Res Chem Intermed
DOI 10.1007/s11164-017-3167-1

Efficient, straightforward, catalyst-free synthesis of medicinally important S-alkyl/benzyl dithiocarbamates under green conditions

Ali Asadipour[1] · Zeynab Shams[1] · Khalil Eskandari[1] · Mohammad-Hassan Moshafi[2] · Ehsan Faghih-Mirzaei[1] · Yaghoub Pourshojaei[1,3]

Received: 19 July 2017 / Accepted: 4 October 2017

Abstract Green synthesis of some novel dithiocarbamate derivatives substituted by aliphatic and aromatic groups as potentially interesting, medicinally important organic compounds via efficient one-pot, catalyst-free reaction is described. In this reaction, dithiocarbamate derivatives are obtained from condensation reaction between primary or secondary amines, carbon disulfide, and alkyl or benzyl halides in one pot and ethanol–aqueous medium. Among aliphatic and aromatic amines, the results generally show that reaction of aliphatic amines with alkyl or benzyl halides led to desired products in highest yields. Also, among aliphatic amines, those which reacted with benzyl halides showed better yields than those that reacted with alkyl halides. Use of environmentally benign solvents is one of the advantages of this procedure. Also, obtaining products in good yield via catalyst-free reaction using a facile, inexpensive, and practical approach can be considered other advantages of this procedure. Target products are very important compounds, because their analogs have been applied in pharmaceutical, chemical, and rubber industries.

Electronic supplementary material The online version of this article (doi:10.1007/s11164-017-3167-1) contains supplementary material, which is available to authorized users.

✉ Khalil Eskandari
khalileskandari@yahoo.com

✉ Yaghoub Pourshojaei
y.pourshoja@kmu.ac.ir

[1] Department of Medicinal Chemistry, Faculty of Pharmacy and Pharmaceutics Research Center, Kerman University of Medical Sciences, Kerman, Iran

[2] Department of Pharmaceutical Science, School of Pharmacy, Kerman University of Medical Science, Kerman, Iran

[3] Neuroscience Research Center, Institute of Neuropharmacology, Kerman University of Medical Sciences, Kerman, Iran

Published online: 20 October 2017

Keywords Dithiocarbamate · Alkyl halide · Amine · Catalyst-free · Ethanol–aqueous medium

Introduction

Over the past few decades, synthesis and development of novel, medicinally important organic compounds with potential applications in medicine and pharmaceutical industries have attracted interest in the fields of synthetic chemistry and pharmacology. Among the broad category of S-containing organic compounds, dithiocarbamate derivatives have been shown to exhibit a wide range of biological and pharmacological activities; For instance, numerous investigations have revealed that dithiocarbamates exhibit various activities, including antiproliferative [1], antiglaucoma [2], antibacterial [3], antifungal [3], spermicidal [4], breast cancer treatment [5], and cholinesterase inhibition [6–8] effects, as well as being used as myocardial imaging agents [9]. In addition, their in vitro antitumor activity against human myelogenous leukemia K562 cells has been described [10]. They are known to be HIV-I NCp7 inhibitors, and antivirus agents [11], as well as nonvanilloid TRPV1 antagonists [12, 13]; For instance, some chemical structures bearing the dithiocarbamate scaffold that have been recognized as potential therapeutic drugs are shown in Fig. 1 [14–16]. Furthermore, dithiocarbamates are widely used as synthetic intermediates [17–21], precursors for synthesis of nanoparticles [22], in vulcanization of rubbers [23], and as ligands for chelating metals [24].

The importance of this type of compound is clear from the discussion above. To date, several routes have been proposed and developed by chemists for synthesis of dithiocarbamates; For instance, reaction of amines with thiophosgene or isothiocyanates (costly and toxic reagents) [25], catalytic reaction of amines with carbon

