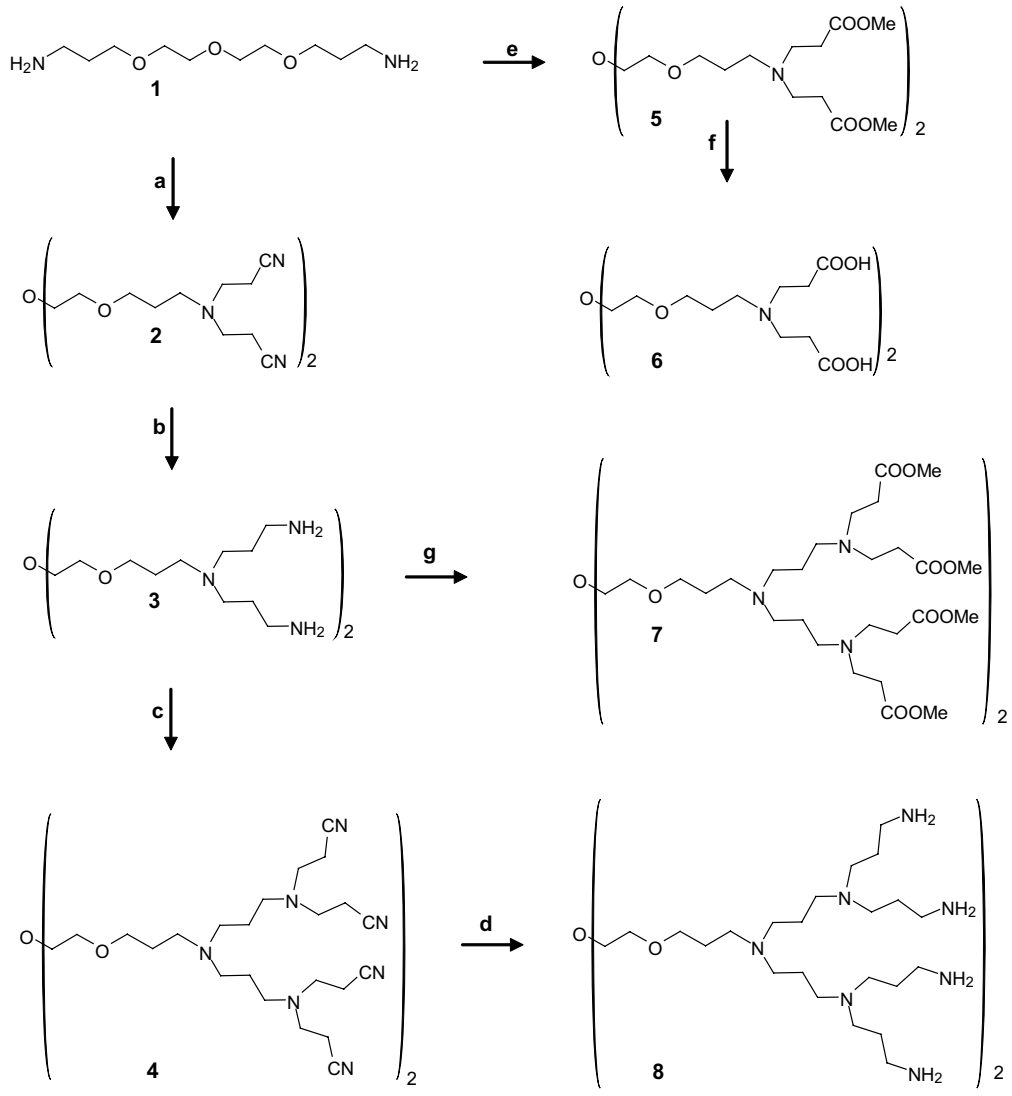

Figure 1. Reaction conditions: (a) AN/H_2O, 96%, 48 h; (b) Pt^0, EtOH, 45 psi H_2, rt, 17 h; (c) AN/H_2O, 40%, 80 h; (d) Pt^0, EtOH, 45 psi H_2, rt, 24 h; (e) MA/MeOH, 93%, 24 h; (f) HCl 1.5 N, rt, 96%, 170 h; (g) MA/MeOH, 46%, 80 h.

respectively, and the disappearance of the IR band of the nitrile group at 2248 cm^{-1}.

