Special Collection

Functionalized Chiral Bambusurils: Synthesis and Host-Guest Interactions with Chiral Carboxylates

Jan Sokolov, Adam Štefek, and Vladimír Šindelář*[a]

Bambusurils are a class of macrocyclic anion receptors that exhibit notable anion recognition properties, able to bind various inorganic anions as well the carboxylates or sulfonates. Recently, we reported enantioselective recognition of chiral carboxylates using non-functionalized chiral bambusuril derivatives. Herein, we report the synthesis and host-guest properties of two new representatives of chiral bambusuril macrocycles bearing ester functional groups, differing by the substituents attached to their portals. Their supramolecular properties in terms of carboxylate binding were studied by means of NMR in DMSO-d_6. The reported bambusurils bind selected chiral carboxylates with enantioselectivity factors up to 3.1. The results indicated that the selectivity towards different carboxylates is governed by the steric constraint of the substituents surrounding bambusuril portals. No clear trend in the binding affinities and their enantioselectivities was found.

Introduction

Many important biological molecules and active pharmaceutical ingredients are chiral.[1,2] With respect to drug research, chiral compounds are often found as single enantiomers, since the opposing enantiomers may not contribute to the treatment or may exhibit undesirable biological activity. This encouraged the development of enantioselective synthetic methodologies as well the analytical methods for determination of enantiomeric excess.[3] Supramolecular chemistry features a variety of systems with high potential for utilization in asymmetric catalysis or chiral sensing. Many representatives of chiral coordination compounds possess catalytic properties,[4] and chiral host molecules such as cyclodextrins or crown ethers can be used in preparing chiral stationary phases for the chromatographic separation of enantiomers.[5,6]

There are many relevant chiral compounds that contain carboxylic or sulfonic groups. These groups are readily deprotonated, yielding anionic forms of these compounds. This opens the opportunity to exploit anion interactions in preparing optically pure compounds. In this respect, there exists an interest to prepare chiral receptors that are able to discriminate enantiomers of anions. Such receptors can be divided into several classes based on major interactions responsible for the anion binding. Major representatives of chiral anion receptors are positively charged. They consist of one or more ammonium and/or guanidinium moieties[7–12] and are usually found protonated at physiological conditions, exploiting charge-assisted hydrogen bonding. However, they are prone to lose their binding properties at higher pH due to deprotonation. On the other hand, neutral receptors can retain their binding ability also at higher pH. In addition, unlike charged receptors, neutral receptors do not possess counter-ions that could interfere with the guest binding and reduce their affinity and selectivity. Traditional neutral anion receptors interact with chiral anions through hydrogen bonding of amide,[13,14] urea[15–20] or thiourea[21–24] moieties. In addition, there are also examples of chiral hosts that utilize halogen bonding[25–28] and metal coordination[29,30] for enantioselective recognition of anionic guests.

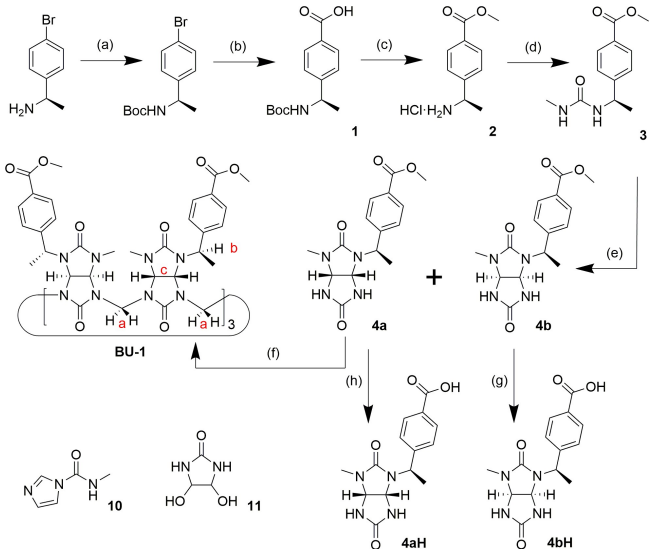
Bambus[6]urils[31–34] are a family of macrocyclic compounds pioneered by our group. They are composed of six repeating 2,4-dialkylglycoluril units connected by a row of methylene bridges. Alternating arrangement and the presence of ethyleneurea motives in their building blocks make bambusurils closely related to hemicucurbituril macrocycles.[35–38] Bambusurils, similar as hemicucurbiturils, can be classified as C–H donors as they bind anionic guests via twelve methine C–H groups inside their cavity. These macrocycles can encapsulate not only a large variety of inorganic anions but also carboxylates and sulfonates.[39,40] Previously, several chiral hemicucurbituril derivatives were reported and their binding to chiral carboxylates were investigated.[41–43]

In our previous research, we developed the synthesis of first chiral bambusurils and studied their affinity and enantioselectivity towards different chiral carboxylate anions.[44] We showed that these bambusurils were able to bind enantiomers of chiral carboxylates with selectivity up to 3.2. However, the absence of functional groups prevented further application of the macrocycles (e.g. for chiral stationary phases of chromatography column). In this work, we present the synthesis of functionalized chiral bambusuril derivatives bearing carboxylic groups, likely to broaden the range of potential application of chiral bambusurils.

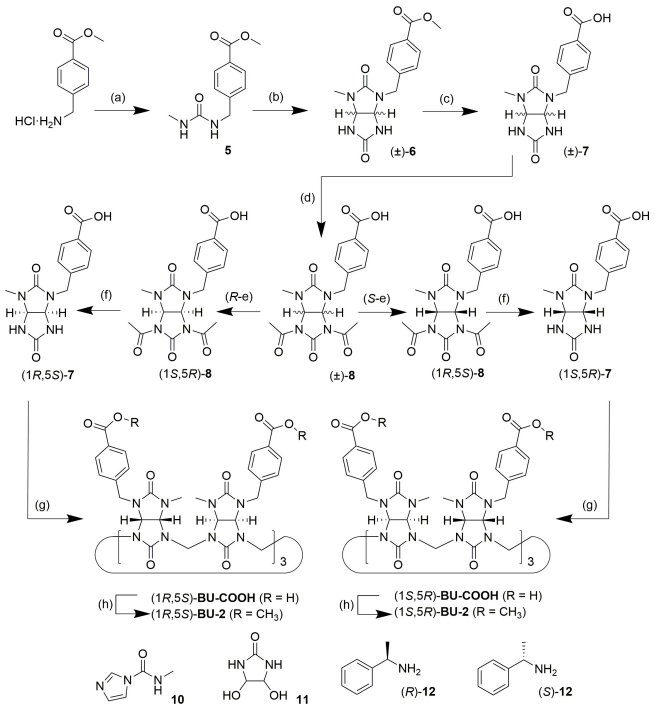
[a] J. Sokolov, A. Štefek, Prof. V. Šindelář
Department of Chemistry and RECETOX
Faculty of Science, Masaryk University
Kamenice 5, 625 00 Brno (Czech Republic)
E-mail: sindelar@chemi.muni.cz

Supporting information for this article is available on the WWW under https://doi.org/10.1002/cplu.202000261

This article is part of a Special Collection on "Chemistry in the Czech Republic".



