Unexpected Formation of Thiophene-annulated Tetrahydro-3-benzazepines by Alkylation of Thiolactams with Ethyl Bromoacetate

Soumya Sarkar[a], Roland Fröhlich[b] and Bernhard Wünsch[a]

[a] Institut für Pharmazeutische und Medizinische Chemie der Westfälischen Wilhelms-Universität Münster, Hittorfstraße 58–62, D-48149 Münster, Germany,

[b] Organisch-Chemisches Institut der Westfälischen Wilhelms-Universität Münster, Corrensstr. 40, D-48149 Münster, Germany

Reprint requests to Prof. B. Wünsch. Tel.: +49-251-8333311. Fax: +49-251-8332144.
E-mail: wuensch@uni-muenster.de

Z. Naturforsch. **2013**, *68b*, 223 – 228 / DOI: 10.5560/ZNB.2013-3030
Received January 14, 2013

In order to synthesize enantiomerically pure tetrahydro-3-benzazepines with diverse substitution patterns, the lactams **3** were converted into thiolactams **4** upon treatment with Lawesson's reagent. Instead of an Eschenmoser sulfide contraction a thiophene annulation reaction occurred, when the thiolactams **4** were reacted with ethyl bromoacetate. Altogether, enantiomerically pure thiophene-annulated 3-benzazepines **7** were prepared in a very short reaction sequence (five reaction steps) starting from commercially available *o*-phenylenediacetic acid.

Key words: Tetrahydro-3-benzazepines, Enantiomerically Pure Compounds, Thiophene Annulation, Thiolactams, Lawesson's Reagent, Eschenmoser Sulfide Contraction, X-Ray Crystal Structure Analysis

Introduction

The tetrahydro-3-benzazepine scaffold (Fig. 1) is a privileged structure in Medicinal Chemistry [1, 2] because it contains the 2-arylethylamine substructure of several neurotransmitters, *e. g.* noradrenaline, dopamine and serotonin. Therefore compounds comprising the 3-benzazepine ring can be used for the activation or inhibition of the corresponding neurotransmitter receptors. Prominent examples are the prototypical dopamine D_1 receptor antagonist SCH23360 [3, 4], the D_1 receptor agonist fenoldopam [3, 4], and the 5-HT_{2C} receptor agonist lorcaserin which is used for the treatment of obesity [5]. Moreover, the tetrahydro-3-benzazepine ring system can be regarded as a homolog of the tetrahydroisoquinoline system, which is also a privileged structure and thus found in several pharmacologically active compounds.

Due to the promising pharmacological potential of tetrahydro-3-benzazepines, our interest has been focused on the development of synthetic methods allowing the stereoselective introduction of different substituents at all positions of the saturated part of the ring system (positions 1 – 5). Recently we have published the asymmetric synthesis of 1-monosustituted [6, 7], 2-monosubstituted [8, 9], 2,3-disusbstitued [10], 1,4-disubstituted [11, 12], and 1,3,4-trisubstituted tetrahydro-3-benzazepines of type **1** [13] (Fig. 1). Some of the prepared compounds showed promising affinity toward σ_1 or NMDA receptors [6, 7, 11, 13]. Therefore, it was planned to expand our synthetic strategy to get access to 2,4-disubstituted and 2,3,4-trisubstituted tetrahydro-3-benzazepines **2**.

Results and Discussion

For the introduction of an additional substituent in 2-position of the 3-benzazepine scaffold, the use of an Eschenmoser sulfide contraction [14] was planned. For this purpose the lactams **3** were prepared by reaction of *o*-phenylenediacetic acid with an excess of methyllithium [15] followed by reductive amination and ring closure [13]. At first the lactams **3** were converted into thiolactams **4** upon treatment with Lawesson's reagent [16, 17] in refluxing toluene. After 2 h the thiolactams **4** were isolated in 81 % – 86 % yields (Scheme 1).

