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Short communication

New gas chromatographic method for the enantioseparation of β-amino acids by a rapid double derivatization technique

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ABSTRACT

A novel gas chromatographic method was developed for the enantioseparation of valuable acyclic and carbocyclic *cis*- and *trans*-β-amino acids, including *cispentacin* and a number of its analogues and homologues. Excellent (in most cases baseline) separation was achieved for the racemates of these β-amino acids on CP-Chirasil-Dex CB or CP-Chirasil L-Val columns after a simple and rapid double derivatization (esterification followed by *N*-acylation). The elution sequences were determined in all cases.

1. Introduction

β-Amino acids are important compounds from both biological and chemical points of view. Some of them exhibit antibacterial activity (*e.g. cispentacin* and *icofungipen*) [1–3]. They have wide-ranging uses in peptide [4–6], heterocyclic [7,8] and combinatorial chemistry [9,10] and drug research [11–14]. Consequently, in the past few years a large number of syntheses (enantioselective synthesis and enzymatic resolution) have been developed for enantiopure cyclic and acyclic β-amino acid derivatives [15,16]. For control of the enantiopurity of the final products, mainly high-performance liquid chromatographic, indirect and direct separation methods have been developed. The indirect methods involve precolumn derivatization with chiral derivatizing agents, with subsequent separation of the diastereoisomers on an achiral column [17–19]. Direct methods are performed by ligand-exchange chromatography, or by the application of chiral stationary phases (CSPs) [20–25]. In the past few years, new types of chiral derivatizing agents and CSPs have been applied for the enantioseparation of both acyclic and carbocyclic β-amino acids by D'Acquarica et al. [26], Hyun et al. [27] and Peter and co-workers [28–31]. Bertrand et al. [32] recently developed a gas chromatographic (GC) method for the separation of 20 proteinogenic amino acid enantiomers via chiral derivatization.

Since one of our main research topics is the development of new enzymatic routes for the synthesis of valuable enantiopure β-amino acids [33–38], we always endeavour to establish the most appropriate analytical method for the enantioseparation of β-amino acids. One of the basic criteria for the method is the ensurance of a rapid sample work-up during the preliminary enzymatic experiments. Accordingly, the present paper describes an easy-to-perform double derivatization technique and a GC method suitable for the enantioseparation of 20 β-amino acids. The enantioseparation is performed on one-pot double-derivatized samples; derivatization is carried out first with diazomethane (CH_2N_2) (caution! derivatization with CH_2N_2 should be performed under a well-working hood), followed by acetic anhydride in the presence of 4-dimethylaminopyridine (DMAP) and pyridine. The derivatized samples are then analysed by using GC with chiral CP-Chirasil-Dex CB or CP-Chirasil L-Val columns.

2. Experimental

2.1. Materials and reagents

The racemic β-amino acids (Fig. 1): *cis*-2-aminocyclopentane-1-carboxylic acid (**1**), *cis*-2-aminocyclopent-3-ene-1-carboxylic acid (**2**), *cis*-2-amino-4-*tert*-butylcyclopentane-1-carboxylic acid (**3**), *cis*-2-aminocyclohexane-1-carboxylic acid (**4**), *cis*-2-aminocyclohex-4-ene-1-carboxylic acid (**5**), *cis*-2-aminocyclohex-3-ene-1-carboxylic acid (**6**), *cis*-2-aminocycloheptane-1-carboxylic acid (**7**), *cis*-2-aminocyclooct-5-ene-1-carboxylic acid (**8**), exo-3-amino-