Scheme 1. Synthetic procedures towards chiral macrocycle **BU-1**. Conditions: (a) Boc_2O, TEA, DCM, 25 °C, 6 h, 98%. (b) 1. MeLi, *n*-BuLi, THF, −78 °C, 0.5 h, 2. CO_2, from −78 to 0 °C, 52%. (c) $SOCl_2$, MeOH, 60 °C, 4 h, 95%. (d) **10**, TEA, DCM, 25 °C, 16 h, 82%. (e) **11**, aq. HCl, 80 °C, 2 h, 39% (**4a**). (f) 1. CH_2O, H_2SO_4, dioxane, 80 °C, 1.5 h, 2. MeOH, H_2O, 80–25 °C, 16 h, 51%. (g) 1. KOH, MeOH, 65 °C, 4 h, 2. aq. HCl, 5%.



Scheme 2. Synthetic procedures towards chiral macrocycles (1*R*,5*S*)-**BU-2** and (1*R*,5*S*)-**BU-2**. Conditions: (a) **10**, TEA, DCM, 25 °C, 16 h, 92%. (b) **11**, aq. HCl, 80 °C, 2 h, 88%. (c) 1. KOH, MeOH, 65 °C, 4 h, 2. aq. HCl, 90%. (d) Ac_2O, H_2SO_4, 25 °C, 16 h, 93%. (*S*-e) 1. (*S*)-**12**, dioxane, 2. aq. HCl. (*R*-e) 1. (*R*)-**12**, dioxane, 2. aq. HCl (f) 1. KOH, MeOH, 25 °C, 10 min, 2. aq. HCl 97%. (g) 1. CH_2O, H_2SO_4, dioxane, 80 °C, 1.5 h, 2. H_2O, NH_3, 3. H_3PO_4. (h) 1. $SOCl_2$, MeOH, 60 °C, 2 h, 2. $AgSbF_6$, MeOH, DCM, 39% over (g) + (h).

Results and Discussion

Synthesis of glycoluril building blocks

We prepared chiral glycolurils using unsymmetrically substituted chiral urea (Scheme 1). The condensation of **3** with **11**[45] produced two diastereomeric glycolurils **4a** and **4b**. Diastereomer **4a** readily precipitated during the reaction and was isolated by simple filtration. On the other hand, **4b** remained dissolved in the mother liquor. Crude **4b** was obtained by evaporation of the solvent and extraction into acetone. Ester **4b** was subsequently hydrolyzed to yield carboxylic acid **4bH**, which was purified by precipitation from water in the presence of a mineral acid. However, low yields of **4bH** (5%) discouraged us from further preparing the bambusuril using this compound.

We also decided to synthesize enantiomers of glycolurils (±)-**6** (Scheme 2) which are analogues of **4a** and **4b** lacking α-methyl groups. In this case, the resulting glycoluril was prepared as a racemate (±)-**6** by the reaction of achiral urea **5** and vicinal diol **11**. Prior to the macrocyclization reaction with formaldehyde, the racemate (±)-**6** has to be separated into enantiomerically pure glycolurils to ensure that the subsequent macrocyclization produces chiral bambusuril as a single isomer. To perform the resolution, glycoluril (±)-**6** had to be modified. Firstly, the ester group was hydrolyzed to give carboxylic acid, producing glycoluril (±)-**7**. Compound (±)-**7** was subsequently treated with Ac_2O, yielding (±)-**8** having enhanced solubility in organic solvents. Enantiomers of (±)-**8** were then resolved by the crystallization with enantiomerically pure 1-phenylethylamine **12** from dioxane. After the resolution, acetyl groups were removed by treatment with KOH yielding enantiomerically pure (1*S*,5*R*)-**7** and (1*R*,5*S*)-**7** suitable for bambusuril synthesis.

Prior to the further use of glycolurils **7**, we assessed their optical purity. Instead of using enantioselective HPLC analysis we were able to utilize NMR spectroscopy for this purpose. We found out that tetrabutylammonium salt of (±)-**7** interacts with the previously reported bambusuril **BU-3**[44] in DMSO-d_6 (Figure 1). The interaction was identified through splitting of the singlet of the methyl group of (±)-**7** into two signals in the presence of excess of **BU-3**. Each signal belongs to different diastereomeric complexes of **BU-3** with enantiomers of **7**. Therefore, it was possible to use ^{1}H NMR to distinguish between enantiomers of **7** and to determine its enantiomeric composition.

As all three glycolurils **4a**, (1*S*,5*R*)-**7**, and (1*R*,5*S*)-**7** were successfully prepared, their absolute configuration was not known. Therefore, we converted the glycolurils to corresponding amides **13**, **14a** and **14b** by the reaction with (*S*)-1-(2-naphthyl)ethylamine (Figure 2). These amides were subsequently crystallized to produce crystals suitable for X-ray diffractometry.[46] Analysis of crystal structures allowed determination of absolute configuration of the corresponding glycolurils.

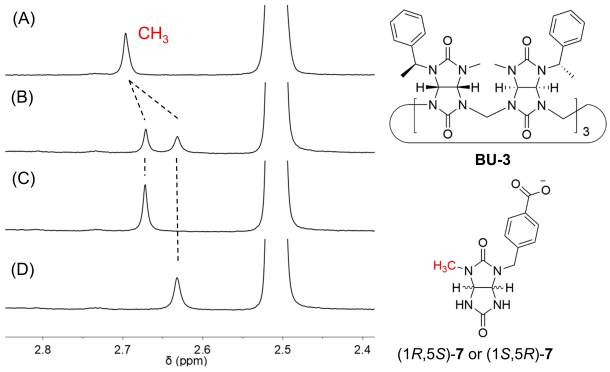


Figure 1. Partial ^{1}H NMR spectra (DMSO-d_6, 300 MHz, 30 °C) of (±)-**7** in the absence of any host (A), (±)-**7** in the presence of **BU-3** (B), (1*R*,5*S*)-**7** in the presence of **BU-3** (C), (1*S*,5*R*)-**7** in the presence of **BU-3** (D). Diastereomeric complexes (1*R*,5*S*)-**7**·**BU-3** and (1*S*,5*R*)-**7**·**BU-3** can be distinguished following the methyl signal of **7** (highlighted with red color). Compound **7** is present as TBA salt at 2.2 mM concentration in all cases, concentration of **BU-3** was 4.4 mM. Signal at 2.5 ppm is DMSO.

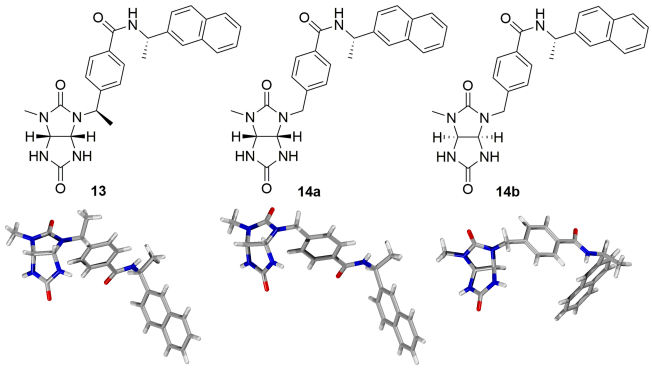


Figure 2. Molecular formulas and X-ray structures of chiral amides **13** (CCDC 2005908), **14a** (CCDC 2005909), and **14b** (CCDC 2005910).

Synthesis of bambusurils

Glycolurils **4a**, (1*S*,5*R*)-**7** and (1*R*,5*S*)-**7** were subjected to macrocyclization reactions, in which corresponding glycolurils reacted with paraformaldehyde in dioxane. Without the presence of template, the reaction would yield unwanted four-membered bambusuril as a main product.[47] Therefore, the reaction was performed in the presence of sulfuric acid, which provides HSO_4^- anion as a template that facilitates the formation of a six-membered macrocycle and also acts as a catalyst. Corresponding bambusurils were isolated from their reaction mixtures as complexes with HSO_4^- (Scheme 1).

