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4-Phenyl-5-(2-Thienylmethyl)-2,4-Dihydro-3*H*-1,2,4-Triazole-3-Selone and 3,3'-Di[4-Phenyl-5-(2-Thienylmethyl)-4*H*-1,2,4-Triazolyl] Diselenide: Synthesis, Structures, and Biocidal Properties

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Abstract—Three new organoselenium compounds are synthesized: *N*-phenyl-2-(2-thienylacetyl)hydrazinecarboselenoamide (**I**), 4-phenyl-5-(2-thienylmethyl)-2,4-dihydro-3*H*-1,2,4-triazole-3-selone (**II**), and 3,3'-di[4-phenyl-5-(2-thienylmethyl)-4*H*-1,2,4-triazolyl] diselenide (**III**). Two of them (compounds **II** and **III**) are characterized by X-ray diffraction analysis (CIF files CCDC nos. 1956602 (**II**) and 1956603 (**III**)). Compound **II** crystallizes in the monoclinic crystal system (space group $P2_1/n$) with two crystallographically independent molecules **A** and **B** being different conformers relative to rotation about the $N_{Trz}–C_{Trz}–C(H_2)–C_{Tph}$ bond, where Trz is triazole and Tph is thiophene (*gauche*-**A** (51.4(3)°) and *cis*-**B** (4.2(4)°)). In the crystal of compound **II**, molecules **A** and **B** form chains along the crystallographic axis *a* due to strong hydrogen bonds N–H···Se. Then the chains are bound into a three-dimensional framework via intermolecular nonvalent interactions Se···S (3.3857(11) Å). Owing to the anomeric effect, diselenide **III** is characterized by the typical gauche conformation of the substituents at the Se–Se bond (torsion angle CSeSeC 83.5(4)°) stabilized by a weak intramolecular hydrogen bond C–H···π. In the crystal of compound **III**, the molecules form chains along the crystallographic acid *b* due to intermolecular noncovalent interactions Se···π(C–C) (3.404(6) and 3.458(12) Å), Se···Se (3.8975(11) Å), and S···N (3.250(5) Å). Bactericidal and fungicidal activity of the synthesized compounds is studied.

Keywords: 1,2,4-triazole-3-selone, 3,3'-di[1,2,4-triazolyl] diselenide, NMR spectroscopy, X-ray diffraction analysis, bactericidal and fungicidal activity

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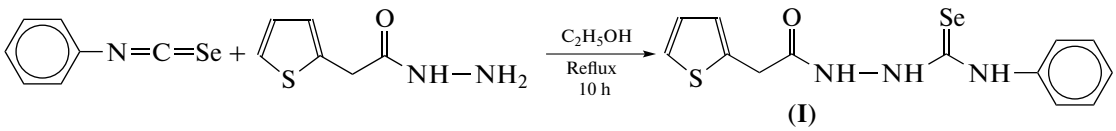
INTRODUCTION

Selenium-containing heterocyclic compounds evoke significant interest of chemists and pharmaceutists involved in research due to a wide range of biological activity, including anticancer, cardioprotective, antibacterial, fungicidal, and antiviral effects [1–4]. However, the chemistry of organoselenium compounds is insufficiently developed compared to the chemistry of organosulfur compounds, because many Se-containing compounds [5] are unstable and available reagent-precursors are lacking.

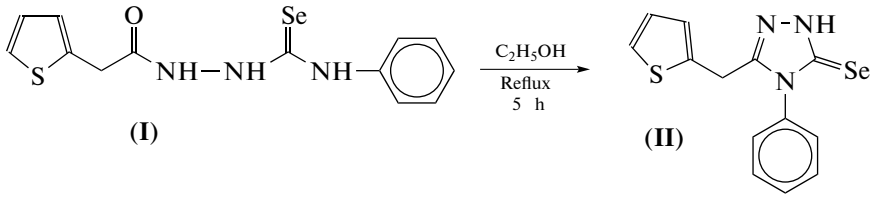
Isoselenocyanates are known as universal building blocks for the synthesis of various selenium-containing heterocyclic organic compounds, in particular, the 1,2,4-triazole-3-selone derivatives [6–8].