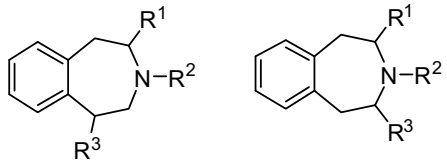
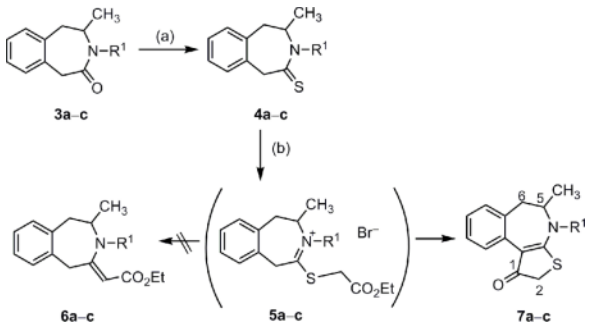


Fig. 1. Tetrahydro-3-benzazepines with different substitution patterns: Compounds of type **1** with promising affinities towards various receptors in the central nervous system have already been synthesized; compounds of type **2** are projected herein.

In order to perform the Eschenmoser sulfide contraction [14] the thiolactam **4a** was reacted with ethyl bromoacetate and subsequently with PPh_3 to obtain the enamino ester **6a**. However, instead of expected **6a** the thiophene-annulated 3-benzazepine **7a** was formed. Repeating the same reaction in refluxing $CHCl_3$ without addition of PPh_3 provided the tricyclic compound **7a** in 48 % yield. The same transformation took place upon reaction of the phenylethyl-substituted enantiomerically pure thiolactams **4b** and **4c** with ethyl bromoacetate. The thieno[3,2-*a*]-[3]benzazepines **7b** and **7c** were isolated in 65 % and 68 % yield, respectively.

The ^{1}H NMR spectrum of the tricyclic compound **7c** displays signals for the aliphatic Ph-CH_2CHCH_3 part of the 3-benzazepine scaffold, *i. e.* a doublet of doublets at 2.47 ppm and a doublet at 2.65 ppm (6-CH_2), a multiplet at 3.77 – 3.84 ppm (5-CH) and a doublet at 0.66 ppm (CH_3). Signals for the ethoxy group of the original ester moiety are missing. Two doublets at 3.68 and 3.74 ppm with a coupling constant of 16.9 Hz represent the protons of the methylene moiety in 2-position. In the ^{13}C NMR spectrum two signals



Scheme 1. Reagents and reaction conditions: (a) Lawesson's reagent, toluene reflux, 2 h, 81 % – 86 %; (b) $BrCH_2CO_2Et$, $CHCl_3$, reflux, 20 h, 48 % – 68 %.

Table 1. Synthesis of thiophene-annulated 3-benzazepines **7** from lactams **3**.

Entry	Educt	R^1	Configuration	Product **4** (yield)	Product **7** (yield)
1	**3a**	benzyl[a]	rac.	**4a** (81 %)	**7a** (48 %)
2	**3b**	(*R*)-1-phenylethyl[b]	(*R*,*R*)	**4b** (86 %)	**7b** (65 %)
3	**3c**	(*S*)-1-phenylethyl[c]	(*S*,*S*)	**4c** (83 %)	**7c** (68 %)

[a] Racemic mixture; [b] configuration in 4-position of the 3-benzazepine ring is (*R*); [c] configuration in 4-position of the 3-benzazepine ring is (*S*).

at 105.5 and 173.1 ppm indicate the presence of two additional olefinic carbon atoms (C-3a and C-10b) and the signal at 195.5 ppm indicates the presence of a ketone carbonyl moiety.

In order to prove the structure of the thiophene-annulated 3-benzazepines **7** unequivocally, the enantiomerically pure compound **7c** was recrystallized from a CH_2Cl_2-*n*-hexane mixture resulting in crystals which were suitable for X-ray crystal structure analysis. The molecular structure of **7c** in the crystal is displayed in Fig. 2. It clearly shows the annulated thiophene moiety with the carbonyl group in 1-position. Moreover, the (*S*)-configuration of both the chiral center in 5-position and in the *N*-substituent is clearly proved by the structure determination.