Our aim was to prepare all bambusurils as methyl esters, suitable derivatives for future supramolecular study in DMSO. Bambusurils bearing carboxylic function were undesired as these groups would compete for binding with the carboxylate guests. Bambusuril **BU-1** was available in its ester form directly after the synthesis as complex with HSO_4^-. It was previously described that, in aqueous media, HSO_4^- is deprotonated to SO_4^{2-} that is poorly complexed by bambusurils due to its strong hydration.[48] Thus, anion-free **BU-1** was obtained after washing the complex in the methanol/water mixture in 51 % yield.

Macrocyclization of **7** produced crude bambusuril **BU-COOH**, bearing carboxylic groups (Scheme 2). Therefore, bambusuril **BU-COOH** was esterified in the presence of $SOCl_2$ providing the bambusuril **BU-2** as its complex with HCl that precipitates from the solution. Chloride anions were removed by treatment of the complex with $AgSbF_6$.[49] Chlorides were precipitated as an insoluble AgCl and replaced with SbF_6^- inside the **BU-2** cavity. The SbF_6^- anion is poorly bound by the bambusuril and was removed by simple washing with methanol and water to yield the anion-free bambusuril **BU-2**.

Host-guest properties

Previously, we published binding affinities of chiral bambusuril **BU-3** (structure shown in Figure 1) with ibuprofen **G1**, *N*-acetyl phenylalanine **G2**, *N*-acetyl leucine **G3**, mandelic acid **G4** and α-methoxyphenyl acetic acid **G5** (Figure 3).[44] In this study we further included the amino acid proline **G6** and have investigated these molecules as guests for the newly prepared bambusurils. Tetrabutylammonium was used as a counter cation for all the guests.

Supramolecular interactions of bambusurils **BU-1** and **BU-2** with chiral carboxylate guests were studied by means of ^{1}H NMR in DMSO-d_6 (Figure 4). Bambusurils were used in the form of methyl esters, as free carboxylic groups would interfere with the binding of carboxylate guests. The complexation was slow

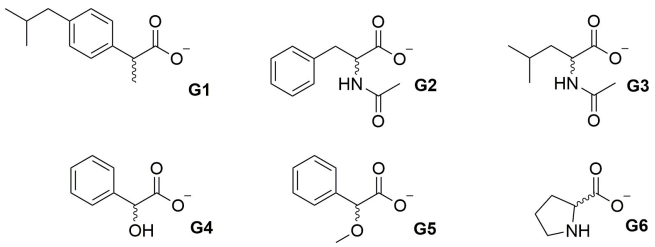


Figure 3. Guests used in this supramolecular study. Counter-ion is tetrabutylammonium in all cases.

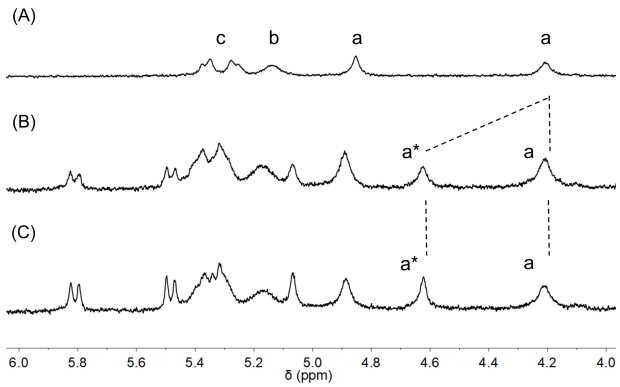


Figure 4. ^{1}H NMR spectra (DMSO-d_6, 300 MHz, 30 °C) of **BU-1** (0.69 mM) in the absence of any guest (A), in the presence of 0.5 equivalent of TBA salt of *R*-**G4** (B) and in the presence of 0.5 equiv. of TBA salt of *S*-**G4** (C). *Signal of the complexed host. Assignment of **BU-1** signals (a, b, and c) is shown in Scheme 1.

on the NMR time scale for all investigated host-guest systems. Therefore, signals of the free host and the complex could be distinguished. Integration of the corresponding signals was used to determine the concentrations of both species from which the association constants were calculated for host-guest complexes of the corresponding bambusurils and chiral anions. We also performed Job plot (Figure S68) to confirm that **BU-1** and **BU-2** and the investigated guests form complexes of 1:1 stoichiometry.

The results of the binding studies are summarized in Table 1. The structure of bambusuril **BU-1** is closely related to that of **BU-3. BU-1** differs from **BU-3** by the presence of the additional methoxycarbonyl groups, however, with the opposite absolute configurations on chiral centers of both macrocycles. For this reason, it was assumed that **BU-1** would preferentially bind enantiomers of guests that are disfavored by the **BU-3**. Indeed, this was observed for **G5**. Enantioselectivity of bambusuril **BU-1** for ***S*-G5** over *R*-**G5** is equal or greater than 3.1 as the association constant of the **BU-1**·*S*-**G5** complex is too high to be determined by direct measurement. Bambusuril **BU-3** also showed the highest enantioselectivity (3.2) towards **G5** among other guests but the macrocycle prefers to bind of *R*-**G5** over *S*-**G5**. On the other hand, in the case of guests **G3** and **G4** both **BU-1** and **BU-3** preferentially bind the same enantiomers. Bambusurils **BU-3** and **BU-1** preferentially bound *S*-**G3** over *R*-**G3** by a factor of 2.2 and >1.7, respectively. Also, *S*-**G4** was bound preferentially over *R*-**G4** by a factor of 1.9 and 1.2. However, no significant differences were observed for guests **G1**, **G2** and **G6**. These results indicate that simple modification of the bambusuril structure has a great impact on the inclusion of chiral carboxylates making it difficult to predict the substituent effect on the guest binding.

When comparing **BU-1** with **BU-2** it is clear that **BU-1** exhibits higher enantioselectivity for the corresponding couples of enantiomers. The better enantioselectivity of **BU-1** is probably due to the presence of extra methyl groups on its benzyl substituents which makes its structure more rigid compared to **BU-2**. Higher flexibility of **BU-2** could be also reason for relatively narrow range of binding affinities from 1.5×10^3 M^{-1} to 3.5×10^3 M^{-1} (except for the **BU-2**·*S*-**G3** complex). Higher enantioselectivity of **BU-1** could be also due to the presence of additional chiral centers on its portals which are in proximity of bound chiral guests. On the other hand, the range of association constants of **BU-1** complexes lays between 2.6×10^3 M^{-1} (for the complexes with *S*-**G1** and *R*-**G1**) and $>1\times10^4$ M^{-1} (for complexes with *S*-**G3**, *S*-**G5**, *S*-**G6** and *R*-**G6**).

Table 1. Association constants and corresponding enantioselectivity values of bambusuril complexes determined by ^{1}H NMR measurements in DMSO-d_6 at 30 °C.