Various derivatives of 1,2,4-triazole-3-selones containing aryl, amino, or alkoxy groups in position 5 and aryl and acyl substituents in positions 1, 2, and 4 are known [9, 10]. However, 1,2,4-triazole-3-selones having only alkyl, aryl, and heteroaryl substituents in positions 4 and 5 have almost been unknown until recently, unlike analogous 1,2,4-triazole-3-thiones. The synthesis of several such 1,2,4-triazole-3-selones has previously been described [11]. Diselenides synthesized from these triazole-3-selones remain undescribed at all.

We carried out the reaction of phenyl isoselenocyanate with 2-thiopheneacetic acid hydrazide in ethanol to form substituted selenosemicarbazide **(I)** by analogy to the published reaction. On reflux in a 10% aqueous solution of NaOH, compound **I** underwent ring closure to form 1,2,4-triazole-3-selone **(II)**.

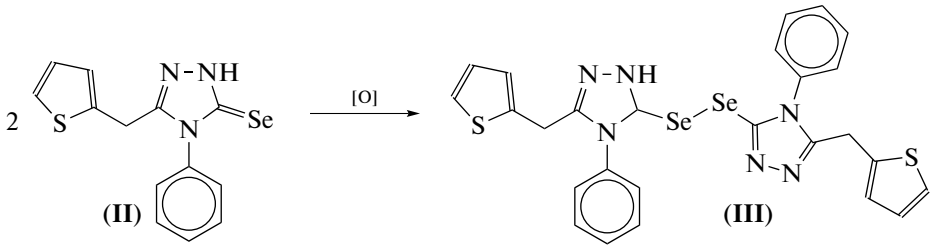


(I)



(I) **(II)**

The recrystallization of compound **II** in boiling ethanol results in its partial oxidation to the corresponding diselenide **III**.



(II) **(III)**

The structures of the synthesized compounds were proved by X-ray diffraction analysis (XRD); ^{1}H, ^{13}C, and ^{77}Se NMR spectroscopy; high-resolution mass spectrometry; and elemental analysis. The bactericidal and fungicidal properties of the synthesized substances were evaluated.

EXPERIMENTAL

The reagents used (NaOH, HCl) were not worse than reagent grade. 2-Thiopheneacetic acid hydrazide (Acros Organics, Belgium) was used as received. Phenyl isoselenocyanate was synthesized using a known procedure [12].

Melting (decomposition) points were determined in evacuated sealed capillaries and are given without correction. The IR spectra of the samples in KBr pellets (substance to KBr ratio 1 : 200) were recorded on a Shimadzu IR Prestige-21 instrument in a range of 4000–400 cm^{-1}. ^{1}H NMR spectra were detected on a Bruker Avance™ 500 spectrometer with the working frequency 500 MHz in the internal stabilization mode of the polar resonance 2H line in $CDCl_3$ at 20°C. Signals were assigned using gradient 2D spectroscopy: proton–proton correlation (GE-COSY), ^{1}H–^{13}C correlation (HSQC), and heteronuclear correlation (HMBC). Chemical shifts are given in ppm relative to tetramethylsilane used as an internal standard. ^{13}C and ^{77}Se NMR spectra were recorded on a Bruker Avance™ 500 spectrometer with the working frequency 125.72 and 95.38 MHz, respectively. High resolution electrospray ionization mass spectra (HR-ESI MS) were detected on a Bruker micrOTOF II instrument on positive ions (the voltage on the capillary was 4500 V) in the scan range (m/z) 50–3000 using the internal calibration (Agilent Tuning Mix, Agilent). The values of m/z are presented for the most intense peak of the isotope cluster. Solutions of the studied substances in acetonitrile were injected with a syringe, and the flow rate was 5 μL/min. Nitrogen served as a spraying gas (4 L/min), and the temperature of the interface was 180°C.

Synthesis of *N*-phenyl-2-(2-thienylacetyl)hydrazinecarboselenoamide (I). A solution of phenyl isoselenocyanate (1.821 g, 10 mmol) in ethanol (20 mL) was added to a boiling solution of 2-thiopheneacetic acid hydrazide (1.562 g, 20 mmol) in ethanol (30 mL). The reaction mixture was kept at the boiling point for 10 h

and cooled down to room temperature. The formed precipitate was washed with ethanol and diethyl ether. The yield of compound **I** as a light brown powder with mp = 144–145°C was 1.895 g (56%).