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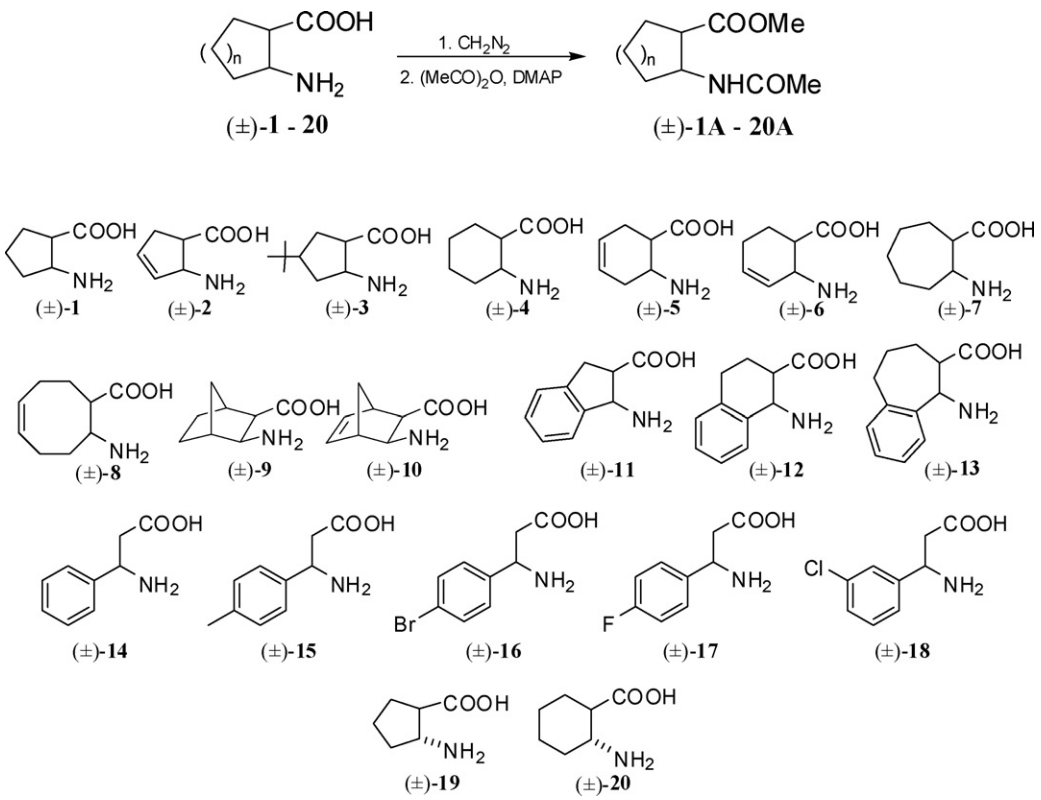

Fig. 1. Derivatization process. *cis*-2-Aminocyclopentane-1-carboxylic acid (**1**), *cis*-2-aminocyclopent-3-ene-1-carboxylic acid (**2**), *cis*-2-amino-4-*tert*-butylcyclopentane-1-carboxylic acid (**3**), *cis*-2-aminocyclohexane-1-carboxylic acid (**4**), *cis*-2-aminocyclohex-4-ene-1-carboxylic acid (**5**), *cis*-2-aminocyclohex-3-ene-1-carboxylic acid (**6**), *cis*-2-aminocycloheptane-1-carboxylic acid (**7**), *cis*-2-aminocyclooct-5-ene-1-carboxylic acid (**8**), exo-3-aminobicyclo[2.2.1]heptane-2-carboxylic acid (**9**), exo-3-aminobicyclo[2.2.1]hept-5-ene-2-carboxylic acid (**10**), *cis*-3,4-benzo-2-aminocyclopentane-1-carboxylic acid (**11**), *cis*-3,4-benzo-2-aminocyclohexane-1-carboxylic acid (**12**), *cis*-3,4-benzo-2-aminocycloheptane-1-carboxylic acid (**13**), *cis*-3-amino-3-phenylpropionic acid (**14**), 3-amino-3-(*p*-tolyl)propionic acid (**15**), 3-amino-3-(*p*-bromophenyl)propionic acid (**16**), 3-amino-3-(*p*-fluorophenyl)propionic acid (**17**), 3-amino-3-(*m*-chlorophenyl)propionic acid (**18**), *trans*-2-aminocyclopentane-1-carboxylic acid (**19**) and *trans*-2-aminocyclohexane-1-carboxylic acid (**20**).