Host	BU-1	K [M^{-1}]×10^3 [1*R*,5*S*]-BU-2	BU-3
S-**G1**	2.6±0.2	2.0±0.5	6.7±1.0
R-**G1**	2.6±0.3	3.0±0.5	7.9±1.0
S-**G2**	3.6±0.4	1.6±0.3	7.9±0.6
R-**G2**	3.0±0.2	1.7±0.4	5.9±0.8
S-**G3**	>10	6.1±0.7	9.1±0.9
R-**G3**	5.8±0.5	3.1±1.1	4.2±0.5
S-**G4**	9.5±0.4	2.6±0.3	1.6±0.4
R-**G4**	4.9±0.6	1.6±0.2	1.4±0.3
S-**G5**	>10	2.7±0.5	2.4±0.4
R-**G5**	3.2±0.6	2.5±0.5	7.6±1.1
S-**G6**	>10	2.9±0.5	9.5±1.1
R-**G6**	>10	2.7±0.5	>10
Host		K_S/K_R	
G1	1.0/1	1/1.5	1/1.1
G2	1.2/1	1/1.1	1.3/1
G3	>1.7/1	2.0/1	2.2/1
G4	1.9/1	1.6/1	1.2/1
G5	>3.1/1	1.1/1	1/3.2
G6	–	1.1/1	<1/1.2

Conclusion

In conclusion we reported the synthesis of two enantiomerically pure bambusuril derivatives bearing ester groups, which are suitable for subsequent modifications. We also demonstrated that previously reported bambusuril **BU-3** can be used as chiral shift agent for determination of enantiomeric excess of glycoluril **7**, which is essential for the synthesis of bambusuril **BU-2**. Supramolecular studies proved enantioselective binding of chiral carboxylate anions. The comparison of bambusuril **BU-1** with **BU-3** shows that introduction of ester function impacts binding preferences. Comparison of **BU-1** and **BU-2** indicate that selectivity of these macrocycles towards structurally different carboxylate guests is influenced by steric constraints of the substituents on the glycoluril moiety.

Experimental Section

Methyl 4-[(1*R*)-1-aminoethyl]benzoate hydrochloride 2

Compound **1**[50] (1.05 g, 4.0 mmol) was dissolved in MeOH (20 mL) and $SOCl_2$ (0.6 mL). The solution was heated to 60 °C for 2 h. The reaction mixture was then concentrated on rotary vacuum evaporator to approximately 1 mL and diluted with diethyl ether (20 mL). The resulting precipitate was collected by filtration, washed with diethyl ether (10 mL) and dried on air to provide compound **2** as a white powder (0.82 g, 3.8 mmol, 95%).

Characterization spectra match the reported data.[51]

N-[(1*R*)-1-(4-Methoxycarbonylphenyl)ethyl]-*N'*-methylurea 3

Compound **2** (4.51 g, 20.9 mmol) and *N*-methylcarbamoylimidazole **10**[52] (4.11 g, 32.9 mmol) were diluted with DCM (100 mL), triethyl amine (5.8 mL, 41.6 mmol) was added and the resulting mixture was stirred at room temperature overnight. DCM was then removed on rotary vacuum evaporator providing crude oily material. The crude material was sonicated with water (50 mL), which resulted in crystallization of the product. Crystals were collected by filtration, washed with water (2×10 mL) and dried under vacuum yielding urea **3** (4.04 g, 17.1 mmol, 82%).

^{1}H NMR (500 MHz, DMSO-d_6) δ 7.90 (d, J=8.2 Hz, 2H), 7.42 (d, J=8.2 Hz, 2H), 6.43 (d, J=7.9 Hz, 1H), 5.67 (q, J=4.6 Hz, 1H), 4.79 (m, 1H), 3.84 (s, 3H), 2.53 (d, J=4.7 Hz, 3H), 1.31 (d, J=7.0 Hz, 3H).

^{13}C NMR (126 MHz, DMSO-d_6) δ 166.10, 157.78, 151.68, 129.12, 127.75, 126.06, 51.95, 48.54, 26.26, 22.91.

HR-MS (APCI+): m/z $[C_{12}H_{14}N_2O+H]^+$ observed: 237.1234, calculated: 237.1235.

(1*S*,5*R*)-2-[(1*R*)-1-(4-Methoxycarbonylphenyl) ethyl]-4-methylglycoluril 4 a

Urea **3** (1.03 g, 4.4 mmol) and **11** (1.09 g, 9.2 mmol) were stirred in aq. HCl (50 mL H_2O and 0.5 mL 35% HCl) at 80 °C for 2 h. The resulting suspension was cooled in an ice bath, solids were collected by filtration and washed with water (2×10 mL). The collected solid was dried under vacuum yielding glycoluril **4 a** as a single stereoisomer (0.55 g, 1.7 mmol, 39%).

^{1}H NMR (500 MHz, DMSO-d_6) δ 7.93 (d, J=8.3 Hz, 2H), 7.53 (s, 1H), 7.49 (s, 1H), 7.44 (d, J=8.2 Hz, 2H), 5.10 (d, J=8.3, 1H), 5.03 (m, 2H), 3.85 (s, 3H), 2.65 (s, 3H), 1.55 (d, J=7.3 Hz, 3H).

^{13}C NMR (126 MHz, DMSO-d_6) δ 166.00, 161.15, 157.05, 146.68, 129.26, 128.48, 127.28, 67.60, 64.34, 52.06, 50.39, 27.62, 18.30.

HR-MS (APCI+): m/z $[C_{16}H_{18}N_4O_4+H]^+$ observed: 319.1402, calculated: 319.1401.

$[\alpha]_D^{23}=-15.2°$ (MeOH, c=0.50 g/100 mL)

(1*S*,5*R*)-2-[(1*R*)-1-(4-Carboxyphenyl)ethyl]-4-methylglycoluril 4 aH

Glycoluril **4 a** (207 mg, 0.60 mmol) and powdered KOH (72 mg, 1.28 mmol) were dissolved in MeOH (4 mL). The solution was heated to 60 °C for 4 h. MeOH was removed on rotary vacuum evaporator and the resulting solid was dissolved in water (5 mL). 35% HCl (0.5 mL) was added dropwise to the solution to precipitate white solid. Solid was collected by filtration, washed with water and dried under vacuum to produce compound **4 aH** (148 mg, 0.45 mmol, 75%).

^{1}H NMR (500 MHz, DMSO-d_6) δ 12.87 (s, 1H), 7.90 (d, J=8.4 Hz, 2H), 7.53 (s, 1H), 7.49 (s, 1H), 7.41 (d, J=8.2 Hz, 2H), 5.10 (d, J=8.2, 1H), 5.06–5.00 (m, 2H), 2.65 (s, 3H), 1.54 (d, J=7.3 Hz, 3H).

^{13}C NMR (126 MHz, DMSO-d_6) δ 167.02, 161.14, 157.05, 146.12, 129.63, 129.39, 127.08, 67.59, 64.29, 50.36, 27.62, 18.35.

HR-MS (ESI): m/z $[C_{14}H_{16}N_4O_4+H]^+$ observed: 305.1244, calculated: 305.1244.

(1*R*,5*S*)-2-[(1*R*)-1-(4-Carboxyphenyl)ethyl]-4-methylglycoluril 4 bH

Urea **3** (1.08 g, 4.6 mmol) and **11** (0.75 g, 6.4 mmol) were stirred in aq. HCl (50 mL H_2O and 0.5 mL 35% HCl) at 80 °C for 2 h. The resulting suspension was cooled in an ice bath, solids were collected by filtration and washed with water (2×10 mL). The collected solid was dried under vacuum yielding glycoluril **4 a** as a single stereoisomer (0.31 g, 3.9 mmol, 21%). The filtrate was evaporated to dryness, resulting solid was treated with acetone (20 mL) and stirred for 1 h. Insoluble solid was removed by filtration and the acetone was evaporated. Resulting solid was dissolved in MeOH (20 mL) and treated with powdered NaOH (0.19 g, 4.8 mmol). The solution was heated to 60 °C for 4 h. MeOH was then evaporated and solids were dissolved in water (10 mL). 35% HCl (0.5 mL) was added to precipitate the product. The precipitate was collected by filtration, washed with water (5 mL) and acetone (5 mL) and dried under yielding glycoluril **4 bH** (75 mg, 0.25 mmol, 5%).