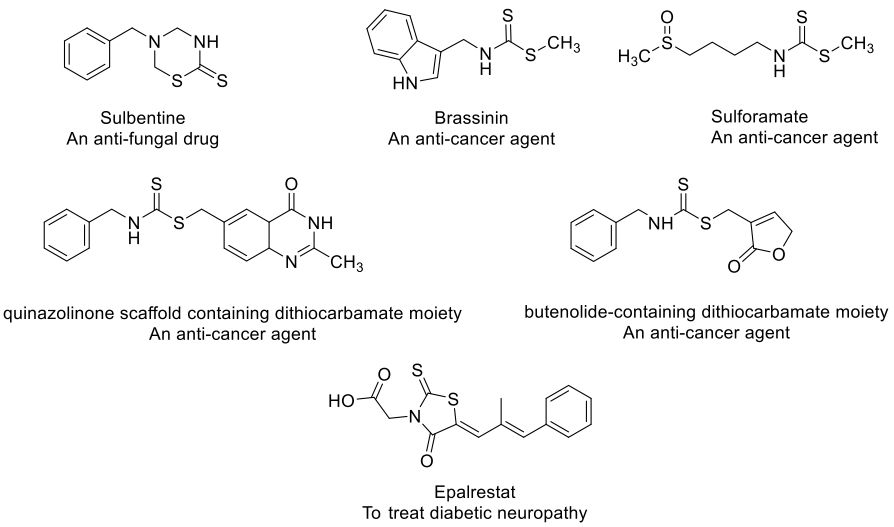


Fig. 1 Selected pharmacologically active organic compounds containing dithiocarbamate framework

disulfide and alkyl halides [26], Michael acceptors [27], organyl thiocyanates [28], allyl acetate [29], epoxide [30], or tosyl hydrazone [31] can lead to dithiocarbamate derivatives. However, there are several disadvantages to some of these methods, including the hazards of handling isothiocyanates, obtaining side-products such as urethane, poor long-term stability of some precursors, multistep and tedious procedures, the need for high reaction temperatures, and obtaining low or moderate yields.

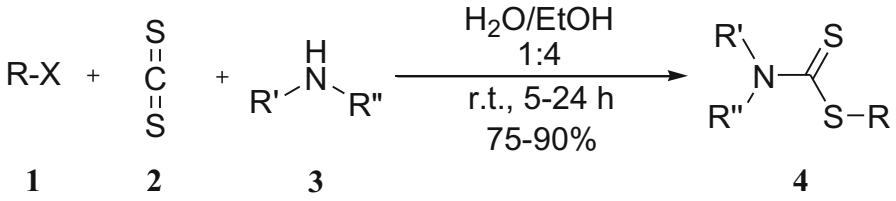
Loading and obtaining organic products in ethanol–aqueous media has attracted significant attention because of its safety, environmental friendliness, and green chemistry features [32–35]. Carrying out organic reactions in water-based systems to successfully obtain products under green conditions is very significant and notable, especially from the industrial and environmental points of view. Therefore, use of nontoxic, readily available, inexpensive, and harmless solvents has received growing attention over the last few decades [32–35].

In continuation of our studies on synthesis of novel derivatives of organic and heterocyclic compounds [36–41], we report herein a new route for efficient, catalyst-free, environmentally safe synthesis of some novel and known dithiocarbamates via one-pot reaction of primary or secondary amines, carbon disulfide, and alkyl or benzyl halides in ethanol–aqueous medium (Scheme 1).

Results and discussion

In the first step, and before expanding its scope, the reaction was examined in presence of various solvents to determine the best solvent(s) for reaction progress. For this purpose, the reaction to obtain product **4e** was selected as a model. The results of this evaluation on the model reaction are summarized in Table 1.

As seen from Table 1, the product yield obtained when using the mixture of H_2O/EtOH (1:4) was maximum. Furthermore, from the obtained data, it can be understood that the progress of the reaction was acceptable without need for any acidic or basic catalyst, which can be considered as one of the advantages of this procedure. Running the reaction in ethanol–aqueous medium with nontoxic solvents



Scheme 1 Catalyst-free synthesis of dithiocarbamate derivatives under green conditions

Table 1 Evaluation of reaction progress in presence of different solvents

Entry	Solvent	Time (h)	Yield[a] (%)
1	Ether	12	30
2	Acetone	12	37
3	THF	10	65
4	Dichloromethane	12	48
4	Chloroform	8	54
5	Toluene	12	10
6	H_2O	10	74
7	EtOH	10	81
8	H_2O/EtOH (1:1)	8	80
9	H_2O/EtOH (1:2)	8	87
10	H_2O/EtOH (1:3)	7	90
11	H_2O/EtOH (1:4)	6	92
12	H_2O/EtOH (1:5)	6	92