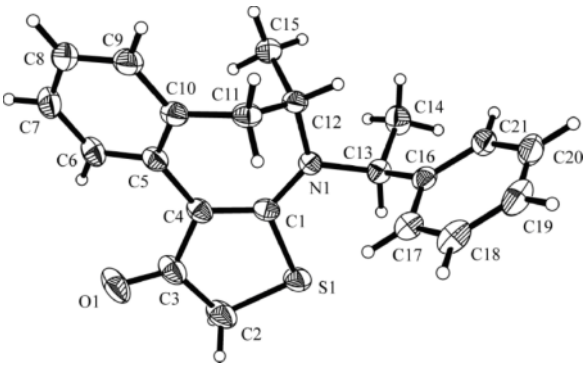


Fig. 2. Molecular structure of **7c** in the crystal (displacement ellipsoids at the 30 % probability level). Important bond lengths (Å) and angles (deg): C(1)–S(1) 1.7695(17), C(1)–C(4) 1.394(2), S(1)–C(2) 1.787(2), C(2)–C(3) 1.509 (3), C(3)–C(4) 1.451(3), N(1)–C(1) 1.346(2), N(1)–C(12) 1.478(2), C(11)–C(12) 1.541(3), N(1)–C(13) 1.491(2); C(1)–C(4)–C(3) 111.79(16), C(2)–C(3)–C(4) 113.30(18), S(1)–C(1)–C(4) 114.31(12), C(1)–S(1)–C(2) 92.41(9), S(1)–C(2)–C(3) 108.19(14), C(5)–C(4)–C(1) 129.07(15), C(4)–C(1)–N(1) 130.35(15), C(1)–N(1)–C(12) 122.76(14), N(1)–C(12)–C(11) 110.48(13), C(12)–C(11)–C(10) 111.87(15).

It is assumed that the thiophene annulation proceeded *via* the following reaction pathway (Scheme 1): At first ethyl bromoacetate reacted with the thiolactams **4** to produce *S*-alkylthioiminium salts **5**. Instead of deprotonation in α-position of the ester moiety of **5**, which would lead to the desired enamino esters **6**, deprotonation took place at the 1-CH_2 moiety of the 3-benzazepine scaffold adjacent to the positive charge. An intramolecular attack of the resulting ketene *N*,*S*-acetals on the ester moiety of **5** provided the tricyclic ketones **7**. This 5-*exo-trig* cyclization is favored according to the Baldwin rules [18].

Since this unexpected annulation reaction gave access to novel thiophene annulated ring systems, the transformations of thiolactams **4** with analogous ethyl 3-bromopropionate and ethyl 2-bromopropionate were investigated. Unfortunately these reactions failed to give the desired thiophene-annulated systems. It is assumed that the bromine atom in β-position of ethyl 3-bromopropionate is less reactive than the bromine atom in α-position of ethyl 2-bromoacetate. The nucleophilic substitution at the secondary C atom of ethyl 2-bromopropionate is sterically inhibited.

A similar thiophene annulation reaction has been reported by G. Lhommet *et al.* [19]. Whereas five-, six-, and seven-membered thiolactams reacted with ethyl bromoacetate to afford the expected enamino esters, the transformation of piperidine-2-thiones and azepane-2-thiones with α-substituted bromoacetates afforded exclusively thiophene-annulated pyridines and azepines. It was argued that the ring size of the thiolactam (6-, 7-membered) and the substituent in α-position of the bromoacetates were responsible for the thiophene annulation. The reaction of secondary β-ketothioamides with ethyl bromoacetate also led to heterocyclic systems instead of enamino esters. In this case the NH moiety of the secondary ketene *N*,*S*-acetal intermediates reacted with the ester moiety leading to 1,3-thiazolidin-4-ones [20]. In the total synthesis of the natural products (±)-lythrancepine II and III a similar thiophene annulation was observed, when a thiolactam reacted with an α-bromoketone [21].

In conclusion, the unexpected formation of thiophene-annulated 3-benzazepines **7** by alkylation of thiolactams **4** with ethyl bromoacetate allows a very facile access to enantiomerically pure tetrasubstituted 3-benzazepines. Together with the three reaction steps required for the synthesis of lactams **3** starting from commercially available *o*-phenylenediacetic acid (reaction with MeLi, reductive amination, cyclization with CDI), the complete reaction sequence comprises only five reaction steps.