For $C_{13}H_{13}N_3OSSe$

Anal. calcd., %	C, 46.16	H, 3.87	N, 12.42
Found, %	C, 46.38	H, 3.78	N, 12.31

HR-ESI MS (*m/z*): found 340.0017; calculated for $[C_{13}H_{13}N_3OSSe + H]^+$ 340.0020. IR (ν, cm^{-1}): 3360, 3289 (NH), 1690 (C=O), 1593 (C–C, Ph), 694 (C–C, Tph). ^1H NMR (DMSO-d_6, 500 MHz, 298 K; δ, ppm): 10.24, 10.07, 10.02 (3 br.s, NH), [7.38 (m, 1H), 6.98 (d, 2H, *J* = 40.2 Hz) Tph], [7.37 (m, 4H), 7.23 (m, 1H) Ph)], 3.76 (s, 2H, CH_2Tph). ^{13}C NMR (DMSO-d_6, 125.72 MHz, 298 K; δ, ppm): 179.34 (C=O), 169.28 (C=Se), 140.20 (1C, Ph), 136.70 (1C, Tph), 127.39 (2CH, Tph), 125.61 (1CH, Tph), 128.53, 127.07, 127.05, 126.44 (5CH, Ph), 34.91(CH_2Tph). ^{77}Se NMR (DMSO-d_6, 95.38 MHz, 298 K; δ, ppm): 183.4 (br.s, $\nu_{1/2}$ = 85.2 Hz).

Synthesis of 4-phenyl-5-(2-thienylmethyl)-2,4-dihydro-3*H*-1,2,4-triazole-3-selone (II). Compound **I** (1.692 g, 10 mmol) was added to a 10% aqueous solution of sodium hydroxide (100 mL), and the mixture was heated to boiling for 5 h. After cooling to room temperature, the reaction mixture was filtered from undissolved particles, and a 10% solution of hydrochloric acid was added dropwise with stirring to pH 3 in the reaction mixture. The formed yellow-brown precipitate was washed with water and dried in air at room temperature. The yield was 1.258 g (79%). The obtained substance was crystallized from ethanol (200 mL) at 0°C. The yield of yellow-green crystals of compound **II** with mp = 172–173°C was 0.685 g (43%).

For $C_{13}H_{11}N_3SSe$

Anal. calcd., %	C, 48.75	H, 3.46	N, 13.12
Found, %	C, 48.38	H, 3.48	N, 13.21

HR-ESI MS (*m/z*): found 321.9911; calculated for $[C_{13}H_{11}N_3SSe + H]^+$ 321.9923. IR (ν, cm^{-1}): 3094 (NH), 1593 (Ph), 1570 (C=N), 699 (Tph). ^1H NMR (DMSO-d_6, 500 MHz, 298 K; δ, ppm): 14.42 (br.s, NH), [7.52 (m, 3H), 7.30 (m, 2H) Ph], [7.35 (dd, 1H, *J* = 5.0, 1.0 Hz), 6.85 (dd, *J* = 5.0 Hz, 3.5 1H), 6.63 (br.dd, 1H, *J* = 3.5, 1.0 Hz) Tph], 4.15 (s, 2H, CH_2Tph). ^{13}C NMR (DMSO-d_6, 125.72 MHz, 298 K; δ, ppm): 161.24 (C=Se), [152.75 (1C, Ph), 134.41, 130.14, 129.77, 128.71, 126.07 (5CH, Ph)], [136.39 (1C, Tph), 127.32, 127.30, 125.96 (3CH, Tph)], 26.40 (CH_2Tph). ^{77}Se NMR (DMSO-d_6, 95.38 MHz, 298 K; δ, ppm): 34.86 (br.s, $\nu_{1/2}$ = 74.8 Hz).