bicyclo[2.2.1]heptane-2-carboxylic acid (**9**), exo-3-aminobicyclo [2.2.1]hept-5-ene-2-carboxylic acid (**10**), *cis*-3,4-benzo-2-amino-cyclopentane-1-carboxylic acid (**11**), *cis*-3,4-benzo-2-aminocyclo-hexane-1-carboxylic acid (**12**), *cis*-3,4-benzo-2-aminocyclo-heptane-1-carboxylic acid (**13**), *cis*-3-amino-3-phenylpropionic acid **14**, 3-amino-3-(*p*-tolyl)propionic acid **15**, 3-amino-3-(*p*-bromophenyl)propionic acid **16**, 3-amino-3-(*p*-fluorophenyl) propionic acid **17** and 3-amino-3-(*m*-chlorophenyl)propionic acid **18** were prepared by the cycloaddition of chlorosulfonyl isocyanate to the corresponding alkene or alkadiene [39–41], followed by ring opening with 18% HCl. *trans*-2-Aminocyclopentane-1-carboxylic acid (**19**) and *trans*-2-aminocyclohexane-1-carboxylic acid (**20**) were prepared by Michael addition of ammonia to 1-cyclopentene- or 1-cyclohexenecarboxylic acid [1,42,43].

The β-amino acid enantiomers involved in the present work were prepared through the CAL-B-catalysed enantioselective ring cleavage of the corresponding racemic β-lactams [33–37] or CAL-B-catalysed enantioselective hydrolysis of the corresponding β-amino esters [38]. High enantioselectivities ($E > 200$; E shows how many times faster than its antipode one enantiomer is transformed into product) were observed for both direct enzymatic methods when the reactions were performed with 0.5 or 1 equivalent of H_2O in $(2\text{-Pr})_2O$ at 60 or 70 °C.

Table 1
Methods used for the enantioseparation of (±)-**1A** to (±)-**20A**.

Method	Column	Temperature programme	Rate of temperature rise (°C min^{-1})	Inlet pressure (kPa)
a	L-Val	100 °C for 10 min → 160 °C	10	85
b	β-CD	120 °C for 10 min → 180 °C	10	100
c	L-Val	100 °C for 15 min → 140 °C	5	85
d	β-CD	90 °C for 25 min → 150 °C	10	120
e	β-CD	120 °C for 7 min → 160 °C	10	120
f	β-CD	120 °C for 10 min → 150 °C	10	120
g	β-CD	120 °C for 7 min → 190 °C	20	120
h	L-Val	120 °C for 7 min → 190 °C	20	140
i	L-Val	120 °C for 7 min → 190 °C	20	85
j	L-Val	120 °C for 12 min → 180 °C	10	140
k	L-Val	120 °C for 15 min → 180 °C	10	100
l	L-Val	120 °C for 2 min → 160 °C	20	160
m	β-CD	120 °C for 4 min → 150 °C	20	120
n	β-CD	120 °C for 7 min → 190 °C	20	120

Chromatographic conditions: column, CP-Chirasil-Dex CB (β-CD) or CP-Chirasil L-Val (L–Val).

Table 2
Dead-time values (t_0), retention factors (k'), separation factors (α), resolutions (R_S) and elution sequences of enantiomers of β-amino acids (±)-**1** to (±)-**20** after double derivatization.