Experimental Section

Chemistry, general

Unless otherwise mentioned, THF was dried with sodium/benzophenone and was freshly distilled before use. Thin layer chromatography (tlc): Silica gel 60 F_{254} plates (Merck). Flash chromatography: Silica gel 60, 40 – 64 μm (Merck); parentheses include: diameter of the column, length of column, fraction size, eluent, R_f value. Melting point: Melting point apparatus SMP 3 (Stuart Scientific), uncorrected. IR: IR spectrophotometer 480Plus FT-ATR-IR (Jasco). ^{1}H NMR (400 MHz), ^{13}C NMR (100 MHz): Mercury plus 400 spectrometer (Varian); δ in ppm relative to tetramethylsilane; coupling constants are given with 0.5 Hz resolution. Where necessary, the assignment of the signals in the ^{1}H NMR and ^{13}C NMR spectra was performed using ^{1}H-^{1}H and ^{1}H-^{13}C COSY NMR spectra. Optical rotation α (deg) was determined with a Polarimeter 341 (Perkin Elmer); length 1 dm, wavelength 589 nm (sodium D line); the unit of the specific rotation $[\alpha]_l^T$ (deg mL dm^{-1} g^{-1}) is omitted; concentration of the sample *c* (g per 100 mL) and the solvents used are given in brackets. MS: EI = electron impact, ESI = electrospray ionization: MicroTof (Bruker Daltronics, Bremen), calibration with sodium formate clusters before measurement. HPLC method for determination of the product purity: Merck Hitachi Equipment; UV detector: L-7400; autosampler: L-7200; pump: L-7100; degasser: L-7614; Method: column: LiChrospher® 60 RP-select B (5 μm), 250 – 4 mm cartridge; flow rate: 1.00 mLmin^{-1}; injection volume: 5.0 μL; detection at λ = 210 nm; solvents: A: water with 0.05 % (v/v) trifluoroacetic acid; B: acetonitrile with 0.05 % (v/v) trifluoroacetic acid: gradient elution: (A %): 0 – 4 min: 90 %, 4 – 29 min: gradient from 90 % to 0 %, 29 – 31 min: 0 %, 31 – 31.5 min: gradient from 0 % to 90 %, 31.5 – 40 min: 90 %.

*General procedure for the synthesis of thiolactams **4***

Lawesson's reagent (1 equiv) was added to a solution of lactam **3** (1 equiv) in toluene (10 mL). The mixture was stirred under reflux for 2 h. The solvent was evaporated *in vacuo* to obtain a viscous oil, which was purified by flash chromatography.

*3-Benzyl-4-methyl-1,3,4,5-tetrahydro-3-benzazepin-2-thione (**4a**)*

Following the General Procedure, Lawesson's reagent (73 mg, 0.18 mmol) was added to a solution of lactam **3a** (49 mg, 0.18 mmol) in toluene (10 mL). The mixture was

stirred under reflux for 2 h. The solvent was evaporated *in vacuo* to obtain a viscous oil, which was purified by flash chromatography ($d = 2$ cm, $l = 10$ cm, $V = 10$ mL, cyclohexane-EtOAc 80 : 20, $R_f = 0.54$ (cyclohexane-EtOAc 60 : 40)). – Colorless viscous oil, yield 42 mg (81 %). – $C_{18}H_{19}NS$ (281.4 gmol^{-1}). – FT-IR (ATR, film): ν (cm^{-1}) = 3026 (aliphatic $C-H$), 1175 ($C=S$). – ^{1}H NMR ($CDCl_3$): δ (ppm) = 1.33 (d, $J = 6.7$ Hz, 3H, CH_3), 2.84 (dd, $J = 16.4/10.6$ Hz, 1H, 5-H), 2.94 (dd, $J = 16.4/5.0$ Hz, 1H, 5-H), 4.33 (d, $J = 14.7$ Hz, 1H, 1-H), 4.43 – 4.52 (m, 1H, 4-H), 4.64 (d, $J = 14.6$ Hz, 1H, 1-H), 4.94 (d, $J = 15.4$ Hz, 1H, NCH_2Ph), 5.64 (d, $J = 15.4$ Hz, 1H, NCH_2Ph), 6.86 – 7.23 (m, 9H, arom). – ^{13}C NMR ($CDCl_3$): δ (ppm) = 20.5 (1C, CH_3), 39.7 (1C, C-5), 51.2 (1C, C-1), 54.6 (1C, C-4), 56.3 (1C, NCH_2Ph), 126.8, 127.1, 127.2, 127.6, 128.5, 129.5 (9C, Ph-*C*H), 134.0, 134.9, 136.3 (3C, Ph-*C*), 203.6 (1C, *C* =S). – Exact mass (ESI): $m/z = 282.1319$ (calcd. 282.1311 for $C_{18}H_{19}NSH$, $[M+H]^+$). – Purity (HPLC): 95.1 % (t_R = 21.3 min).