3,3'-Di[4-phenyl-5-(2-thienylmethyl)-4*H*-1,2,4-triazolyl] diselenide (III). A mother liquor (200 mL) obtained after the crystallization of compound **II** was evaporated to 50 mL, and the remained volume was kept at –20°C. The formed precipitate of compound **III** was filtered off and dried at room temperature. The yield of yellow-green crystals of compound **III** with mp = 140–142°C was 0.429 g (34.2%).

For $C_{26}H_{20}N_6S_2Se_2$

Anal. calcd., %	C, 48.91	H, 3.16	N, 13.16
Found, %	C, 48.78	H, 3.18	N, 13.21

HR-ESI MS (*m/z*): found 640.9596; calculated for $[C_{26}H_{20}N_6S_2Se_2 + H]^+$ 640.9591. IR (ν, cm^{-1}): 1631, 1596, 1498, 1431, 697 (Tph). ^1H NMR (DMSO-d_6, 500 MHz, 298 K; δ, ppm): [7.49 (m, $1H_{para}$), 7.40 (m, $2H_{meta}$), 6.94 (d, $2H_{ortho}$, *J* = 7.5 Hz) Ph], [7.34 (d, 1H, *J* = 5.0 Hz), 6.85 (dd, *J* = 5.0 Hz, 3.5 1H), 6.55 (d, 1H, *J* = 3.5 Hz) Tph], 4.21 (s, 2H, CH_2Tph). ^{13}C NMR (DMSO-d_6, 125.72 MHz, 298 K; δ, ppm): 155.47 (C, Trz), 142.50 (C–Se), [137.60, 127.26, 125.85 (3CH, Tph), 126.87 (1C, Tph)], [133.75 (C, Ph.), 130.16_{meta}, 129.70_{para}, 128.18_{ortho} (5CH, Ph)], 26.07 (CH_2Tph). ^{77}Se NMR (DMSO-d_6, 95.38 MHz, 298 K; δ, ppm): 379.35 (br.s, $\nu_{1/2}$ = 25.4 Hz).

XRD. The crystals suitable for XRD studies were obtained by the recrystallization of compounds **II** and **III** from ethanol. The experiment was carried out on a BELOK synchrotron station at the Kurchatov Institute Russian Research Center (λ = 0.96990 Å, Rayonix SX165 CCD detector, φ scan mode) [13]. The experimental data were processed using the iMOSFLM program, which is a subprogram of the CCP4 program package [14]. The structures were solved by a direct method and refined by full-matrix least squares for F^2_{hkl} in the anisotropic approximation for non-hydrogen atoms. The thiophene cycles in compound **II** (molecules **A** and **B**) and one of the thiophene cycles in compound **III** are disordered over two positions each with populations of 90 : 10 and 75 : 25 (**II**) and 70 : 30 (**III**), respectively. The hydrogen atoms of the amino groups in compound **II** were revealed objectively in the difference Fourier syntheses and refined isotropically with the fixed displacement parameters ($U_{iso}(H) = 1.2U_{equiv}(N)$). The positions of other hydrogen atoms in compounds **II** and **III** were calculated geometrically and included in the refinement with the fixed positional parameters (riding model) and isotropic displacement parameters ($U_{iso}(H) = 1.2\ U_{iso}(C)$). An X-ray radiation absorption correction was applied using the Scala program packages [15]. All calculations on crystal structure refinement were performed using the SHELXTL program package [16]. The crystallographic data and parameters of XRD experiments are presented in Table 1.

Table 1. Selected crystallographic data and structure refinement parameters for compounds **II** and **III**

Parameters	Value	
	II	**III**
Empirical formula	$C_{13}H_{11}N_3SSe$	$C_{26}H_{20}N_6S_2Se_2$
FW	320.27	638.52
Temperature, K	100	100
Crystal sizes, mm	0.16 × 0.10 × 0.10	0.25 × 0.20 × 0.10
Crystal system	Monoclinic	Triclinic
Space group	$P2_1/n$	$P\bar{1}$
a, Å	9.6850(8)	9.2390(19)
b, Å	18.444(2)	11.316(2)
c, Å	14.8771	13.877(3)
α, deg	90	75.919(11)
β, deg	91.262(6)	78.807(13)
γ, deg	90	68.137(12)
V, Å^3	2656.9(5)	1297.4(5)
Z	8	2
ρ_{calc}, g/cm^3	1.601	1.635
μ, mm^{-1}	3.889	3.982
F(000)	1280	636
Range of data collection over θ, deg	31	31
Measured reflections	21112	17313
Independent reflections	5929	5832
Number of refined parameters	344	332
R_1 ($I > 2\sigma(I)$)	0.0401	0.0624
wR_2 (all data)	0.0998	0.1524
GOOF	1.047	1.003
T_{min}, T_{max}	0.540; 0.660	0.390; 0.630
Residual electron density ($\Delta\rho_{min}/\Delta\rho_{max}$), e Å^{-3}	−0.659/0.873	−0.814/2.879