Compound	Method	t_0 (min)	k_1	α	R_S	Elution sequence
(±)-**1A**	a	1.93	6.93	1.017	2.72	1*R*,2*S* < 1*S*,2*R*
(±)-**2A**	a	1.93	8.62	1.010	1.39	1*R*,2*S* < 1*S*,2*R*
(±)-**3A**	b	1.65	11.80	1.006	1.12	1*R*,2*S*,4*R* < 1*S*,2*R*,4*S*
(±)-**4A**	a	1.93	7.46	1.012	2.18	1*R*,2*S* < 1*S*,2*R*
(±)-**5A**	a	1.93	9.42	1.010	1.94	1*R*,2*S* < 1*S*,2*R*
(±)-**6A**	a	1.93	9.81	1.013	1.69	1*R*,2*S* < 1*S*,2*R*
(±)-**7A**	c	1.93	16.18	1.013	2.69	1*R*,2*S* < 1*S*,2*R*
(±)-**8A**	d	1.58	36.42	1.011	1.19	1*R*,2*S* < 1*S*,2*R*
(±)-**9A**	e	1.66	11.22	1.019	1.77	1*S*,2*R*,3*S*,4*R* < 1*R*,2*S*,3*R*,4*S*
(±)-**10A**	f	1.66	13.53	1.016	2.25	1*R*,2*R*,3*S*,4*S* < 1*S*,2*S*,3*R*,4*R*
(±)-**11A**	g	1.66	11.15	1.016	2.06	1*S*,2*S* < 1*R*,2*R*
	h	1.14	16.69	1.013	1.51	1*R*,2*R* < 1*S*,2*S*
(±)-**12A**	g	1.66	23.82	1.016	1.73	1*S*,2*S* < 1*R*,2*R*
	h	1.14	15.81	1.014	1.84	1*R*,2*R* < 1*S*,2*S*
(±)-**13A**	i	1.44	11.17	1.029	1.33	1*R*,2*R* < 1*S*,2*S*
(±)-**14A**	j	1.14	11.22	1.007	1.35	*R* < *S*
(±)-**15A**	k	1.73	28.02	1.007	0.95	*R* < *S*
(±)-**16A**	j	1.14	26.19	1.016	1.44	*R* < *S*
(±)-**17A**	l	0.67	11.32	1.037	1.56	*R* < *S*
(±)-**18A**	l	0.67	21.46	1.035	1.20	*R* < *S*
(±)-**19A**	m	1.65	11.51	1.018	1.28	1*S*,2*S* < 1*R*,2*R*
(±)-**20A**	n	1.65	7.06	1.009	1.73	1*S*,2*S* < 1*R*,2*R*

Chromatographic conditions: column, CP-Chirasil-Dex CB or CP-Chirasil L-Val; for methods a–n, see Table 1.

Acetic anhydride [$(MeCO)_2O$], propionic anhydride [$(EtCO)_2O$], butanoic anhydride [(n-$PrCO)_2O$] and hexanoic anhydride [(n-pentyl$CO)_2O$] were purchased from Acros (Berse, Belgium); DMAP, pyridine and *p*-tolylsulfonylmethylnitrosamide (the starting substance for the preparation of CH_2N_2 [44,45]) were from Fluka (Buchs, Switzerland); HPLC grade methanol was obtained from Scharlau (Barcelona, Spain).

2.2. Double derivatization of β-amino acids

In order to prepare the corresponding (±)-**1A** to (±)-**20A**, β-amino acids (±)-**1** to (±)-**20** were derivatized first with CH_2N_2 in a well-working hood: to 0.5 mL of a 0.05 M methanolic solution of β-amino acid, a saturated solution of CH_2N_2 in diethyl ether was added dropwise until the yellow colour persisted. In the next acylation step, one or other anhydride [$(MeCO)_2O$ or $(EtCO)_2O$ or (n-$PrCO)_2O$ or (n-pentyl$CO)_2O$] (15 μL) and 15 μL of a mixture of DMAP and pyridine (5:95, w/w) were added to the same test-tube. After shaking for 2–3 s, the double derivatized samples [(±)-**1A** to (±)-**20A**] (Fig. 1) were analysed on GC chiral columns.

2.3. Apparatus and methods

The Varian 3900 (Varian, Walnut Creek, CA, USA) GC system, equipped with an autoinjector (CP-8410) and a flame ionization detector, was controlled by Varian Star Workstation software. The chiral capillary columns used were CP-Chirasil-Dex CB [a cyclodextrin molecule bonded to dimethylpolysiloxane (CP Sil 5 type), 25 m × 0.25 mm I.D., 0.25 μm film thickness] and CP-Chirasil L-Val (a dimethylsiloxane with approximately 20% L-valine build into the siloxane chain, 25 m × 0.25 mm I.D., 0.12 μm film thickness), both Varian products. All analyses for double derivatized amino acids (**1A**–**20A**) were performed with N_2 as carrier gas, with the column temperature and inlet pressure were adjusted to an optimized programme (Table 1). The injector and detector temperatures were set at 250 and 270 °C, respectively.