*(R)-4-Methyl-3-[(R)-1-phenylethyl]-1,3,4,5-tetrahydro-3-benzazepin-2-thione (**4b**)*

Following the General Procedure, Lawesson's reagent (87 mg, 0.21 mmol) was added to a solution of lactam **3b** (60 mg, 0.21 mmol) in toluene (10 mL). The mixture was stirred under reflux for 2 h. The solvent was evaporated *in vacuo* to obtain a viscous oil, which was purified by flash chromatography ($d = 2$ cm, $l = 10$ cm, $V = 10$ mL, cyclohexane-EtOAc 90 : 10, $R_f = 0.60$ (cyclohexane-EtOAc 60 : 40)). – Colorless solid, m. p. 108 – 110 °C, yield 54 mg (86 %). – $C_{19}H_{21}NS$ (295.4 gmol^{-1}). – FT-IR (ATR, film): ν (cm^{-1}) = 2973 (aliphatic $C-H$), 1173 ($C=S$). – ^{1}H NMR ($CDCl_3$): δ (ppm) = 1.47 (d, $J = 7.1$ Hz, 3H, CH_3), 1.58 (d, $J = 7.1$ Hz, 3H, CH_3), 2.51 – 2.67 (m, 2H, 5-H), 3.73 – 3.87 (m, 1H, 4-H), 4.37 (d, $J = 14.9$ Hz, 1H, 1-H), 4.46 (d, $J = 14.9$ Hz, 1H, 1-H), 6.75 – 7.25 (m, 10H, NCH(CH$_3$)Ph/arom). – ^{13}C NMR ($CDCl_3$): δ (ppm) = 15.3 (1C, CH_3), 22.6 (1C, CH_3), 39.5 (1C, C-5), 51.1 (1C, C-1), 52.4 (1C, C-4), 60.8 (1C, NCH(CH$_3$)Ph), 127.0, 127.1, 127.2, 127.7, 128.4, 128.7, 129.8 (9C, Ph-*C*H), 134.5, 135.1, 138.8 (3C, Ph-*C*), 203.2 (1C, *C* =S). – $[\alpha]_{589}^{20} = +7.0$ (c = 1.00, CH_2Cl_2). – Exact mass (ESI): $m/z = 318.1288$ (calcd. 318.1287 for $C_{19}H_{21}NSNa$, $[MNa]^+$). – Purity (HPLC): 97.3 % ($t_R = 22.8$ min).

*(S)-4-Methyl-3-[(S)-1-phenylethyl]-1,3,4,5-tetrahydro-3-benzazepin-2-thione (**4c**)*

Following the General Procedure, Lawesson's reagent (73 mg, 0.18 mmol) was added to a solution of lactam **3c** (50 mg, 0.18 mmol) in toluene (10 mL). The mixture was stirred under reflux for 2 h. The solvent was evaporated *in vacuo* to obtain a viscous oil, which was purified by flash chromatography ($d = 2$ cm, $l = 10$ cm, $V = 10$ mL, cyclohexane-EtOAc 90 : 10, $R_f = 0.60$ (cyclohexane-EtOAc 60 : 40)). – Colorless solid, m. p. 108 – 110 °C, yield 44 mg (83 %). – $[\alpha]_{589}^{20} = -7.5$ ($c = 1.00$, CH_2Cl_2). – Exact mass (ESI): $m/z = 318.1279$ (calcd. 318.1287 for $C_{19}H_{21}NSNa$, $[MNa]^+$). – Purity (HPLC): 98.4 % ($t_R = 22.1$ min).