The structures were deposited with the Cambridge Crystallographic Data Centre (CIF files CCDC nos. 1956602 (**II**) and 1956603 (**III**); http://ccdc.cam.ac.uk/getstructures).

Methods of microbiological studies. Bactericidity of compounds **I** and **II** was evaluated against the following bacteria: Gram-positive strain *Staphylococcus aureus* and Gram-negative strain *Escherichia coli*. The tested compounds were placed in Petri dishes in wells with an agarized medium of a beef-extract agar (D = 5 mm) and inoculated by a bacterial suspension prepared in a physiological solution (1 × 10^8 cells/mL). Incubation was carried out in a thermostat at 37°C for 24 h.

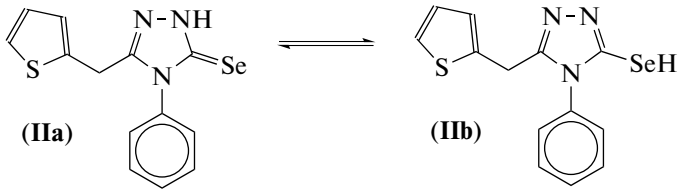
A mixed culture (association) of the following fungi was used for the evaluation of the fungicidal properties of compounds **I** and **II**: *Aspergillus niger*, *Aspergillus terreus*, *Aspergillus oryzae*, *Chaetomium globosum*, *Paecilomyces variotii*, *Penicillium funiculosum*, *Penicillium chrysogenum*, *Penicillium cyclopium*, and *Trichoderma viride*. The latter is widely applied in standard methods for testing the resistance of industrial materials to biodamages.

The compositions were placed in Petri dishes in well with a Czapek–Dox agar medium. The tests to the association (mixture) of the test cultures were carried out at 29°C and the moisture content higher than 90% for 14 days.

The degrees of bactericidity or fungicidity were estimated from the value of the growth inhibition zone of the test cultures formed around the wells with the studied compound.

RESULTS AND DISCUSSION

We attempted to synthesize 1,2,4-triazole-3-selone (**II**) under the earlier described conditions [11]. At the first stage, substituted selenosemicarbazide (**I**) was synthesized via the reaction of phenyl isoselenocyanate with 2-thiopheneacetic acid hydrazide in ethanol by analogy to the synthesis described earlier [11]. However, we failed to synthesize the corresponding compound **II** under the described conditions [11]. The reflux of compound **I** in ethanol for 10 h afforded no compound **II** even in trace amounts. Therefore, in order to synthesize compound **II**, we carried out ring closure of the synthesized selenocarbazide by reflux in a 10% aqueous solution of NaOH for 5 h. It is known that this method is widely used for the synthesis of similar 1,2,4-triazole-3-thiones.



(IIa) **(IIb)**

It is known that heterocyclic thiols and selenols can exist in both thione or selone and thiol or selenol forms [17]. However, the thione or selone forms (**IIa**) are more stable for these compounds [17, 18]. The ^{1}H NMR spectrum of synthesized compound **II** in DMSO-d_6 contains a broadened singlet at 14.38 ppm corresponding to the signal of the NH group in compound **IIa**. The signal broadening is probably due to fast exchange processes between two tautomeric forms of the compounds. The ^{77}Se NMR spectrum of compound **II** also exhibits a significant signal broadening. The widths of the signal at the half-height ($\nu_{1/2}$) is 74.8 Hz, which can be explained by exchange processes between two tautomeric forms.