Once **3** was obtained, its Michael reaction with acrylonitrile led to **4** with a yield of 40%.[20] The presence of the typical band of the nitrile group at 2250 cm^{-1} (FTIR) and the appearance of the ^1H NMR resonances at δ 1.66 (12H, br), 2.47 (32H, br), 2.81 (16H, t), 3.36 (4H, t), 3.55 (8H, br) confirmed the success of this reaction.

Tetraester **5** was synthesized in 93% yield[17] by the Michael reaction of **1** with an excess of methylacrylate (50%) and was identified by the ^1H NMR signals appearing at δ 2.40 (12H, br), 2.74 (8H, t) and 3.62 (12H, s), and the ^{13}C NMR carbonyl carbon signal at δ 172.87. Subsequently, hydrolysis under acid conditions of **5** using 1.5 N HCl resulted in **6** with a yield of 96%.[19] The presence of carboxylic acid groups was confirmed by ^1H NMR through the disappearance of the signal at δ 3.62 (12H, s) of methyl ester and ^{13}C NMR by the disappearance of the peak at δ 51.35 (OCH_3) and the appearance of a peak at δ 174.58 (*C*OOH).

Octamethyl ester **7** was obtained from **3** in 46% yield[20] by Michael addition using methylacrylate in excess (70%).

Reduction of octanitrile **4** (Pt^0, EtOH, 45 psi H_2, rt, 24 h) led to octaamine **8** (95% yield),[21] as confirmed by the appearance of ^{13}C NMR peaks at δ 39.21 and 30.97, assigned to the α- and β-aminomethylene groups, respectively.

Yield optimization of the described Michael addition reactions required high temperatures and long reaction times. The reduced reactivity of the amine, compared with those in conventional Michael additions, can only be explained by a reduction in the nucleophilic capacity of the amine groups in the dendrimerization of Jeffamines. According to Dusek and Matejka,[16] the reactivity

of the terminal primary amino groups of these PPO- or POE-based amines differs from that of NH_2 groups of aliphatic amines for two main reasons, namely (i) the presence of the methyl substitution effect in the amine group reactivity is more negative than in aliphatic amines, and (ii) the inter- and intramolecular interactions caused by hydrogen bond formation. Consequently, the presence of the ether group in the Jeffamines, were the oxygen atom is a strong H-acceptor, appears to be responsible for the decrease of the amine nucleophilicity.

Once the described pathways were optimized, two additional commercial Jeffamines were used to obtain the tetranitriles **9** and **13**,[17] the tetraamines **10** and **14**,[18] the tetraesters **11** and **15**[17] and the tetraacids **12** and **16**,[19] shown in Figure 2 for the Jeffamine D230, and in Figure 3 for the Jeffamine ED600.

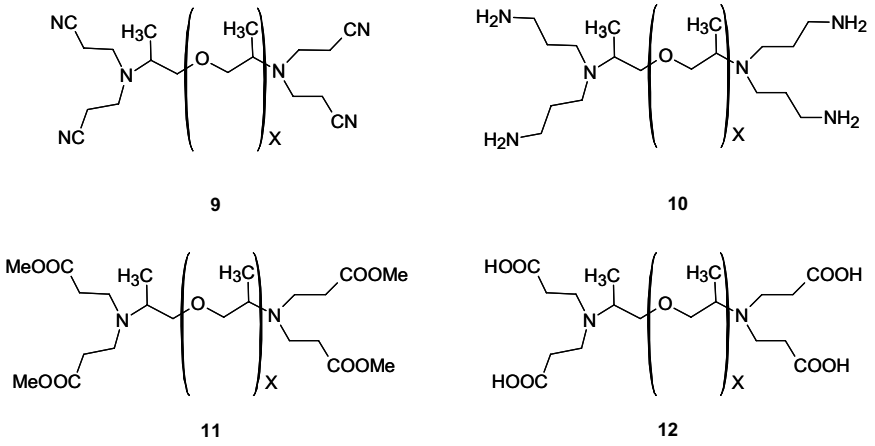

Figure 2. Compounds derived from Jeffamine D230, with $x = 2–3$.