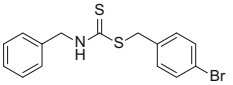
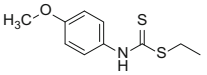
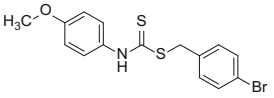
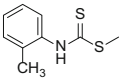
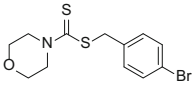
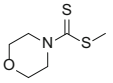
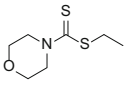
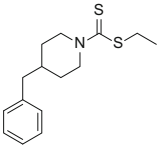
[a] Isolated yields

makes the procedure environmentally safe and compatible with green chemistry, while the addition of precursors and synthesis of products in one pot to obtain products in good to excellent yield represent further advantages of this procedure. Therefore, we decided to run this reaction in ethanol–aqueous medium, H_2O/EtOH (1:4), without use of any catalysts in one pot. After identifying appropriate solvents as reaction media, in order to examine the generality and expand the scope of the reaction, this three-component reaction was carried out with numerous primary or secondary amines, carbon disulfide, and some different alkyl or benzyl halides in one pot in presence of the mixture of H_2O/EtOH (1:4). The obtained products and results are summarized in Table 2.

In general, among cyclic or linear alkylamines and arylamines, cyclic alkylamines such as piperidine and morpholine showed higher yields compared with the others. It is believed that nucleophilicity of cyclic alkylamines is higher than others, and the nonbonding electron pair on nitrogen is more accessible because they are rigid and nonflexible. The main role of water as part of the reaction media and its mechanism are still not clear. In contrast to the low solubility of amines and alkyl halides in water, this three-component reaction is accelerated in ethanol–aqueous medium, progressing efficiently at ambient temperature.

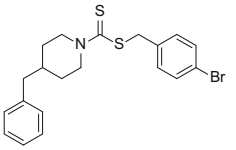
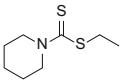
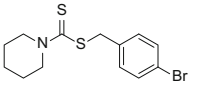
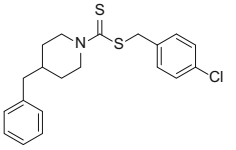
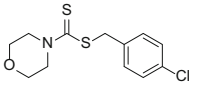
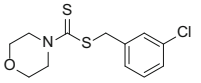
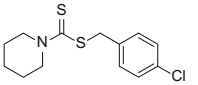
The structures of all newly prepared compounds were deduced from their Fourier-transform infrared (FT-IR), ^{1}H and ^{13}C nuclear magnetic resonance (NMR) spectroscopy, and elemental analyses. For instance, the FT-IR spectrum of compound **4k** exhibited CH aromatic and aliphatic stretching bands at 2991, 2940, and 2852 cm^{-1}. The band appearing at 1585 cm^{-1} is related to C–C stretching of aromatic ring. The bands at 1479 and 1277 cm^{-1} correspond to C–N and C=S stretching, respectively. In addition, the peak at 1425 cm^{-1} corresponds to aromatic C–C bending. In the ^{1}H NMR spectrum of **4k**, four protons of aromatic ring are represented by two doublets at 7.46 ppm ($J = 9$ Hz) and 7.31 ppm ($J = 9$ Hz). A singlet at 4.56 ppm corresponds to benzylic CH_2 group. The four protons of -CH_2-N-CH_2 appear at 4.32 and 3.90 ppm as two broad singlets. Also, a broad singlet at

Table 2 Efficient synthesis of medicinally important dithiocarbamate derivatives in ethanol–aqueous medium

Entry	Product	Yield[a] (%)	M.p. (°C)/[Lit.]
1	 **4a**	75	64–67[b]
2	 **4b**	70	70–73[b]
3	 **4c**	74	115–119 (115) [42]
4	 **4d**	69	140–143 (140–141) [43]
5	 **4e**	92	89–90 (90–91) [44]
6	 **4f**	89	81–84 (82–84) [45]
7	 **4g**	90	39–42 (40) [46]
8	 **4h**	85	48–50[b]

1.73 corresponds to other six protons of piperidinyl ring. The ^{13}C NMR spectrum of **4k** exhibits 10 distinguished peaks, in agreement with the compound's chemical structure. Furthermore, the CHN analysis results strongly confirmed the structure of **4k**.