^{1}H NMR (500 MHz, DMSO-d_6) δ 12.82 (s, 1H), 7.86 (d, J=8.3 Hz, 2H), 7.54 (s, 1H), 7.46 (d, J=8.3 Hz, 2H), 7.35 (s, 1H), 5.40 (d, J=8.3, 1H), 5.17 (d, J=8.3, 1H), 4.82 (q, J=7.3 Hz, 1H), 2.65 (s, 3H), 1.57 (d, J=7.3 Hz, 3H).

^{13}C NMR (126 MHz, DMSO-d_6) δ 167.15, 161.00, 157.27, 148.70, 129.14, 129.11, 126.63, 67.87, 64.62, 51.21, 27.76, 17.91.

HR-MS (ESI): m/z $[C_{14}H_{16}N_4O_4-H]^-$ observed: 303.1097, calculated: 303.1099.

Bambusuril BU-1

Glycoluril **4 a** (360 mg, 1.13 mmol) and paraformaldehyde (43 mg, 1.43 mmol) were dissolved in the mixture of dioxane (5 mL) and H_2SO_4 (0.3 mL). The solution was stirred at 80 °C for 90 min. Mixture was then cooled to room temperature, solids were collected by filtration and washed with diethyl ether (10 mL). Crude product was diluted with methanol (5 mL) and water (50 mL), heated to 80 °C for 2 h and then cooled down to room temperature and stirred overnight. Precipitated solids were collected by filtration and dried under vacuum. The solid material was diluted with DCM (15 mL), the insoluble particles were filtered off, DCM was removed on rotary vacuum evaporator yielding anion-free bambusuril **BU-1** (190 mg, 0.095 mmol, 51%) as a white solid.

^{1}H NMR (500 MHz, DMSO-d_6) δ 7.83 (d, J=8.1 Hz, 12H), 7.37 (d, J=8.1 Hz, 12H), 5.35 (d, J=6.7 Hz, 6H), 5.27 (d, J=6.7 Hz, 6H), 5.15 (m, 6H), 4.85 (s, 6H), 4.19 (s, 6H), 3.85 (s, 18H), 3.02 (s, 18H), 1.62 (d, J=6.8 Hz, 18H).

^{13}C NMR (126 MHz, DMSO-d_6) δ 165.91, 158.38, 157.74, 147.71, 129.20, 128.14, 126.39, 69.68, 69.00, 54.27, 52.05, 48.57, 47.60, 30.69, 18.80.

HR-MS (ESI): m/z $[C_{96}H_{108}N_{24}O_{24}+Cl]^-$ observed: 2016.7669, calculated: 2016.7691, m/z $[C_{96}H_{108}N_{24}O_{24}+SbF_6]^-$ observed: 2215.6927, calculated: 2215.6911

$[\alpha]_D^{23}=21.4°$ (MeOH/DCM 1:1, c=0.50 g/100 mL)

N-(4-Methoxycarbonylbenzyl)-*N*′-methylurea 5

Methyl-(4-aminomethyl)benzoate hydrochloride[53] (15.0 g, 74.3 mmol) and **10** (11.3 g, 90.3 mmol) were diluted with DCM (300 mL), triethyl amine (48 mL) was added and the reaction mixture was stirred at room temperature overnight. DCM was then removed on rotary vacuum evaporator providing crude oily material. The crude material was sonicated with water (100 mL), which resulted in crystallization of the product. Crystals were collected by filtration, washed with water (2×20 mL) and dried under vacuum yielding compound **5** (15.2 g, 68.4 mmol, 92%)

^{1}H NMR (500 MHz, DMSO-d_6) δ 7.90 (d, J=8.5 Hz, 2H), 7.37 (d, J=8.5 Hz, 2H), 6.47 (t, J=6.0 Hz, 1H), 5.86 (d, J=4.6 Hz, 1H), 4.27 (d, J=6.1 Hz, 2H), 3.84 (s, 3H), 2.57 (d, J=4.7 Hz, 3H).

^{13}C NMR (126 MHz, DMSO-d_6) δ 166.13, 158.60, 146.94, 129.09, 127.83, 127.05, 51.96, 43.50, 42.69, 26.43.

HR-MS (APCI+): m/z $[C_{12}H_{16}N_2O_3+H]^+$ observed: 223.1076, calculated: 223.1077.

(±)-2-(4-Methoxycarbonylbenzyl)-4-methylglycoluril (±)-6

Urea **5** (15.2 g, 68.4 mmol) and **11**[45] (15.0 g, 127 mmol) were stirred in aq. HCl (175 mL H_2O with 1.75 mL 35% HCl) at 80 °C for 1 h. More **11** (1.50 g, 12.7 mmol) was then added and the stirring of the mixture at 80 °C for 1 h continued for one more hour. The resulting suspension was cooled in an ice bath, solids were collected by filtration and washed with water. The collected solid was dried under vacuum yielding glycoluril (±)-**6** (18.25 g, 60.0 mmol, 88%).

^{1}H NMR (500 MHz, DMSO-d_6) δ 7.91 (d, J = 8.3 Hz, 2H), 7.58 (s, 1H), 7.53 (s, 1H), 7.39 (d, J = 8.3 Hz, 2H), 5.18 (d, J = 8.1 Hz, 1H), 5.09 (d, J = 8.1, 1H), 4.60 (d, J = 16.1 Hz, 1H), 4.14 (d, J = 16.1 Hz, 1H), 3.84 (s, 3H), 2.70 (s, 3H).

^{13}C NMR (126 MHz, DMSO-d_6) δ 166.07, 160.93, 157.52, 143.32, 129.33, 128.50, 127.82, 67.38, 65.33, 52.06, 43.88, 27.76.

HR-MS (APCI+): m/z $[C_{14}H_{16}N_4O_4+H]^+$ observed: 305.1243, calculated: 305.1244.

(±)-2-(4-Carboxybenzyl)-4-methylglycoluril (±)-7

Glycoluril (±)-**6** (5.5 g, 18.1 mmol) and powdered KOH (2.0 g, 35 mmol) were dissolved in MeOH (45 mL). The solution was heated to 60 °C for 3 h. MeOH was removed on rotary vacuum evaporator and the resulting solid was dissolved in water (25 mL). 35% HCl (6 mL) was added dropwise to the solution to produce an amorphous solid. The suspension was sonicated to make the solid crystallize, crystals were collected by filtration, washed with water and dried under vacuum to produce compound (±)-**7** (4.70 g, 16.2 mmol, 90%).

^{1}H NMR (500 MHz, DMSO-d_6) δ 12.86 (s, 1H), 7.91 (d, J = 8.3 Hz, 2H), 7.57 (s, 1H), 7.53 (s, 1H), 7.36 (d, J = 8.3 Hz, 2H), 5.17 (d, J = 8.1 Hz, 1H), 5.08 (d, J = 8.1 Hz, 1H), 4.60 (d, J = 16.0 Hz, 1H), 4.12 (d, J = 16.1 Hz, 1H), 3.31 (s, 3H).

^{13}C NMR (126 MHz, DMSO) δ 167.07, 160.90, 157.46, 142.74, 129.63, 129.45, 127.63, 67.33, 65.24, 43.82, 27.74.

HR-MS (APCI+): m/z $[C_{13}H_{14}N_4O_4+H]^+$ observed: 291.1089, calculated: 291.1088.