3. Results and discussion

Two GC CSPs, CP-Chirasil-Dex CB and CP-Chirasil L-Val, were used for the separation of all racemic double derivatized amino acids (±)-**1A** to (±)-**20A**. In almost all cases, only one CSP proved applicable for overall or partial separation, except in the cases of (±)-**11A** and (±)-**12A**, when both columns gave baseline separations, but the elution sequences for the enantiomers on the two columns differed. The retention factor (k'), selectivity (α) and resolution (R_S) for each compound under the optimized conditions are listed in Table 2.

3.1. Influence of compound structure on chiral recognition

Under the same separation conditions (method a), the cyclopentane and cyclohexane β-amino acids (±)-**1** and (±)-**4** exhibited shorter retention times than those of their unsaturated homologues (±)-**2**, (±)-**5** and (±)-**6** on the CP-Chirasil L-Val column (Table 2). Likewise under the same conditions, the retention time increased with increasing ring size of the cyclic amino acids (data not shown). In general, it was concluded that the larger cyclic molecules and the sterically more hindered acyclic ones need longer retention times for adequate separation.

It is difficult to compare the earlier-devised direct chiral HPLC methods [30] with the present GC method. Both methods

Table 3
Validation parameters evaluated in the optimized methods (a–n) and the respective RSD (%) for accuracy and day-to-day repeatability.

Compound	Method	t_R (min)	RSD[a] (%)	LOD[b] (ng)	LOQ[b] (ng)	Repeatability			
						After 10 h		After 72 h	
						t_R (min)	RSD[a] (%)	t_R (min)	RSD[a] (%)
(±)-**5A**	a	15.94 16.10	5.0 4.9	18	55	15.90 16.06	4.6 4.5	15.90 16.06	4.6 4.5
(±)-**3A**	b	21.12 21.25	4.1 4.1	27	80	21.12 21.27	4.3 4.3	21.17 21.32	4.3 4.4
(±)-**7A**	c	29.39 29.74	6.6 6.2	15	45	29.37 29.66	6.4 6.4	29.64 29.91	6.5 6.4
(±)-**8A**	d	59.24 59.89	6.1 6.2	22	70	59.88 60.41	2.6 2.5	58.85 59.44	2.7 2.8
(±)-**9A**	e	20.16 20.52	4.7 4.7	15	50	20.24 20.69	4.3 4.3	20.17 20.52	4.0 4.1
(±)-**10A**	f	24.13 24.49	4.5 4.8	25	80	24.10 24.51	4.5 4.4	24.16 24.55	4.3 4.4
(±)-**11A**	g	19.94 20.23	10.6 11.4	5	20	19.93 20.23	10.2 11.1	19.93 20.22	8.9 8.7
(±)-**12A**	g	25.46 25.86	4.1 4.2	16	50	25.45 25.82	4.3 4.4	25.48 25.83	4.4 4.4
(±)-**11A**	h	12.73 12.89	8.5 8.6	12	40	12.70 12.84	7.9 7.9	12.71 12.83	7.7 7.8
(±)-**13A**	i	17.52 17.99	6.3 6.2	17	50	17.76 18.22	6.6 6.7	17.58 18.06	6.5 6.5
(±)-**16A**	j	31.00 31.48	3.4 3.1	22	65	30.88 31.31	3.5 3.4	30.11 30.60	4.0 3.9
(±)-**15A**	k	21.18 21.31	3.7 3.6	16	50	21.06 21.19	3.3 3.2	21.06 21.16	4.3 4.3
(±)-**17A**	l	8.25 8.42	4.9 5.0	35	110	8.08 8.19	5.2 5.3	8.15 8.28	5.3 5.4
(±)-**19A**	m	20.64 20.94	7.7 7.7	15	45	20.64 20.89	7.3 7.4	20.64 20.95	7.3 7.3
(±)-**20A**	n	13.29 13.45	7.3 7.2	20	60	13.18 13.30	7.3 7.4	13.22 13.38	7.5 7.4