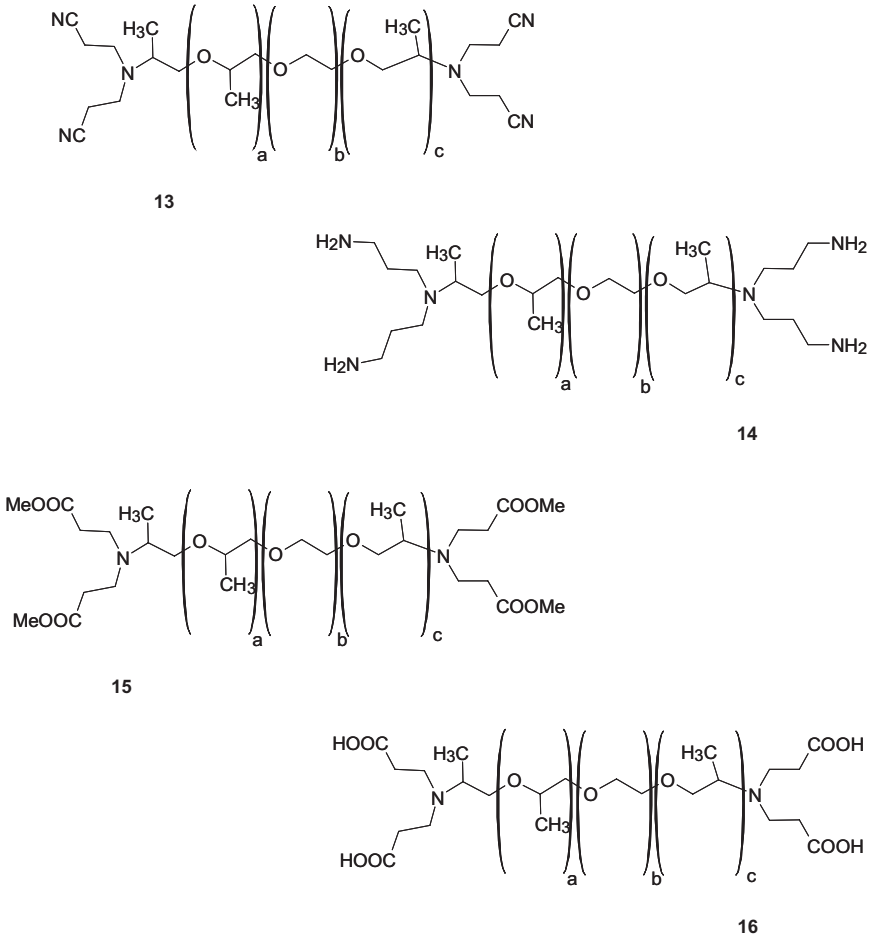

Figure 3. Compounds derived from the Jeffamine ED600, with $b = 9$ and $a + c = 3.6$.

The syntheses products **9**–**16** are yet to be optimized, due their different solubilities, compared with those of their counterparts prepared from 4,7,10-trioxa-1,13-tridecanediamine (structure **1**). Jeffamines with CN and OMe in their surface were highly soluble in a wide range of solvents, such as chloroform, dichloromethane and hexane, whereas products with NH_2 and COOH, were only soluble in water and DMSO. These results show how the dendronization affects the behaviour of the final products.

A study of the potential applications of these novel Jeffamine-based dendritic structures in the preparation of functional materials is currently in progress.