Table 2 continued

Entry	Product	Yield[a] (%)	M.p. (°C)/[Lit.]
9	 **4i**	88	89–91[b]
10	 **4j**	79	153–156[c] (155–159) [47]
11	 **4k**	82	74–77[b]
12	 **4l**	86	101–104[b]
13	 **4m**	84	74–78 (79–81) [28]
14	 **4n**	89	55–58[b]
15	 **4o**	85	84–87 (83–85) [28]

[a] Isolated yields

[b] Novel products

[c] Physical form of isolated product is viscose liquid (oil), therefore its boiling point has been measured

Experimental

All chemicals and starting materials were purchased from Merck and Sigma-Aldrich chemical companies and were used without further purification. Electrothermal IA9100 melting point apparatus fixed at 1 °C/min was used for melting point measurements. Bruker FT-IR Tensor 27 infrared spectrophotometer with KBr as matrix was used for recording IR spectra. Fourier-transform nuclear magnetic resonance Bruker Avance Ultrashield spectrometer (at 500 MHz for ^{1}H NMR and 125 MHz for ^{13}C NMR, with DMSO-d_6 as solvent) was applied for recording ^{1}H and ^{13}C NMR spectra. Elemental analyses (C/H/N/S) were carried out on a Heraeus Rapid analyzer; the results showed good agreement (± 0.3 %) with calculated values. Reaction progress was monitored on TLC-grade silica gel G/UV (254 nm) plates.

General procedure for preparation of S-alkyl/benzyl dithiocarbamates

To a stirred round-bottomed flask containing 15 mL solvent (H_2O/EtOH, 1:4) equipped with ice bath, appropriate amine (1 mmol), and carbon disulfide (1.6 mmol) were added. After 2 h of stirring, appropriate alkyl or benzyl halide (1 mmol) was added. Then, the temperature of the mixture was allowed to reach room temperature. Reaction progress was monitored by TLC (*n*-hexane/EtOAc, 4:1 as eluents). After reaction completion in appropriate time (5–24 h), the product was precipitated. The synthesized compound was filtrated to obtain crude product. Pure product was obtained by trituration in boiling ethanol. If the synthesized compound was not precipitated, the solvent was evaporated by rotary evaporator under reduced pressure to give crude product. Afterwards, pure product was obtained by column chromatography using EtOAc/*n*-hexane 1:6 as eluent.

Representative spectral data

*4-Bromobenzyl benzylcarbamodithioate (**4a**)* FT-IR (KBr, $\bar{\upsilon}$, cm^{-1}): 3310, 3026, 2995, 2903, 1639, 1601, 1506, 1485, 1390, 1235, 1087, 1052, 1009. ^{1}H NMR ($CDCl_3$, 300 MHz) δ (ppm): 9.54 (1H, d, $J = 6$ Hz, NH), 7.45 (2H, d, $J = 6$ Hz, CH_{Ar}), 7.38–7.22 (5H, m, CH_{Ar}), 7.13 (2H, d, $J = 6$ Hz, CH_{Ar}), 4.93 (2H, d, $J = 6$ Hz, CH_2), 4.55 (2H, s, CH_2). ^{13}C NMR ($CDCl_3$, 75 MHz) δ (ppm): 197.0, 131.7, 131.6, 131.0, 130.7, 130.5, 129.7, 128.9, 128.8, 128.3, 121.5, 51.4, 42.6. Anal. Calcd. for $C_{15}H_{14}BrNS_2$ (352.31): C, 51.14; H, 4.01; N, 3.98; S, 18.20. Found: C, 51.33; H, 4.15; N, 4.01, S, 18.15.