[a] Six replicate measurements (racemic samples injected in 0.5 μL) after double derivatization of: 1.10 mg mL^{-1} (±)-**3**, 1.05 mg mL^{-1} (±)-**5**, 1.2 mg mL^{-1} (±)-**7**, 0.85 mg mL^{-1} (±)-**8**, 1.05 mg mL^{-1} (±)-**9**, 1.00 mg mL^{-1} (±)-**10**, 0.55 mg mL^{-1} (±)-**11**, 0.63 mg mL^{-1} (±)-**12**, 1.26 mg mL^{-1} (±)-**13**, 1.05 mg mL^{-1} (±)-**15**, 1.05 mg mL^{-1} (±)-**16**, 1.08 mg mL^{-1} (±)-**17**, 1.12 mg mL^{-1} (±)-**19** and 0.65 mg mL^{-1} (±)-**20**; RSD values were calculated for each set of peak areas for the corresponding enantiomer and its antipode enantiomer.
[b] Baseline-separated racemate.

ensure baseline separations for the investigated cycloalkane and cycloalkene β-amino acids. It is extremely important that not even traces of racemization were observed during double derivatization of β-amino acids, which indicates that the presented GC method is highly suitable for enantioseparation and hence the determination of enantiomeric excess values for β-amino acids. Furthermore, the GC method can be successfully used to follow the progress of enzymatic reactions where the enantioseparation of substrates (*e.g.* β-lactams [33–37]) needs a chiral GC column.

The CP-Chirasil-Dex CB column was the more appropriate for β-amino acids bearing two or more ring systems, *i.e.* (±)-**9**, (±)-**10**, (±)-**11**, (±)-**12** and (±)-**13** or a larger cyclic molecule, (±)-**8**. It seems that inclusion complex formation between the analyte and *β*-CD is more favourable for analytes with one larger ring or two ring systems. The steric effect is probably the reason why the *trans* isomers of the pairs *cis*- and *trans*-2-aminocyclopentane-1-carboxylic acid and *cis*- and *trans*-2-aminocyclohexane-1-carboxylic acid are better separated on the CP-Chirasil-Dex CB column (Table 2).

To investigate the influence of the second step of derivatization, several anhydrides, *e.g.* $(MeCO)_2O$, $(EtCO)_2O$ and $(n\text{-pentylCO})_2O$, were involved in the double derivatization of (±)-**12**. Replacing $(MeCO)_2O$ with longer chain anhydrides increased the retention time and the resolution became poorer. It was concluded that the best combination of retention time and separation was observed with $(MeCO)_2O$.

3.2. Linearity, limit of detection (LOD), limit of quantification (LOQ), accuracy and precision

All of the optimized methods (a–n) were validated in terms of the LOD and LOQ, linearity, accuracy and intra- and inter-day repeatabilities, calculated via the relative standard deviation (RSD) for (±)-**3A**, (±)-**5A**, (±)-**7A** to (±)-**13A**, (±)-**15A** to (±)-**17A**, (±)-**19A** and (±)-**20A** [46,47]. The LOD, defined as the signal equal to three times the baseline noise, and the LOQ, defined as the signal equal to 10 times the baseline noise, the accuracy and the intra- and inter-day repeatabilities are presented in Table 3. The samples proved stable in time; no significant changes were observed for the retention time (t_R) or for the RSD values as concerns intra-day and inter-day repeatabilities.