(±)-2,4-Diacetyl-6-(4-carboxybenzyl)-8-methylglycoluril (±)-8

Glycoluril (±)-**7** (14.2 g, 48.9 mmol) was suspended in acetic anhydride (36 mL). Upon stirring concentrated H_2SO_4 (36 drops) was added. The reaction mixture was stirred at room temperature overnight providing clear yellowish solution. The solution was concentrated on rotary vacuum evaporator, diluted with water (50 mL) and extracted with DCM (2×50 mL). Combined extracts were dried over anhydrous $MgSO_4$, filtered and evaporated. Acetic acid in the crude product was removed by co-evaporation with acetonitrile (2×50 mL) on rotary vacuum evaporator. Compound (±)-**8** was isolated as a white solid (17.0 g, 45.4 mmol, 93%).

^{1}H NMR (500 MHz, DMSO-d_6) δ 12.83 (s, 1H), 7.88 (d, J = 8.3 Hz, 2H), 7.30 (d, J = 8.1 Hz, 2H), 5.79 (d, J = 8.5 Hz, 1H), 5.76 (d, J = 8.6 Hz, 1H), 4.55 (d, J = 16.3 Hz, 1H), 4.47 (d, J = 16.3 Hz, 1H), 2.87 (s, 3H), 2.46 (s, 3H), 2.26 (s, 3H).

^{13}C NMR (126 MHz, DMSO-d_6) δ 171.29, 171.02, 167.12, 158.48, 151.57, 143.44, 129.38, 129.27, 126.80, 66.62, 64.92, 46.39, 31.05, 24.38, 23.93.

HR-MS (APCI+): m/z $[C_{17}H_{18}N_4O_6+H]^+$ observed: 375.1298, calculated: 375.1299.

Enantiomerically pure (1*S*,5*R*)-7 and (1*R*,5*S*)-7

Glycoluril (±)-**8** (17.0 g, 46.7 mmol) was dissolved in dioxane (600 mL). Upon stirring *S*-**12** (2.83 g, 3.01 mL, 23.4 mmol) was added. The addition of amine resulted in crystallization of salt of enantiomerically enriched (1*R*,5*S*)-**8** as within 1 h. Solid was collected by filtration. The mother liquor was treated with *R*-**12** (2.83 g, 3.01 mL, 23.4 mmol) to crystallize (1*S*,5*R*)-**8**. Crystals were collected by filtration. To isolate glycoluril **8** from the salt as free carboxylic, the salt was placed into separatory funnel, treated with DCM (100 mL), water (95 mL) and concentrated hydrochloric acid (5 mL) and shaken until dissolution. The organic layer was separated, aqueous layer was once more extracted with DCM (50 mL), combined extracts were dried over anhydrous $MgSO_4$, filtered and evaporated providing enriched enantiomer of as a white solid. Yield of the (1*R*,5*S*)-**8** after first crystallization was 5.50 g, yield of (1*S*,5*R*)-**8** was 4.54 g.

The crystallization of each enriched enantiomer was twice repeated. For the following crystallizations only 200 mL of dioxane and 1 equivalent of **12** were used. Final yield of (1*R*,5*S*)-**8** was 4.51 g, yield of the (1*S*,5*R*)-**8** 4.04 g.

Enantiomerically pure glycoluril (1*R*,5*S*)-**8** (4.51 g. 12.0 mmol) was dissolved in MeOH (40 mL), powdered KOH (2.70 g, 48.0 mmol) was added. Potassium salt of glycoluril (1*S*,5*R*)-**7** crystallized within 10 min. Crystals were isolated by filtration, dissolved in water (15 mL) and the glycoluril (1*S*,5*R*)-**7** was precipitated with concentrated HCl (2 mL). Precipitate was collected by filtration, washed with water and dried under vacuum providing glycoluril (1*S*,5*R*)-**7** as a white solid (3.38 g, 11.6 mmol, 97%).

$[\alpha]_D^{23} = 52.0°$ ((1*R*,5*S*)-**7**, MeOH, c = 0.50 g/100 mL)

$[\alpha]_D^{23} = -48.0°$ ((1*S*,5*R*)-**7**, MeOH, c = 0.50 g/100 mL)

Bambusuril BU-2

Glycoluril (1*R*,5*S*)-**7** (0.60 g, 2.1 mmol) and paraformaldehyde (72.0 mg, 2.4 mmol) were dissolved in the mixture of dioxane (10 mL) and H_2SO_4 (0.3 mL). The solution was stirred at 80 °C for 90 min. Mixture was then cooled to room temperature, solids were collected by filtration, washed with diethyl ether and dissolved in a mixture of water (9 mL) and 25% ammonia (1 mL) and stirred for 15 min. Phosphoric acid (1.5 mL) was then added to the solution to precipitate the macrocycle. Crude macrocycle (570 mg) bearing COOH groups was isolated. Solids were collected by filtration, washed with water (3×10 mL) and dried under vacuum. Dry solid was then dissolved in the mixture of MeOH (10 mL) and $SOCl_2$ (0.4 mL) and the solution was heated to 55 °C for 90 min. Pure product precipitated during the reaction. After cooling to room temperature, the precipitate was collected by filtration and washed with MeOH (2×5 mL), yielding **BU-2**·HCl complex (295 mg, 0.15 mmol, 44%). The solid was dissolved in the mixture of DCM (5 mL) and MeOH (5 mL). The solution was treated by $AgSbF_6$ (86 mg, 0.25 mmol) in MeOH (5 mL) and stirred for 15 min. Precipitated solid removed by filtration through filter paper, solution was concentrated to approximately 2 mL. Solution was diluted with demineralized water (10 mL) to precipitate the macrocycle. Solid was collected by filtration and dried under vacuum yielding anion-free bambusuril **BU-2** (253 mg, 0.13 mmol, 39%) as a white solid.

^{1}H NMR (500 MHz, DMSO-d_6) δ 7.84 (d, J = 8.1 Hz, 12H), 7.30 (d, J = 8.1 Hz, 12H), 5.22 (d, J = 8.0 Hz, 6H), 5.13 (d, J = 7.9 Hz, 6H), 4.83 (s, 6H), 4.71 (d, J = 16.9 Hz, 6H), 4.58 (d, J = 17.0 Hz, 6H), 4.10 (s, 6H), 3.85 (s, 18H), 3.03 (s, 18H).

^{13}C NMR (126 MHz, DMSO-d_6) δ 165.87, 158.93, 158.14, 143.68, 129.21, 128.41, 126.82, 69.64, 68.93, 52.02, 47.84, 47.54, 46.91, 31.03.

HR-MS (ESI): m/z $[C_{90}H_{96}N_{24}O_{24}+Cl]^-$ observed: 1932.6728, calculated: 1932.6752, m/z $[C_{90}H_{96}N_{24}O_{24}+SbF_6]^-$ observed: 2131.6022, calculated: 2131.5972.

$[\alpha]_D^{23} = -17.8°$ ((1*R*,5*S*)-**BU-2**, MeOH/DCM 1:1, c = 0.50 g/100 mL)

Glycoluril amide 13

Glycoluril **4aH** (50 mg, 0.16 mmol), *N*-hydroxysuccinimide (NHS) (26 mg, 0.22 mmol) and DCC (46 mg, 0.22 mmol) were dissolved in DMF (4 mL) and stirred at 25 °C for 16 h. Solution was then treated with (*S*)-1-(2-naphthyl)ethylamine **15** (50 mg, 0.29 mmol) and triethyl amine (90 mL, 0.65 mmol) in DMF (0.5 mL) and stirred for more 24 h. DMF was evaporated and solids were washed with water (4 mL). Crude product was purified by silica gel column chromatography (eluent DCM:MeOH, 9:1). Compound **13** was isolated as white solid (50 mg, 0.11 mmol, 69%).