*4-Benzyl-5-methyl-5,6-dihydro-2H-thieno[3,2-a][3]benzazepin-1(4H)-one (**7a**)*

To a solution of thiolactam **4a** (50 mg, 0.18 mmol) in $CHCl_3$ (10 mL), an excess of ethyl bromoacetate (199 μL, 1.8 mmol) was added. The mixture was stirred under reflux for 20 h. The solvent was evaporated *in vacuo* and the crude product was purified by flash chromatography ($d = 2$ cm, $l = 20$ cm, $V = 10$ mL, cyclohexane-EtOAc 80 : 20, $R_f = 0.30$ (cyclohexane-EtOAc 60 : 40)). – Colorless solid, m. p. 182 – 184 °C, yield 28 mg (48 %). – $C_{20}H_{19}NOS$ (321.4 gmol^{-1}). – FT-IR (ATR, film): ν (cm^{-1}) = 2968 (aliphatic *C–H*), 1658 (*C=O*). – ^{1}H NMR ($CDCl_3$): δ (ppm) = 0.80 (d, $J = 6.5$ Hz, 3H, CH_3), 2.68 (dd, $J = 14.6/6.0$ Hz, 1H, 6-H), 3.18 (d, $J = 14.7$ Hz, 1H, 6-H), 3.68 – 3.74 (m, 2H, 2-H), 3.90 – 3.98 (m, 1H, 5-H), 4.60 (d, $J = 17.0$ Hz, 1H, NCH_2Ph), 4.90 (d, $J = 17.0$ Hz, 1H, NCH_2Ph), 6.89 – 7.41 (m, 8H, arom), 7.88 – 8.01 (m, 1H, arom). – ^{13}C NMR ($CDCl_3$): δ (ppm) = 18.5 (1C, CH_3), 36.8 (1C, C-6), 40.3 (1C, C-2), 57.4 (1C, C-5), 60.2 (1C, NCH_2Ph), 105.6 (1C, C-3a), 125.6, 126.6, 126.9, 128.1, 128.5, 129.1, 129.3 (9C, Ph-*C*H), 133.1, 134.5, 135.2 (3C, Ph-*C*), 174.7 (1C, C-10b), 194.8 (1C, *C*=O). – Exact mass (ESI): $m/z = 322.1274$ (calcd. 322.1260 for $C_{20}H_{19}NOSH$, $[M+H]^+$). – Purity (HPLC): 88.5 % ($t_R = 21.0$ min).

*(R)-5-Methyl-4-[(R)-1-phenylethyl]-5,6-dihydro -2H-thieno[3,2-a][3]benzazepin-1(4H)-one (**7b**)*

To a solution of thiolactam **4b** (35 mg, 0.12 mmol) in $CHCl_3$ (10 mL), an excess of ethyl bromoacetate (133 μL, 1.20 mmol) was added. The mixture was stirred under reflux for 20 h. The solvent was evaporated *in vacuo*, and the crude product was purified by flash chromatography ($d = 2$ cm, $l = 20$ cm, $V = 10$ mL, cyclohexane-EtOAc 80 : 20, $R_f = 0.32$ (cyclohexane-EtOAc 60 : 40)). – Colorless solid, m. p. 143 – 144 °C, yield 26 mg (65 %). – $C_{21}H_{21}NOS$ (335.5 gmol^{-1}). – FT-IR (ATR, film): ν (cm^{-1}) = 2966 (aliphatic *C–H*), 1660 (*C=O*). – ^{1}H NMR ($CDCl_3$): δ (ppm) = 0.66 (d, $J = 6.7$ Hz, 3H, CH_3), 1.69 (d, $J = 6.9$ Hz, 3H, CH_3), 2.47 (dd, $J = 14.7/6.7$ Hz, 1H, 6-H), 2.65 (d, $J = 14.7$ Hz, 1H, 6-H), 3.68 (d, $J = 16.9$ Hz, 1H, 2-H), 3.74 (d, $J = 16.9$ Hz, 1H, 2-H), 3.77 – 3.84 (m, 1H, 5-H), 5.61 (q, $J = 6.9$ Hz, 1H, NCH(CH$_3$)Ph), 6.74 – 7.46 (m, 8H, arom), 8.03 – 8.20 (m, 1H, arom). – ^{13}C NMR ($CDCl_3$): δ (ppm) = 18.9 (1C, CH_3), 20.7 (1C, CH_3), 36.9 (1C, C-6), 41.9 (1C, C-2), 53.4 (1C, C-5), 61.9 (1C, NCH(CH$_3$)Ph), 105.5 (1C,