The ^{1}H NMR spectrum of compound **II** also exhibits a significant signal broadening for the protons of the NH groups. In the ^{77}Se NMR spectrum, $\nu_{1/2}$ = 85.2 Hz. This can be explained by both the fast exchange processes in the tautomeric forms HN–C=O ↔ N=C–OH and HN–C=Se ↔ N=C–SeH and the hindered rotation of the molecule because of the partial double bonding of the C and N atoms in the amide and selenoamide fragments.

The structure of selone **II** is confirmed by the XRD results. The asymmetric part of the crystal cell of compound **II** contains two crystallographically independent molecules **A** and **B** representing different conformers relative to the rotation about the N_{Trz}–C_{Trz}–$C(H_2)$–C_{Tph} bond, where Trz is triazole and Tph is thiophene (*gauche*-**A** (51.4(3)°) and *trans*-**B** (−176.0(2)°)). In other respects, molecules **A** and **B** are identical in structure (Fig. 1) and, hence, we present the geometric characteristics of molecule **A** only when discussing the structure of compound **II**.

Compound **II** contains three cycles: triazole (***A***), phenyl (***B***), and thiophene (***C***). The phenyl cycles (***B***) in molecules **A** and **B** are nearly perpendicular to the triazole cycles (***A***) (the torsion angles C(1)N(3)-C(8)C(13) and C(14)N(6)C(21)C(26) are 66.9(3)° and 104.1(3)°, respectively). The thiophene cycle (***C***) in molecule **B** is nearly perpendicular to the both planes (***A***) and (***C***), whereas the planes of the cycles (***C***) in molecule **A** are nearly parallel to the plane of the phenyl ring (***B***) and perpendicular to the plane of the triazole ring (***A***).

The angles between the planes (***A***), (***B***), and (***C***) are as follows: ***A/B*** 63.90(10)°, ***A/C*** 81.08(11)°, and ***B/C*** 26.72(10)° in molecule **A**; and ***A/B*** 76.09(10)°, ***A/C*** 89.18(13)°, and ***B/C*** 50.75(11)° in molecule **B**.

Owing to steric reasons, the C(2)C(3)C(4) and C(15)C(16)C(17) bond angles in molecules **A** and **B** are increased compared to an ideal tetrahedral value of 109.5° and are equal to 112.9(2)° and 113.7(2)°, respectively.

The bond lengths in molecule **A** (N(1)–N(2) 1.377(3), N(1)–C(1) 1.325(3), N(3)–C(1) 1.368(3), and N(3)–C(2) 1.383(3) Å) and in molecule **B** (N(4)–N(5) 1.376(3), N(4)–C(14) 1.325(3), N(6)–C(14) 1.366(3), and N(6)–C(15) 1.377(3) Å) in the selenotriazole fragment correspond to the ordinary character, whereas the bonds in molecule **A** (Se(1)=C(1) 1.847(3) and N(2)=C(2) 1.305(3) Å) and molecule **B** (Se(2)=C(14) 1.845(3) and N(5)=C(15) 1.298(3) Å) are double and their lengths are close to the corresponding distances in related 1,2,4-triazole-3-selones (Table 2) [11, 19].

It should be mentioned that the compound synthesized in [11] is close in structure to selone **II**. However, the authors [11] explained that the XRD data were unsatisfactory because of a poor quality of the crystals and, hence, the geometric parameters were not discussed.

In the crystal of compound **II**, molecules **A** and **B** form chains along the crystallographic axis *a* due to strong hydrogen bonds N–H···Se (N(4)–H(4)···Se(1) (*x*, *y*, *z*), N–H 0.88(3), H···Se 2.50(3) Å, angle N–H···Se 170(3)°, N(1)–H(1)···Se(2) (1 + *x*, *y*, *z*), N–H 0.90(3), H···Se 2.51(3) Å, angle N–H···Se 167(3)°). Then the chains are bound into a three-dimensional framework via intermolecular nonvalent interactions