^{1}H NMR (500 MHz, DMSO-d_6) δ 8.85 (d, J = 8.0 Hz, 1H), 7.91–7.84 (m, 6H), 7.57 (dd, J = 8.5, 1.6 Hz, 1H), 7.54–7.44 (m, 4H), 7.39 (d, J = 8.3 Hz, 2H), 5.33 (m, 1H), 5.14–4.88 (m, 3H), 2.65 (s, 3H), 1.57 (d, J = 7.1 Hz, 3H), 1.54 (d, J = 7.3 Hz, 3H).

^{13}C NMR (126 MHz, DMSO-d_6) δ 165.29, 161.15, 157.07, 144.16, 142.36, 133.45, 132.83, 132.01, 127.81, 127.61, 127.53, 127.39, 126.81, 126.05, 125.53, 124.96, 124.01, 67.57, 64.20, 50.32, 48.54, 27.62, 22.00, 18.37.

HR-MS (APCI+): m/z $[C_{26}H_{27}N_5O_3+H]^+$ observed: 458.2185, calculated: 458.2187.

Glycoluril amides 14a and 14b

Enantiomerically pure glycoluril (1*R*,5*S*)-**8** (0.3 g, 0.8 mmol), NHS (0.11 g, 1.0 mmol) and DCC (0.22 g, 1.1 mmol) were dissolved in THF (4 mL). Solution was stirred at 25 °C overnight. Solids were removed by filtration and THF was evaporated. Remaining solid was dissolved in DCM (20 mL) and washed with brine (10 mL). Organic phase was dried over anhydrous $MgSO_4$. The solution was treated with **15** (140 mg, 0.8 mmol) and triethyl amine (0.11 mL, 0.8 mmol) and stirred for 2 h. After that more **15** (30 mg, 0.2 mmol) was added and the solution was stirred for more 4 h. Last portion of **15** (30 mg, 0.2 mmol) was added and the solution was stirred overnight. Solution was then washed with brine (10 mL), dried over anhydrous $MgSO_4$ and DCM evaporated. Resulting solid was dissolved in MeOH (20 mL), treated with powdered KOH (100 mg, 1.8 mmol) and stirred for 15 min. After that MeOH was evaporated and solids were washed with water (8 mL). Crude product was purified by silica gel column chromatography (eluent DCM:MeOH, 9:1). Compound **14a** was isolated as white solid (210 mg, 0.5 mmol, 59%). Compound **14b** was prepared analogically with similar yield starting from compound (1*R*,5*S*)-**8**.

14a

^{1}H NMR (500 MHz, DMSO-d_6) δ 8.85 (d, J = 8.0 Hz, 1H), 7.87 (m, 6H), 7.60–7.53 (m, 3H), 7.51–7.44 (m, 2H), 7.34 (d, J = 8.2 Hz, 2H), 5.33 (m, 1H), 5.16 (d, J = 8.1 Hz, 1H), 5.05 (d, J = 8.1 Hz, 1H), 4.60 (d, J = 15.8 Hz, 1H), 4.08 (t, J = 15.8 Hz, 1H), 2.70 (s, 3H), 1.57 (d, J = 7.1 Hz, 3H).

^{13}C NMR (126 MHz, DMSO-d_6) δ 165.34, 160.92, 157.44, 142.36, 140.75, 133.44, 132.83, 132.01, 127.82, 127.60, 127.57, 127.46, 127.39, 126.05, 125.53, 124.97, 124.02, 67.29, 65.16, 48.54, 43.78, 27.73, 22.00.

HR-MS (APCI+): m/z $[C_{25}H_{25}N_5O_3+H]^+$ observed: 444.2027, calculated: 444.2030.

14b

^{1}H NMR (500 MHz, DMSO-d_6) δ 8.85 (d, J = 8.0 Hz, 1H), 7.87 (m, 6H), 7.61–7.53 (m, 3H), 7.52–7.43 (m, 2H), 7.34 (d, J = 8.2 Hz, 2H), 5.33 (m, 1H), 5.16 (d, J = 8.1 Hz, 1H), 5.05 (d, J = 8.1 Hz, 1H), 4.60 (d, J = 15.8 Hz, 1H), 4.08 (t, J = 15.8 Hz, 1H), 2.70 (s, 3H), 1.57 (d, J = 7.1 Hz, 3H).

^{13}C NMR (126 MHz, DMSO-d_6) δ 165.34, 160.92, 157.44, 142.36, 140.75, 133.44, 132.83, 132.01, 127.81, 127.60, 127.57, 127.46, 127.39, 126.05, 125.53, 124.96, 124.01, 67.29, 65.14, 48.54, 43.77, 27.73, 22.01.

HR-MS (APCI+): m/z $[C_{25}H_{25}N_5O_3+H]^+$ observed: 444.2029;, calculated: 444.2030.

Preparation of tetrabutylammonium salts of chiral acids

Chiral acid (6.84 mmol) was dissolved in methanol (1–2 mL). Volumetric solution of tetrabutylammonium hydroxide (0.5009 M, 13.8 mL) was added. The solution was shaken and left to stand for 10 min. Then the methanol was evaporated under vacuum and the oily residue was dried under high vacuum to provide corresponding tetrabutylammonium salt.

Acknowledgements

This work was supported by the Czech Science Foundation (No. 18-21801S). We thank the CETOCOEN EXCELLENCE Teaming 2 project (supported by MEYS CR: CZ.02.1.01/0.0/0.0/17_043/0009632) and the RECETOC research infrastructure (LM2018121). We acknowledge the CF X-ray diffraction and Bio-SAXS and CF Proteomic supported by the CIISB research infrastructure (LM2018127 funded by MEYS CR).

Conflict of Interest

The authors declare no conflict of interest.

Keywords: anion receptors · enantioselective recognition · glycolurils · host-guest systems · macrocycles

[1] D. J. Ager, Ed., *Handbook of Chiral Chemicals*, Taylor & Francis, Boca Raton, **2006**.
[2] A. Berthod, Ed., *Chiral Recognition in Separation Methods: Mechanisms and Applications*, Springer, Heidelberg; New York, **2010**.
[3] D. Leung, S. O. Kang, E. V. Anslyn, *Chem. Soc. Rev.* **2012**, *41*, 448–479.
[4] C. Tan, D. Chu, X. Tang, Y. Liu, W. Xuan, Y. Cui, *Chem. Eur. J.* **2019**, *25*, 662–672.
[5] P. J. Lebed, S. Keunchkarian, J. Osorio Grisales, C. B. Castells, *J. Chromatogr. A* **2014**, *1324*, 198–206.
[6] M. H. Hyun, *J. Chromatogr. A* **2016**, *1467*, 19–32.
[7] A. Echavarren, A. Galan, J. M. Lehn, J. De Mendoza, *J. Am. Chem. Soc.* **1989**, *111*, 4994–4995.