C-3a), 125.4, 126.3, 127.4, 128.6, 128.8, 129.1, 129.4 (9C, Ph-*C*H), 133.7, 135.3, 138.3 (3C, Ph-*C*), 173.1 (1C, C-10b), 195.5 (1C, *C*=O). – $[\alpha]_{589}^{20} = +71.2$ ($c = 0.20$, CH_2Cl_2). – Exact mass (ESI): $m/z = 336.1429$ (calcd. 336.1422 for $C_{21}H_{21}NOSH$, $[M+H]^+$). – Purity (HPLC): 97.2 % (t_R = 22.0 min).

*(S)-5-Methyl-4-[(S)-1-phenylethyl]-5,6-dihydro-2H-thieno[3,2-a][3]benzazepin-1(4H)-one (**7c**)*

To a solution of thiolactam (S_a-,4*S*)-**4c** (60 mg, 0.20 mmol) in $CHCl_3$ (10 mL), an excess of ethyl bromoacetate (221 µL, 2.0 mmol) was added. The mixture was heated to reflux for 20 h. The solvent was evaporated *in vacuo*, and the crude product was purified by flash chromatography ($d = 2$ cm, $l = 20$ cm, $V = 10$ mL, cyclohexane-EtOAc 80 : 20, $R_f = 0.32$ (cyclohexane-EtOAc 60 : 40)). – Colorless solid, m. p. 143 – 144 °C, yield 46 mg (68 %). – $[\alpha]_{589}^{20} = -70.3$ ($c = 0.68$, CH_2Cl_2). – Exact mass (ESI): $m/z = 336.1420$ (calcd. 336.1422 for $C_{21}H_{21}NOSH$, $[M+H]^+$). –Purity (HPLC): 96.9 % (t_R = 21.9 min).

*X-Ray crystal structure analysis of **7c***

For the X-ray crystal structure analysis, a sample of **7c** was recrystallized from CH_2Cl_2-*n*-hexane. A data set was collected with a Nonius KappaCCD diffractometer. Programs used: data collection: COLLECT (Nonius B. V., **1998**); data reduction: DENZO-SMN [22]; absorption correction: DENZO [23]; structure solution: SHELXS-97 [24]; structure refinement: SHELXL-97 [25]; graphics: XP (Bruker Analytical X-ray Instruments Inc., **2000**).

Crystal structure data: Formula $C_{21}H_{21}NOS$; M_r = 335.45; colorless crystal, 0.30 × 0.27 × 0.15 mm^3; orthorhombic; space group $P2_12_12_1$ (no. 19), $Z = 4$; a = 8.7257(3), b = 10.2788(3), c = 19.4764(10) Å; V = 1746.83(12) Å^3; $\rho_{calcd} = 1.28$ gcm^{-3}; $\mu = 1.7$ mm^{-1}. Data collection: Radiation: CuK_α, $\lambda = 1.54178$ Å; $T = 223$ (2) K; ω- and φ-scans, 9028 reflections collected ($\pm h$, $\pm k$, $\pm l$), $[(\sin\theta)/\lambda] = 0.60$ Å^{-1}, empirical absorption correction, $T_{min/max} = 0.632/0.786$, 2873 independent ($R_{int} = 0.032$) and 2805 "observed" reflections [$I > 2\sigma(I)$]. Refinement: 219 refined parameters, $R1$ [$I > 2\sigma(I)$] = 0.031, $wR2$ (all data) = 0.080, Flack parameter x 0.048(17), max. / min. residual electron density 0.12/ − 0.16 eÅ^{-3}. Hydrogen atoms calculated and refined as riding atoms.

CCDC 913691 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from Cambridge Crystallographic Data Centre *via* www.ccdc.cam.ac.uk/data_request/cif.

Acknowledgement

We wish to thank the NRW Graduate School of Chemistry for a scholarship, which is funded by the Government of the State Nordrhein-Westfalen and the Westfälische Wilhelms-Universität Münster.