The degree of linearity between the peak areas (three measurements for each sample injected in a volume of 0.5 μL) and the amount of double-derivatized (±)-**11** (100, 50, 10, 5, 1, 0.5 and 0.1 mg mL^{-1}) was evaluated for the racemic **11A** obtained. The calibration graph ($y = 9445x - 5832.3$) was characterized by a correlation coefficient of 0.998. The linear-

ity was also examined between the calculated enantiomeric excess [$ee_{calc} = (m_{RR} - m_{SS})/(m_{RR} + m_{SS})$, where m is the amount of amino acid enantiomers *RR*-**12** and *SS*-**12** (mg) used for sample preparation] and the enantiomeric excess determined experimentally by injecting the sample obtained after double derivatization (mixture of *RR*-**12A** and *SS*-**12A**) into the GC chiral column [$ee_{cexp} = (A_{RR} - A_{SS})/(A_{RR} + A_{SS})$, where A is the peak area of *RR*-**12A** and *SS*-**12A**]. The calibration graph ($y = 1.0019x - 0.0099$) passed through the origin (as judged for the racemic mixture) with a correlation coefficient of >0.999. This excellent correlation likewise excludes the occurrence of racemization of the sample during the double derivatization.

4. Conclusions

A new GC method has been developed for the enantioseparation of valuable β-amino acids. The simple and rapid double derivatization of samples resulted in the expected volatile derivatives, which were analysed by GC with chiral columns of CP-Chirasil-Dex CB or CP-Chirasil L-Val. Most of the analysed β-amino acid derivatives were baseline-separated. Although this method was not devised as a quantitative one, good validation results were observed, while the excellent correlation between ee_{calc} for **12** and ee_{exp} for **12A** ($r^2 = 0.9998$) excluded the occurrence of racemization of the sample during the double derivatization. The elution sequences were determined in all cases; as a general rule, it was found that for cyclic *cis*-β-amino acids the 1*R*,2*S* enantiomer always elutes before the 1*S*,2*R* enantiomer, and for acyclic β-amino acids the *R* enantiomer elutes before the *S* enantiomer. The results presented in this work suggest that this new area of GC applicability will undoubtedly facilitate the enantiomeric separation of many β-amino acids.