*Ethyl (4-methoxyphenyl)carbamodithioate (**4b**)* FT-IR (KBr, $\bar{\upsilon}$, cm^{-1}): 3119, 3020, 2958, 2927, 2834, 1603, 1510, 1250, 1011. ^{1}H NMR ($CDCl_3$, 300 MHz) δ (ppm): 9.26 (1H, s, NH), 7.31 (2H, d, $J = 6$ Hz, CH_{Ar}), 6.94 (2H, d, $J = 6$ Hz, CH_{Ar}), 3.85 (3H, s, OCH_3), 3.29 (2H, q, $J = 6$ Hz, CH_2), 1.36 (3H, t, $J = 6$ Hz, CH_3). ^{13}C NMR ($CDCl_3$, 75 MHz) δ (ppm): 202.7, 159.0, 130.8, 127.6, 114.4, 55.5, 30.7, 13.7. Anal.

Calcd. for $C_{10}H_{13}NOS_2$ (227.34): C, 52.83; H, 5.76; N, 6.16; S, 28.20. Found: C, 52.88; H, 5.68; N, 6.20, S, 28.11.

Ethyl 4-benzylpiperidine-1-carbodithioate ***(4h)*** FT-IR (KBr, $\bar{\upsilon}$, cm^{-1}): 3024, 2990, 2930, 1602, 1493, 1473, 1437, 1260, 1186, 1056, 1002, 927, 749, 701. ^{1}H NMR ($CDCl_3$, 300 MHz) δ (ppm): 7.35–7.16 (5H, m, CH_{Ar}), 5.62 (1H, brs, CH), 4.66 (1H, brs, CH), 3.33 (2H, q, $J = 6$ Hz, CH_2), 3.08 (2H, brs, CH_2), 2.60 (2H, d, $J = 6$ Hz, CH_2), 1.98–1.87 (1H, m, CH), 1.82 (1H, brs, CH), 1.78 (1H, brs, CH), 1.39 (3H, t, $J = 6$ Hz, CH_3), 1.37 (2H, brs, CH_2). ^{13}C NMR ($CDCl_3$, 75 MHz) δ (ppm): 196.1, 139.7, 129.0, 128.3, 126.1, 51.7, 50.3, 42.6, 38.1, 31.8, 31.5, 13.7. Anal. Calcd. for $C_{15}H_{21}NS_2$ (279.46): C, 64.47; H, 7.57; N, 5.01; S, 22.94. Found: C, 64.55; H, 7.43; N, 5.12, S, 22.78.

4-Bromobenzyl 4-benzylpiperidine-1-carbodithioate ***(4i)*** FT-IR (KBr, $\bar{\upsilon}$, cm^{-1}): 3059, 3015, 2994, 2934, 1640, 1473, 1451, 1238, 1104, 1002, 933, 745, 703. ^{1}H NMR ($CDCl_3$, 300 MHz) δ (ppm): 7.47 (2H, d, $J = 9$ Hz, CH_{Ar}), 7.34-7.25 (5H, m, CH_{Ph}), 7.17 (2H, d, $J = 9$ Hz, CH_{Ar}), 5.6 (1H, brs, CH), 4.58 (1H, brs, CH), 4.57 (2H, brs, CH_2), 3.11 (2H, brs, CH_2), 2.60 (2H, d, $J = 3$ Hz, CH_{2Bn}), 2.03–1.90 (1H, m, CH), 1.82 (1H, brs, CH), 1.78 (1H, brs, CH), 1.37 (2H, brs, CH_2). ^{13}C NMR ($CDCl_3$, 75 MHz) δ (ppm): 194.8, 139.6, 135.6, 131.7, 131.1, 129.1, 128.4, 126.2, 121.4, 52.2, 50.6, 42.6, 41.3, 38.1, 31.9. Anal. Calcd. for $C_{20}H_{22}BrNS_2$ (420.43): C, 57.14; H, 5.27; N, 3.33; S, 15.25. Found: C, 57.29; H, 5.31; N, 3.36, S, 15.29.