[1] J. Weinstock, J. P. Hieble, J. W. Wilson III, *Drug Fut.* **1985**, *10*, 645–696.
[2] M. Kawase, S. Saito, N. Motohashi, *Int. J. Antimicrob Agents* **2000**, *14*, 193–201.
[3] D. L. Ladd, J. Weinstock, M. Wiese, G. W. Gessner, J. L. Sawyer, K. E. Flaim, *J. Med. Chem.* **1986**, *29*, 1904–1912.
[4] W. H. Frishman, *J. Clin. Pharmacol.* **1998**, *38*, 2–13.
[5] B. M. Smith, J. M. Smith, J. H. Tsai, J. A. Schultz, C. A. Gilson, S. A. Estrada, R. R. Chen, D. M. Park, E. B. Prieto, C. S. Gallardo, D. Sengupta, P. I. Dosa, J. A. Covel, A. Ren, R. R. Webb, N. R. A. Beeley, M. Marin, M. Morgan, S. Espitia, H. R. Saldana, C. Bjenning, K. T. Whelan, A. J. Grottick, F. Menzaghi, W. J. Thomsen, *J. Med. Chem.* **2008**, *51*, 305–313.
[6] O. Krull, B. Wünsch, *Bioorg. Med. Chem.* **2004**, *12*, 1439–1451.
[7] U. Wirt, D. Schepmann, B. Wünsch, *Eur. J. Org. Chem.* **2007**, 462–475.
[8] S. M. Husain, R. Fröhlich, B. Wünsch, *Tetrahedron: Asymmetry* **2008**, *19*, 1613–1616.
[9] S. M. Husain, R. Fröhlich, B. Wünsch, *J. Org. Chem.* **2009**, *74*, 2788–2793.
[10] S. Sarkar, S. M. Husain, D. Schepmann, R. Fröhlich, B. Wünsch, *Tetrahedron* **2012**, *68*, 2687–2695.
[11] S. M. Husain, M. T. Heim, D. Schepman, B. Wünsch, *Tetrahedron: Asymmetry* **2009**, *20*, 1383–1392.
[12] S. Sarkar, D. Schepmann, B. Wünsch, *Tetrahedron: Asymmetry* **2011**, *22*, 1411–1422.
[13] S. Sarkar, D. Schepmann, J. Köhler, R. Fröhlich, B. Wünsch, *Eur. J. Org.* Chem. **2012**, 5980–5990.
[14] M. Roth, P. Dubs, E. Göschi, A. Eschenmoser, *Helv. Chim. Acta* **1971**, *54*, 710–714.
[15] S. M. Husain, B. Wünsch, *Synthesis* **2008**, 2729–2732.
[16] S. Scheibye, B. S. Pederson, S.-O. Lawesson, *Bull. Soc. Chim. Belg.* **1978**, *87*, 299–304.
[17] M. P. Cava, M. I. Levinson, *Tetrahedron* **1985**, *22*, 5061–5087.
[18] J. E. Baldwin, *J. Chem. Soc., Chem. Commun.* **1976**, *18*, 734–736.
[19] P. Marchand, C. Bellec, M.-C. Fargeau-Bellassoued, C. Nezry, G. Lhommet, *Heterocycles* **1996**, *43*, 63–70.

[20] T. S. Jagodzinski, A. Wesolowska, J. G. Sosnicki, *Polish. J. Chem.* **2000**, *74*, 1101–1114.
[21] D. J. Hart, W.-P. Hong, L.-Y. Hsu, *J. Org. Chem.* **1987**, *52*, 4665–4673.
[22] Z. Otwinowski, W. Minor in *Methods in Enzymology*, Vol. 276, *Macromolecular Crystallography*, Part A (Eds.: C. W. Carter Jr, R. M. Sweet), Academic Press, New York, **1997**, pp. 307–326.
[23] Z. Otwinowski, D. Borek, W. Majewski, W. Minor, *Acta Crystallogr*. **2003**, *A59*, 228–234.
[24] G. M. Sheldrick, *Acta Crystallogr*. **1990**, *A46*, 467–473.
[25] G. M. Sheldrick, *Acta Crystallogr*. **2008**, *A64*, 112–122.