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References

[1] F. Fülöp, Chem. Rev. 101 (2001) 2181.
[2] K. Park, M.J. Kurth, Tetrahedron 58 (2002) 8629.
[3] J. Mittendorf, J. Benet-Buchholz, P. Fey, K.H. Mohrs, Synthesis (2003) 136.
[4] F. Fülöp, T.A. Martinek, G.K. Tóth, Chem. Soc. Rev. 35 (2006) 323.
[5] J.L. Price, W.S. Horne, S.H. Gellman, J. Am. Chem. Soc. 129 (2007) 6376.
[6] T.A. Martinek, I.M. Mándity, L. Fülöp, G.K. Tóth, E. Vass, M. Hollósi, E. Forró, F. Fülöp, J. Am. Chem. Soc. 128 (2006) 13539.
[7] S. Gyónfalvi, Z. Szakonyi, F. Fülöp, Tetrahedron: Asymmetry 14 (2003) 3965.
[8] P.H. Carter, US 2005277666; Chem. Abstr. 144 (2005) 51452.
[9] I. Kanizsai, S. Gyónfalvi, Z. Szakonyi, R. Sillanpää, F. Fülöp, Green Chem. 9 (2007) 357.
[10] L. Kiss, E. Forró, R. Sillanpää, F. Fülöp, J. Org. Chem. 72 (2007) 8786.
[11] E. Juaristi, V.A. Soloshonok, Enantioselective Synthesis of β-Amino Acids, Wiley-Interscience, New York, 2005.
[12] B.P. Mowery, S.E. Lee, D.A. Kissounko, R.F. Epand, R.M. Epand, B. Weisblum, S.S. Stahl, S.H. Gellman, J. Am. Chem. Soc. 129 (2007) 15474.
[13] Z. Hameršak, M. Roje, A. Avdagić, V. Šunjić, Tetrahedron: Asymmetry 18 (2007) 635.
[14] C.S. Stauffer, A. Datta, J. Org. Chem. 73 (2008) 4166.
[15] J.A. Miller, S.T. Nguyen, Mini Rev. Org. Chem. 2 (2005) 39.
[16] E. Forró, F. Fülöp, Mini Rev. Org. Chem. 1 (2004) 931.
[17] I. Ilisz, R. Berkecz, A. Péter, J. Pharm. Biomed. Anal. 47 (2008) 1.
[18] A. Péter, F. Fülöp, J. Chromatogr. A 715 (1995) 219.
[19] A. Péter, M. Péter, F. Fülöp, G. Török, G. Tóth, D. Tourwé, J. Sápi, Chromatographia 51 (2000) S148.
[20] A. Péter, G. Török, D.W. Armstrong, J. Chromatogr. A 793 (1998) 283.
[21] G. Török, A. Péter, F. Fülöp, Chromatographia 48 (1998) 20.
[22] G. Török, A. Péter, P. Csomós, L.T. Kanerva, F. Fülöp, J. Chromatogr. A 797 (1998) 177.
[23] A. Péter, L. Lázár, F. Fülöp, D.W. Armstrong, J. Chromatogr. A 926 (2001) 229.
[24] A. Péter, A. Árki, E. Vékes, D. Tourwé, L. Lázár, F. Fülöp, D.W. Armstrong, J. Chromatogr. A 1031 (2004) 171.
[25] A. Péter, J. Chromatogr. A 955 (2002) 141.
[26] I. D'Acquarica, F. Gasparrini, D. Misiti, G. Zappia, C. Cimarelli, G. Palmieri, A. Carotti, S. Cellamare, C. Villani, Tetrahedron: Asymmetry 11 (2000) 2375.
[27] M.H. Hyun, S.C. Han, S.H. Whangboo, J. Chromatogr. A 992 (2003) 47.
[28] R. Berkecz, R. Török, I. Ilisz, E. Forró, F. Fülöp, D.W. Armstrong, A. Péter, Chromatographia 63 (2006) S37.
[29] A. Árki, D. Tourwé, M. Solymár, F. Fülöp, D.W. Armstrong, A. Péter, Chromatographia 60 (2004) S43.
[30] A. Péter, A. Árki, D. Tourwé, E. Forró, F. Fülöp, D.W. Armstrong, J. Chromatogr. A 1031 (2004) 159.
[31] A. Sztojkov-Ivanov, L. Lázár, F. Fülöp, D.W. Armstrong, A. Péter, Chromatographia 64 (2006) 89.
[32] M. Bertrand, A. Chabin, B.A. Brack, F. Westall, J. Chromatogr. A 1180 (2008) 131.
[33] E. Forró, F. Fülöp, Tetrahedron: Asymmetry 15 (2004) 2875.
[34] E. Forró, F. Fülöp, Org. Lett. 5 (2003) 1273.
[35] E. Forró, F. Fülöp, Tetrahedron: Asymmetry 15 (2004) 573.
[36] E. Forró, F. Fülöp, Chem. Eur. J. 12 (2006) 2587.
[37] E. Forró, T. Paál, G. Tasnádi, F. Fülöp, Adv. Synth. Catal. 348 (2006) 917.
[38] E. Forró, F. Fülöp, Chem. Eur. J. 22 (2007) 6397.
[39] E. Nativ, P. Rona, Isr. J. Chem. 10 (1972) 55.
[40] R. Singh, R.D.G. Cooper, Tetrahedron 50 (1994) 12049.
[41] P. Furet, C. Garcia-Echeverria, B. Gay, J. Scoepfer, M. Zeller, J. Rahuel, J. Med. Chem. 42 (1999) 2358.
[42] H. Plieninger, K. Schneider, Chem. Ber. (1959) 1594.
[43] G. Bernáth, K.L. Láng, G. Göndös, P. Márai, K. Kovács, Acta Chim. Acad. Sci. Hung. 74 (1972) 479.
[44] F. Arndt, Org. Synth., Coll. 2 (1943) 165.
[45] J.A. More, D.E. Reed, Org. Synth., Coll. 5 (1973) 351.
[46] G.M.F. Pinto, I.C.S.F. Jardim, J. Chromatogr. A 869 (2000) 463.
[47] D.L. Flumignan, F.O. Ferreira, A.G. Tininis, M.N. Lopes, J.E. Oliveira, J. Chromatogr. A 1202 (2008) 181.