4-Bromobenzyl piperidine-1-carbodithioate ***(4k)*** FT-IR (KBr, $\bar{\upsilon}$, cm^{-1}): 3052, 2991, 2940, 1585, 1479, 1425, 1221, 1131, 1007, 974, 830, 741, 500. ^{1}H NMR ($CDCl_3$, 300 MHz) δ (ppm): 7.46 (2H, d, $J = 9$ Hz, CH_{Ar}), 7.31 (2H, d, $J = 9$ Hz, CH_{Ar}), 4.56 (2H, s, CH_2), 4.32 (2H, brs, CH_2), 3.90 (2H, brs, CH_2), 1.73 (6H, brs, $3CH_2$). ^{13}C NMR ($CDCl_3$, 75 MHz) δ (ppm): 194.8, 135.8, 131.6, 131.0, 121.3, 53.1, 51.5, 41.2, 26.0, 24.2. Anal. Calcd. for $C_{13}H_{16}BrNS_2$ (330.30): C, 47.27; H, 4.88; N, 4.24; S, 19.41. Found: C, 47.31; H, 4.75; N, 4.29, S, 19.50.

4-Chlorobenzyl 4-benzylpiperidine-1-carbodithioate ***(4l)*** FT-IR (KBr, $\bar{\upsilon}$, cm^{-1}): 3062, 3015, 2995, 2934, 1594, 1491, 1471, 1451, 1238, 1093, 1028, 1003, 746, 703. ^{1}H NMR ($CDCl_3$, 300 MHz) δ (ppm): 7.37 (2H, d, $J = 9$ Hz, CH_{Ar}), 7.35-7.23 (5H, m, CH_{Ph}), 7.17 (2H, d, $J = 9$ Hz, CH_{Ar}), 5.59 (1H, brs, CH), 4.59 (1H, bs, CH), 4.58 (2H, brs, CH_2), 3.10 (2H, brs, CH_2), 2.60 (2H, d, $J = 9$ Hz, CH_2), 2.00–1.87 (1H, m, CH), 1.83 (1H, brs, CH), 1.78 (1H, brs, CH), 1.38 (2H, brs, CH_2). ^{13}C NMR ($CDCl_3$, 75 MHz) δ (ppm): 194.9, 139.7, 135.0, 133.3, 130.7, 129.1, 128.7, 128.4, 126.2, 52.2, 50.4, 42.6, 41.3, 33.1, 31.8. Anal. Calcd. for $C_{20}H_{22}ClNS_2$ (375.97): C, 63.89; H, 5.90; N, 3.73; S, 17.05. Found: C, 63.91; H, 5.67; N, 3.81, S, 17.11.

3-Chlorobenzyl morpholine-4-carbodithioate ***(4n)*** FT-IR (KBr, $\bar{\upsilon}$, cm^{-1}): 3050, 2976, 2919, 1596, 1449, 1422, 1267, 1244, 1114, 1031, 996, 866, 776, 713, 539. ^{1}H NMR ($CDCl_3$, 300 MHz) δ (ppm): 7.42 (12H, s, CH_{Ar}), 7.32–7.26 (3H, m, CH_{Ar}), 4.60 (2H, s, CH_2), 4.30 (2H, brs, CH_2), 4.04 (2H, brs, CH_2), 3.79 (4H, s, $2CH_2$). ^{13}C NMR ($CDCl_3$, 75 MHz) δ (ppm): 196.5, 138.2, 134.3, 129.8, 129.3, 127.7, 127.5, 66.2, 50.8, 41.0. Anal. Calcd. for $C_{12}H_{14}ClNOS_2$ (287.82): C, 50.08; H, 4.90; N, 4.87; S, 22.28. Found: C, 50.19; H, 4.88; N, 4.81, S, 22.17.

Conclusions

We developed a simple and highly efficient catalyst-free protocol for synthesis of some novel dithiocarbamate derivatives by one-pot three-component reaction between different alkyl and aryl amines, carbon disulfide, and numerous alkyl and benzyl halides in ethanol–aqueous medium. High to excellent product yield, atom economy, obtaining some novel, potentially interesting, medicinally important molecules, and use of readily available starting materials are some of the remarkable advantages of this procedure.

Acknowledgements The authors gratefully thank the Pharmaceutics Research Center, Institute of Neuropharmacology, Kerman University of Medical Sciences for supporting this work.