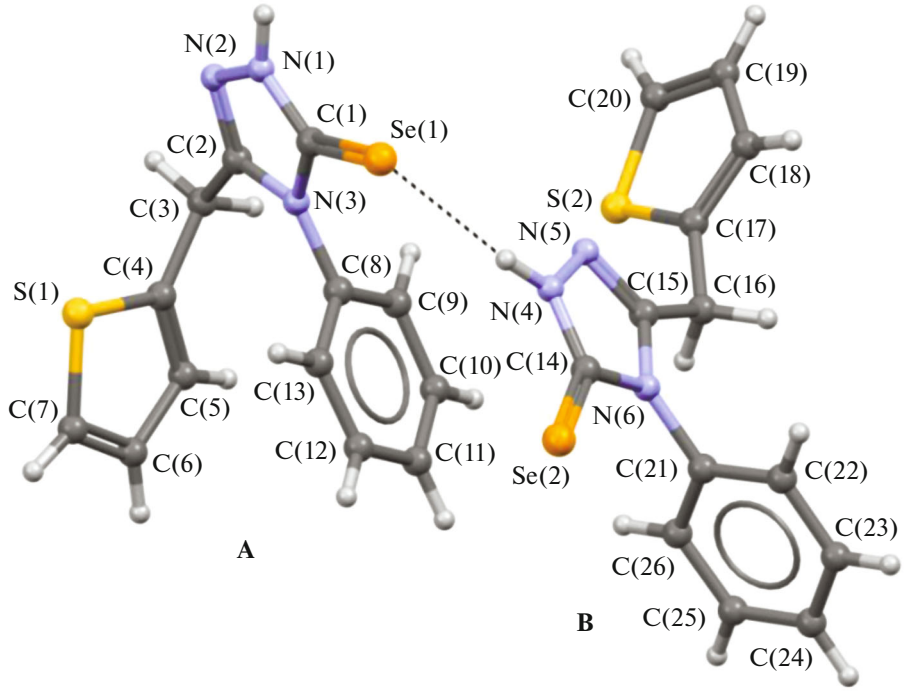


Fig. 1. Molecular structures of compound **II** (**A** and **B**). The intramolecular hydrogen bond N–H···Se is shown by dash.

Se···S (3.3857(11) Å, the sum of the van der Waals radii of the selenium and sulfur atoms is equal to 3.80 Å [20, 21] (Fig. 2a)) and weak hydrogen bonds of the C–H···π type between the hydrogen atoms of the methylene groups and thiophene cycles (C_{Tph} is the center of the thiophene ring) (the H(3A)···C_{Tph}, C(7)···H(3A), and C(6)···H(3A) distances are 2.63, 2.84, and 2.90 Å, respectively) [22] (Fig. 2b).

According to the data of the ^{1}H NMR spectrum, compound **II** precipitated from an aqueous solution contains no other products. However, it was found that the recrystallization of compound **II** from boiling ethanol resulted in its partial transformation into diselenide **III**. In addition, elemental selenium precipitates.

Compound **III** is probably formed during the oxidation of selone **II** with air oxygen at elevated temperature. This assumption is favored by the result of a special experiment on reflux of compound **II** in anhydrous ethanol in an argon medium. In this case, according to the data of ^{1}H NMR spectroscopy, no trace amounts of compound **III** are formed in 5 h.

It is known that during formation many diselenides are prone to eliminate selenium to form the corresponding selenides. However, no formation of selenide is observed in our case. The isolation of elemental selenium occurs probably during the decomposition of selone **II**, which results in a substantial decrease in the yield of compound **II** after recrystallization from ethanol. Similar processes of the decomposition and oxidative dimerization of 5-amino-4-phenyl-2,4-dihydro-3*H*-1,2,4-triazole-3-selone were described [9].

Triazole diselenides with the unsubstituted NH group in position 4 are known [23–25] along with the triazole diselenide containing amino groups in position 5 and phenyl groups in position 4 described earlier [9]. However, triazole diselenides containing alkyl and aryl substituents in positions 4 and 5 remained unknown up to the present work.

Compound **III** is deselenide and consists of two triazole fragments of compound **II** bound to each other via the –Se–Se– diselenide bridge (Fig. 3).