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17. General procedure for the synthesis of compounds **2**, **5**, **9**, **11**, **13** and **15** by Michael addition. To a solution of diamine **1**, Jeffamine D230 or Jeffamine ED600 (2.3 mmol) in water (5 mL) at 5 °C, acrylonitrile (18.4 mmol) was added dropwise. After stirring for 1 h at 5 °C, the resulting mixture was heated to 80 °C for 24 h to obtain compounds **2** and **5**, for 80 h for **9** and **13** and for 48 h for **11** and **15**. After cooling, the solvent and the excess acrylonitrile were removed in vacuo to give a residue that was dissolved in CH_2Cl_2, washed repeatedly with water, dried ($MgSO_4$) and concentrated in vacuo to give the yellowish octanitriles **2**, **9**, **13** and octamethyl esters **5**, **11**, **15**. Compound **2**: 96% yield. ^{13}C NMR ($CDCl_3$) δ 17.34 (CH_2CN), 27.87 (CH_2CH_2CH2), 49.92 (CH_2CH_2CN), 50.16 (NCH_2), 68.33 (CH_2O), 70.51 (CH_2CH_2O), 70.86 (CH_2CH_2O), 119.06 (CN); ^1H NMR ($CDCl_3$) δ 1.73 (4H, q), 2.52 (8H, t), 2.66 (4H, t), 2.86 (8H, t), 3.56 (4H, s), 3.62 (8H, s); IR 1116, 1470, 2248, 2866, 2923 cm^{-1}. Compound **5**: 93% yield. ^{13}C NMR ($CDCl_3$) δ 27.18 (CH_2CH_2CH2), 32.42 (CH_2COOCH_3), 49.16 ($CH_2CH_2COOCH_3$), 55.20 (CH_2N), 58.35 (OCH_3), 68.92 (CH_2O), 69.96 (CH_2CH_2O), 70.40 (CH_2CH_2O), 172.87 ($COCH_3$); ^1H NMR ($CDCl_3$) δ 1.68 (4H, q), 2.38–2.50 (12H, m), 2.74 (8H, t), 3.44 (4H, t), 3.59 (8H, t), 3.50–3.67 (20H, m); IR 1118, 1465, 1736, 2852, 2919 cm^{-1}. Compound **9**: ^{13}C NMR ($CDCl_3$) δ 14.50 (br CH_3CH_2N), 17.40 (br CH_3CH_2O), 19.15 (CH_2CN), 47.57 (br, CH_2CH_2CN), 55.90 (CH), 56.20 (CH), 72.24–75.80 (CH_2O and CHO), 119.22 (CN); ^1H NMR ($CDCl_3$) δ 1.05–1.17 (12H, m), 2.49 (8H, t), 2.75–3.75 (20H, m), IR 1095, 1375, 1461, 2244, 2852, 2919 cm^{-1}. Compound **11**: ^{13}C NMR ($CDCl_3$) δ 14.52 (br CH_3CH_2N), 17.43 (br CH_3CH_2O), 34.46 (CH_2COOCH_3), 47.93 (br, $CH_2CH_2COOCH_3$), 55.56 (m, CH and OCH_3), 72.20–75.80 (CH_2O and CHO), 172.90 ($COOCH_3$); ^1H NMR ($CDCl_3$)δ 1.06–1.18 (12H, m), 2.60 (8H, t), 2.90 (8H, t), 3.35–3.85 (24H, m); IR 1105, 1360, 1463, 1735, 2852, 2919 cm^{-1}. Compound **13**: ^{13}C NMR ($CDCl_3$) δ 14.72 (br CH_3CH_2N), 17.45 (br CH_3CH_2O), 19.11 (CH_2CN), 47.57 (br, CH_2CH_2CN), 55.93 (CH), 56.26 (CH), 70.89–75.69 (CH_2O and CHO), 119.22 (CN); ^1H NMR ($CDCl_3$) δ 1.03–1.14 (12H, m), 2.47 (8H, t), 2.89 (12H, m), 3.20–3.70 (54H, m); IR 1115, 1365, 1460, 2247, 2849, 2918 cm^{-1}. Compound **15**: ^{13}C NMR ($CDCl_3$) δ 14.72 (br CH_3CH_2N), 17.46 (br CH_3CH_2O), 34.43 (CH_2COOCH_3), 47.57 (br, $CH_2CH_2COOCH_3$), 55.93 (OCH_3), 56.26 (NCH), 70.80–75.70 (CH_2O and CHO), 171.90 ($COOCH_3$); ^1H NMR ($CDCl_3$) δ 1.03–1.14 (12H, m), 2.46 (8H, t), 2.89 (12H, t), 3.20–3.70 (66H, m); IR 1107, 1373, 1459, 1734, 2862, 2921 cm^{-1}.
18. General procedure for the synthesis of compounds **3**, **10**, **14** by catalytic hydrogenation. A stirred EtOH suspension of compounds **2**, **9** or **13** (232 μmol), PtO_2 (20 mg) and HCl 37% (130 μL) was maintained at 45 psi of H_2 and 25 °C for 17 h for compound **3** and 24 h for compounds **10** and **14**. The solution was then filtered and evaporated in vacuo and extracted with water to obtain the tetraamines. Compound **3**: ^{13}C NMR (D_2O) δ 22.94 ($CH_2CH_2NH_2$), 24.71 (CH_2CH_2N), 37.80 (CH_2NH_2), 51.34 and 52.24 (CH_2NCH_2), 68.79 ($CH_2CH_2CH_2N$), 70.73 and 70.77 (CH_2CH_2O); ^1H NMR δ 1.45–1.85 (12*H*, m), 2.30–2.65 (20*H*, m), 3.53 (4*H*, t), 3.63 (8*H*, m); IR 1120, 1407, 1470, 1537, 1618, 2869, 2938, 3363 cm^{-1}. Compound **10**: ^{13}C NMR (D_2O) δ 9.00, 9.30 and 9.83 (CH_3CHN), 15.63, 15.93 and 16.06 (CH_3CHO), 22.58 ($CH_2CH_2CH_2$), 36.61 (CH_2NH_2), 48.38 and 48.44 (CH_2NCH_2), 58.38 and 58.70 (CHN), 66.18, 66.44, 66.47, 67.98 and 68.80 (CH_2O), 73.98 (CH_2O), 74.96 (OCH); ^1H NMR δ 0.90–1.30 (12*H*, m), 2.07 (8*H*, br m), 2.80–3.90 (28*H*, m); IR 1105, 1377, 1460, 2852, 2919, 3380 cm^{-1}. Compound **14**: ^{13}C NMR (D_2O) δ 9.03, 9.35 and 9.85 (CH_3CHN), 15.60, 15.89 and 16.10 (CH_3CHO), 22.60 ($CH_2CH_2CH_2$), 36.60 (CH_2NH_2), 48.40 and 48.48 (CH_2NCH_2), 58.41 and 58.74 (CHN), 66.20, 66.48, 66.50, 68.08 and 68.78 (CH_2O), 74.09 (CH_2O), 74.99 (OCH); ^1H NMR δ 0.90–1.30 (12*H*, m), 2.10 (8*H*, br m), 2.60–3.90 (68*H*, m); IR 1106, 1375, 1484, 2861, 2940, 3343 cm^{-1}.