References

1. S.L. Cao, Y. Han, C.Z. Yuan, Y. Wang, Z. Xiahou, J. Liao, R.T. Gao, B.B. Mao, B.L. Zhao, Z.F. Li, X. Xu, Eur. J. Med. Chem. **64**, 401 (2013)
2. F. Carta, M. Aggarwal, A. Maresca, A. Scozzafava, R. McKenna, E. Masini, C.T. Supuran, J. Med. Chem. **55**, 1721 (2012)
3. G. Turan-Zitouni, A. Özdemir, K. Güven, Arch. Pharm. Chem. Life Sci. **338**, 96 (2005)
4. N. Lal, S. Jangir, V. Bala, D. Mandalapu, A. Sarswat, L. Kumar, A. Jain, L. Kumar, B. Kushwaha, A. K. Pandey, S. Krishna, T. Rawat, P.K. Shukla, J.P. Maikhuri, M.I. Siddiqi, G. Gupta, V.L. Sharma, Eur. J. Med. Chem. **115**, 275 (2016)
5. G. Brahemi, F.R. Kona, A. Fiasella, D. Buac, J. Soukupova, A. Brancale, A.M. Burger, A.D. Westwell, J. Med. Chem. **53**, 2757 (2010)
6. D. Mehlika, A. Altintop, G. Selen, Y. Özkay, Z.A. Kaplancıkli, Arch. Pharm. Chem. Life Sci. **346**, 571 (2013)
7. S. Levent, U. Cevik, B.N. Saglik, Y. Ozkay, O.D. Can, U.D. Ozkay, U. Uçucu, Phosphorus Sulfur Silicon Relat. Elem. **192**, 469 (2017)
8. W. Yuan, Z. Shang, X. Qiang, Z. Tan, Y. Deng, Res. Chem. Intermed. **40**, 787 (2014)
9. C. Bolzati, M. Cavazza-Ceccato, S. Agostini, F. Refosco, Y. Yamamichi, S. Tokunaga, D. Carta, N. Salvarese, D. Bernardini, G. Bandoli, Bioconjugate Chem. **21**, 928 (2010)
10. S.L. Cao, Y.P. Feng, Y.Y. Jiang, S.Y. Liu, G.Y. Ding, R.T. Li, Bioorg. Med. Chem. Lett. **15**, 1915 (2005)
11. A. Goel, S.J. Majur, R.J. Fattah, T.L. Hartman, J.A. Turpin, M. Huang, W.G. Rice, E. Appella, J.K. Inman, Bioorg. Med. Chem. Lett. **12**, 767 (2002)
12. H. Sudhamani, S.K.T. Basha, S. Muni, C. Reddy, B. Sreedhar, S. Adam, C.N. Raju, Res. Chem. Intermed. **42**, 7471 (2016)
13. Y.G. Suh, Y.S. Lee, K.H. Min, O.H. Park, J.K. Kim, H.S. Seung, S.Y. Seo, B.Y. Lee, Y.H. Nam, K. O. Lee, H.D. Kim, H.G. Park, J. Lee, U.O.J.O. Lim, S.U. Kang, M.J. Kil, J. Koo, S.S. Shin, Y.H. Joo, J.K. Kim, Y.S. Jeong, S.Y. Kim, Y.H. Park, J. Med. Chem. **48**, 5823 (2005)
14. R. Mary-Ann, N.L. Borja, Pharmacotherapy **28**, 646 (2008)
15. D. Chaturvedi, S. Zaidi, Res. Rev. J. Chem. **5**, 10 (2016)
16. H. Hänel, W. Raether, W. Dittmar, Ann. N. Y. Acad. Sci. **544**, 329 (1988)
17. U. Boas, H. Gertz, J.B. Christensen, P.M.H. Heegaard, Tetrahedron Lett. **45**, 269 (2004)
18. A. Ziyaei-Halimehjani, Y. Pourshojaei, M.R. Saidi, Tetrahedron Lett. **50**, 32 (2009)
19. A. Zare, M. Merajoddin, A.R. Moosavi-Zare, M. Zarei, M.H. Beyzavi, M.A. Zolfigol, Res. Chem. Intermed. **42**, 2365 (2016)
20. S.M. Kanan, M.C. Kanan, H.H. Patterson, Res. Chem. Intermed. **32**, 871 (2006)
21. M.J. Hyun, M. Shin, Y.J. Kim, Y.W. Suh, Res. Chem. Intermed. **42**, 57 (2016)
22. W.N. Kun, S. Mlowe, L.D. Nyamen, P.T. Ndifon, M.A. Malik, O.Q. Munro, N. Revaprasadu, Chem. Eur. J. **22**, 13127 (2016)