[8] F. P. Schmidtchen, *Tetrahedron Lett.* **1989**, *30*, 4493–4496.
[9] M. D. Best, S. L. Tobey, E. V. Anslyn, *Coord. Chem. Rev.* **2003**, *240*, 3–15.
[10] P. Blondeau, M. Segura, R. Pérez-Fernández, J. de Mendoza, *Chem. Soc. Rev.* **2007**, *36*, 198–210.
[11] M. P. Conley, J. Valero, J. de Mendoza, in *Supramol. Chem.* (Eds.: P. A. Gale, J. W. Steed), John Wiley & Sons, Ltd, Chichester, UK, **2012**.
[12] V. D. Jadhav, F. P. Schmidtchen, *J. Org. Chem.* **2008**, *73*, 1077–1087.
[13] T. Ema, K. Okuda, S. Watanabe, T. Yamasaki, T. Minami, N. A. Esipenko, P. Anzenbacher, *Org. Lett.* **2014**, *16*, 1302–1305.
[14] A. Akdeniz, T. Minami, S. Watanabe, M. Yokoyama, T. Ema, P. Anzenbacher, *Chem. Sci.* **2016**, *7*, 2016–2022.
[15] Y. Willener, K. M. Joly, C. J. Moody, J. H. R. Tucker, *J. Org. Chem.* **2008**, *73*, 1225–1233.
[16] K. M. K. Swamy, N. Jiten Singh, J. Yoo, S. K. Kwon, S.-Y. Chung, C.-H. Lee, J. Yoon, *J. Inclusion Phenom. Macrocyclic Chem.* **2010**, *66*, 107–111.
[17] D. Lichosyt, S. Wasiłek, J. Jurczak, *J. Org. Chem.* **2016**, *81*, 7342–7348.
[18] F. Botha, J. Budka, V. Eigner, O. Hudeček, L. Vrzal, I. Císařová, P. Lhoták, *Tetrahedron* **2014**, *70*, 477–483.
[19] Y. Hu, Y. Li, J. F. Joung, J. Yin, S. Park, J. Yoon, M. H. Hyun, *Sens. Actuators B* **2017**, *241*, 224–229.
[20] S. Ito, M. Okuno, M. Asami, *Org. Biomol. Chem.* **2018**, *16*, 213–222.
[21] G.-Y. Qing, Y.-B. He, Y. Zhao, C.-G. Hu, S.-Y. Liu, X. Yang, *Eur. J. Org. Chem.* **2006**, *2006*, 1574–1580.
[22] M. K. Choi, H. N. Kim, H. J. Choi, J. Yoon, M. H. Hyun, *Tetrahedron Lett.* **2008**, *49*, 4522–4525.
[23] M. Mačková, J. Mikšátko, J. Budka, V. Eigner, P. Cuřínová, P. Lhoták, *New J. Chem.* **2015**, *39*, 1382–1389.
[24] P. Cios, J. Romański, *Tetrahedron Lett.* **2016**, *57*, 3866–3869.
[25] J. Y. C. Lim, I. Marques, L. Ferreira, V. Félix, P. D. Beer, *Chem. Commun.* **2016**, *52*, 5527–5530.
[26] J. Y. C. Lim, I. Marques, V. Félix, P. D. Beer, *J. Am. Chem. Soc.* **2017**, *139*, 12228–12239.
[27] J. Y. C. Lim, I. Marques, V. Félix, P. D. Beer, *Angew. Chem. Int. Ed.* **2018**, *57*, 584–588.
[28] T. Bunchuay, A. Docker, A. J. Martinez-Martinez, P. D. Beer, *Angew. Chem. Int. Ed.* **2019**, *58*, 13823–13827.
[29] L. A. Joyce, M. S. Maynor, J. M. Dragna, G. M. da Cruz, V. M. Lynch, J. W. Canary, E. V. Anslyn, *J. Am. Chem. Soc.* **2011**, *133*, 13746–13752.
[30] S. Sheykhi, L. Mosca, J. M. Durgala, P. Anzenbacher, *Chem. Commun.* **2019**, *55*, 7183–7186.
[31] J. Svec, M. Necas, V. Sindelar, *Angew. Chem. Int. Ed.* **2010**, *49*, 2378–2381.
[32] M. Singh, E. Solel, E. Keinan, O. Reany, *Chem. Eur. J.* **2015**, *21*, 536–540.
[33] T. Lizal, V. Sindelar, *Isr. J. Chem.* **2018**, *58*, 326–333.
[34] O. Reany, A. Mohite, E. Keinan, *Isr. J. Chem.* **2018**, *58*, 449–460.
[35] Y. Miyahara, K. Goto, M. Oka, T. Inazu, *Angew. Chem. Int. Ed.* **2004**, *43*, 5019–5022.
[36] M. Lisbjerg, B. M. Jessen, B. Rasmussen, B. E. Nielsen, A. Ø Madsen, M. Pittelkow, *Chem. Sci.* **2014**, *5*, 2647–2650.
[37] N. N. Andersen, M. Lisbjerg, K. Eriksen, M. Pittelkow, *Isr. J. Chem.* **2018**, *58*, 435–448.
[38] K. Kim, Ed., *Cucurbiturils and Related Macrocycles*, Royal Society Of Chemistry, London, **2020**.
[39] V. Havel, V. Sindelar, M. Necas, A. E. Kaifer, *Chem. Commun.* **2014**, *50*, 1372–1374.
[40] V. Havel, V. Sindelar, *ChemPlusChem* **2015**, *80*, 1601–1606.
[41] R. Aav, E. Shmatova, I. Reile, M. Borissova, F. Topić, K. Rissanen, *Org. Lett.* **2013**, *15*, 3786–3789.
[42] E. Prigorchenko, M. Öeren, S. Kaabel, M. Fomitšenko, I. Reile, I. Järving, T. Tamm, F. Topić, K. Rissanen, R. Aav, *Chem. Commun.* **2015**, *51*, 10921–10924.
[43] R. Aav, K. Mishra, *Symmetry* **2018**, *10*, 98.
[44] J. Sokolov, V. Šindelář, *Chem. Eur. J.* **2018**, *24*, 15482–15485.
[45] J. Svec, M. Dusek, K. Fejfarova, P. Stacko, P. Klán, A. E. Kaifer, W. Li, E. Hudeckova, V. Sindelar, *Chem. Eur. J.* **2011**, *17*, 5605–5612.
[46] Deposition Numbers 2005908 (for **13**), 2005909 (for **14a**), and 2005910 (for **14b**) contain the supplementary crystallographic data for this paper. These data are provided free of charge by the joint Cambridge Crystallographic Data Centre and Fachinformationszentrum Karlsruhe Access Structures service www.ccdc.cam.ac.uk/structures.
[47] V. Havel, J. Svec, M. Wimmerova, M. Dusek, M. Pojarova, V. Sindelar, *Org. Lett.* **2011**, *13*, 4000–4003.
[48] V. Havel, M. Babiak, V. Sindelar, *Chem. Eur. J.* **2017**, *23*, 8963–8968.
[49] D. Azazna, M. Lafosse, J. Rivollier, J. Wang, I. B. Cheikh, M. Meyer, P. Thuéry, J.-P. Dognon, G. Huber, M.-P. Heck, *Chem. Eur. J.* **2018**, *24*, 10793–10801.
[50] M. El Qacemi, J. Y. Cassayre, *Methods of pest control in soybean*, WO2014/19609.
[51] *Pfizer Japan Inc.; Pfizer Inc. – WO2005/105732, 2005, A1*.
[52] P. A. Duspara, Md. S. Islam, A. J. Lough, R. A. Batey, *J. Org. Chem.* **2012**, *77*, 10362–10368.
[53] M. A. Yawer, V. Havel, V. Sindelar, *Angew. Chem. Int. Ed.* **2015**, *54*, 276–279.

Manuscript received: April 1, 2020
Revised manuscript received: May 27, 2020