19. General procedure for synthesis of compounds **6**, **12** and **16** by hydrolysis. These tetramethyl esters were hydrolyzed with HCl 1.5 N at 25 °C for 170 h. The solvent and the excess HCl were then removed in vacuo to obtain the tetraacids **6**, **12** and **16**, as yellowish oils. Compound **6**: ^{13}C NMR (D_2O) δ 23.84 ($CH_2CH_2CH_2$), 28.91 (CH_2COOH), 49.95 (CH_2CH_2COOH), 52.81 (NCH_2), 68.61 (OCH_2), 70.20 (OCH_2), 174.58 (CO_2H); ^{1}H NMR (D_2O) δ 2.14 (4*H*, t), 3.01 (8*H*, t), 3.43 (4*H*, t), 3.58 (8*H*, t), 3.73 (12H, br s); IR 1125, 1473, 1735, 2860, 2920, 3350 cm^{-1}. Compound **12**: ^{13}C NMR (D_2O) δ 14.55 (br CH_3CH_2N), 17.40 (br CH_3CH_2O), 28.96 (CH_2COOH), 51.01 (br, CH_2CH_2COOH), 55.95 (*C*H), 56.20 (*C*H), 72.30–75.85 (CH_2O and *C*HO), 174.22 (*C*OOH); ^{1}H NMR ($CDCl_3$) δ 1.05–1.22 (12H, m), 2.92 (8H, t), 3.00–3.95 (20H, m), IR 1098, 1379, 1451, 1734, 2870, 2925, 3430 cm^{-1}. Compound **14**: ^{13}C NMR (D_2O) δ ^{13}C NMR (D_2O) δ 14.57 (br CH_3CH_2N), 17.43 (br CH_3CH_2O), 28.98 (CH_2COOH), 51.03 (br, CH_2CH_2COOH), 55.93 (*C*H), 56.17 (*C*H), 72.25–75.82 (CH_2O and *C*HO), 174.32 (*C*OOH); ^{1}H NMR ($CDCl_3$) δ 1.05–1.22 (12H, m), 2.92 (8H, t), 3.00–3.95 (60H, m); IR 1103, 1370, 1458, 1736, 2865, 2915, 3453 cm^{-1}.