23. P.J. Nieuwenhuizen, A.W. Ehlers, J.G. Haasnoot, S.R. Janse, J. Reedijk, E.J. Baerends, J. Am. Chem. Soc. **121**, 163 (1999)
24. G. Hogarth, Mini. Rev. Med. Chem. **12**, 1202 (2012)
25. W. Chin-Hsien, Synthesis, 622 (1981)
26. D. Chaturvedi, S. Ray, Tetrahedron Lett. **47**, 1307 (2006)
27. Y. Ma, J. Xu, Synthesis **44**, 2225 (2012)
28. K. Biswas, S. Ghosh, P. Ghosh, B. Basu, J. Sulfur Chem. **37**, 361 (2016)
29. A. Saha, B.C. Ranu, RSC Adv. **2**, 6329 (2012)
30. N. Azizi, E. Gholibeglo, RSC Adv. **2**, 7413 (2012)
31. Q. Sha, Y.Y. Wei, Org. Biomol. Chem. **11**, 5615 (2013)
32. N.A. Isley, S. Dobarco, B.H. Lipshutz, Green Chem. **16**, 1480 (2014)
33. K. Eskandari, B. Karami, S. Khodabakhshi, J. Chem. Res. **38**, 600 (2014)
34. J.H. Clark, Nat. Chem. **1**, 12 (2009)
35. K. Eskandari, B. Karami, M. Farahi, V. Mouzari, Tetrahedron Lett. **57**, 487 (2016)
36. S. Rahmani-Nezhad, L. Khosravani, M. Saeedi, K. Divsalar, L. Firoozpour, Y. Pourshojaei, Y. Sarrafi, H. Nadri, A. Moradi, M. Mahdavi, A. Shafiee, A. Foroumadi, Synth. Commun. **45**, 751 (2015)
37. Y. Pourshojaei, A. Gouranourimi, S. Hekmat, A. Asadipour, S. Rahmani-Nezhad, A. Moradi, H. Nadri, F.H. Moghadam, S. Emami, A. Foroumadi, A. Shafiee, Eur. J. Med. Chem. **97**, 181 (2015)
38. F. Mehrabi, Y. Pourshojaei, A. Moradi, M. Sharifzadeh, L. Khosravani, R. Sabourian, S. Rahmani-Nezhad, M. Mohammadi-Khanaposhtani, M. Mahdavi, A. Asadipour, H.R. Rahimi, S. Moghimi, A. Foroumadi, Future Med. Chem. **9**, 659 (2017)
39. K. Eskandari, B. Karami, Monatsh. Chem. **147**, 2119 (2016)
40. B. Karami, R. Ferdosian, K. Eskandari, J. Chem. Res. **38**, 41 (2014)
41. B. Karami, K. Eskandari, M. Azizi, Lett. Org. Chem. **10**, 722 (2013)
42. S. Trivedi, Vidya **6**, 165 (1963)
43. R.M. Ottenbrite, J. Chem. Soc. Perkin Trans. 1: Org. Bioorg. Chem. **1972**, 88 (1972–1999)
44. S. Qiang, W. Yun-Yang, Org. Biomol. Chem. **11**, 5615 (2013)
45. C.N. Kapanda, G.G. Muccioli, G. Labar, J.H. Poupaert, D.M. Lambert, J. Med. Chem. **52**, 7310 (2009)
46. M. Toumi, N. Raouafi, K. Boujlel, I. Tapsoba, J.P. Picard, M. Bordeau, Phosphorus Sulfur Silicon Relat. Elem. **182**, 2477 (2007)
47. O. Lieber, J. Org. Chem. **22**, 88 (1957)