20. General procedure for synthesis of compounds **4** and **7** by Michael addition. To a solution of tetraamine **3** (230 μmol) in water (5 mL) kept at 5 °C, acrylonitrile (for **4**) or methylacrylate (for **7**) (18.4 mmol) was added dropwise. After stirring for 1 h at 0 °C, the resulting mixture was heated at 80 °C for 80 h to obtain compounds **4** and **7**. After cooling, the solvent and the excess acrylonitrile were removed in vacuo to give a residue that was dissolved in CH_2Cl_2, washed repeatedly with water, dried ($MgSO_4$) and concentrated in vacuo to give the yellowish octanitrile **4** and octamethyl esters **7**. Compound **4**: 40% yield. ^{13}C NMR (CD_2Cl_2) δ 17.08 (CH_2CN), 27.66 ($CH_2CH_2CH_2$), 27.86 ($CH_2CH_2CH_2$), 49.86 (CH_2CH_2CN), 50.16, 50.50 and 51.02 (NCH_2), 68.33 (CH_2O), 70.51 (CH_2CH_2O), 70.86 (CH_2CH_2O), 119.06 (*C*N); ^{1}H NMR (CD_2Cl_2) δ 1.50–1.80 (12H, m), 2.40–2.60 (32H, m), 2.81 (16H, t), 3.46 (4H, t), 3.55 (8H, m); IR 1130, 1471, 1650, 2250, 2950, 2979 cm^{-1}. Compound **7**: 46% yield. ^{13}C NMR ($CDCl_3$) δ 27.36 and 27.90 ($CH_2CH_2CH_2$), 32.86 (CH_2COOCH_3), 50.25 ($CH_2CH_2COOCH_3$), 52.16, 52.55 and 53.24 (NCH_2), 56.63 (OCH_3), 68.98 (CH_2O), 70.59 and 70.68 (CH_2CH_2O), 172.86 (COOCH3); ^{1}H NMR ($CDCl_3$) δ 1.57–2.20 (12H, m), 2.10–2.80 (52H, m), 3.40–3.70 (32H, m); IR 1136, 1470, 1645, 1738, 2955, 2983 cm^{-1}.

21. Procedure for the synthesis of compound **8** by catalytic hydrogenation. A stirred EtOH suspension of compounds **4** (115 μmol), PtO_2 (20 mg) and HCl 37% (130 μL) was maintained at 45 psi of H_2 and 25 °C for 24 h. The solution was filtered and evaporated in vacuo and then extracted with water to give octaamines. Compound **8**: ^{13}C NMR (D_2O) δ 27.34 and 28.17 ($CH_2CH_2CH_2$), 30.97 ($CH_2CH_2NH_2$), 39.21 (CH_2NH_2), 50.75, 51.34, 52.24 and 53.03 (CH_2NCH_2), 68.89 (CH_2O), 70.73 and 70.77 (CH_2CH_2O); ^{1}H NMR δ 1.67 (28*H*, m), 2.51 (26*H*, m), 3.54 (4*H*, t), 3.65 (8*H*, m); IR 1115, 1407, 1475, 1540, 2870, 2936, 3383 cm^{-1}.