Owing to the anomeric effect, diselenide **III** has a typical gauche conformation of the substituents at the Se–Se bond (the CSeSeC torsion angle is 83.5(4)°) stabilized by a weak intramolecular hydrogen bond C(13)–H(13)···π(C(24)–C(25)) (the H(13)···C(24) and H(13)···C(25) distances are 2.90 and 3.06 Å, respectively). The phenyl substituents are twisted relative to the triazole cycle (the angles between the planes are 78.33° and 72.92°, respectively) and are nearly perpendicular to each other (the dihedral angle is 94.5(2)°).

In one of the organic fragments, the thiophene cycle is nearly coplanar to the triazole cycle (the angle between the planes is 13.6(2)°), whereas the thiophene cycle in another fragment is turned by an angle of 83.8(2)° relatively the triazole cycle.

Table 2. Selected bond lengths and bond and torsion angles in compound **II**

Bond	*d*, Å		Bond angle	ω, deg	
	A	**B**		**A**	**B**
Se(1)–C(1)	1.847(3)	1.845(3)	N(1)C(1)Se(1)	126.94(2)	126.55(2)
N(1)–C(1)	1.325(3)	1.325(3)	N(3)C(1)Se(1)	128.8(2)	129.4(2)
N(1)–N(2)	1.377(3)	1.376(3)	C(2)N(2)N(1)	103.6(2)	103.5(2)
N(2)–C(2)	1.305(3)	1.298(3)	C(1)N(3)C(2)	107.4(2)	107.4(2)
N(3)–C(1)	1.368(3)	1.366(3)	C(2)C(3)C(4)	112.9(2)	113.7(2)
N(3)–C(2)	1.383(3)	1.377(3)	C(1)N(3)C(8)	127.1(2)	127.0(2)
N(3)–C(8)	1.441(3)	1.440(3)	C(2)N(3)C(8)	125.4(2)	125.6(2)
C(2)–C(3)	1.492(3)	1.494(3)	N(3)C(2)C(3)	124.8(2)	122.0(2)
C(3)–C(4)	1.504(3)	1.470(3)	N(2)C(2)N(3)	111.0(2)	111.4(2)
C(4)–C(5)	1.358(2)	1.387(4)	Torsion angle	γ, deg	
C(5)–C(6)	1.422(2)	1.388(4)		**A**	**B**
C(6)–C(7)	1.360(2)	1.380(5)	C(2)C(3)C(4)C(5)	15.7(9)	106.6(7)
S(1)–C(4)	1.715(2)	1.685(2)	C(2)C(3)C(4)S(1)	52.3(3)	–91.8(3)
S(1)–C(7)	1.716(2)	1.732(2)	C(1)N(3)C(8)C(13)	66.9(3)	104.1(3)
			C(2)N(3)C(8)C(9)	62.0(3)	103.5(3)

The Se–Se bond length in compound **III** is 2.3461(8) Å, being in the range of the corresponding distances in related diselenides (Table 3).

The bond lengths in the selenotriazole fragments of the molecule of compound **III** Se(1)–C(1) (1.888(5) Å), N(3)–C(1) (1.377(6) Å), N(3)–C(2) (1.358(6) Å), N(1)–N(2) (1.390(6) Å), Se(2)–C(14) (2.3462(8) Å), N(6)–C(14) (1.366(6) Å), N(6)–C(15) (1.370(6) Å), and N(4)–N(5) (1.396(6) Å) correspond to the ordinary character, whereas the N(1)=C(1) (1.318(6) Å), N(2)=C(2) (1.325(6) Å), N(4)=C(14) (1.306(6) Å), and N(5)=C(15) (1.328(6) Å) bonds are double (Table 3).

In the crystal of compound **III**, the molecules form chains along the crystallographic axis *b* due to intermolecular nonvalent interactions Se···π(C–C) (3.404(6), 3.458(12) and 3.335(9) Å), Se···Se (3.8975(11) Å), and S···N (3.250(5) Å) (the sums of the van der Waals radii of the selenium and carbon atoms, two selenium atoms, and sulfur and nitrogen atoms are 3.75, 4.00, and 3.30 Å, respectively [20, 21]) (Fig. 4a).

The study of the crystal packing in more detail showed that the H(25) atoms of the phenyl fragment were arranged between the molecules of compound **III** nearly with a slight shift opposite the center of the thiophene cycle. The distance from the H(25A) hydrogen atom of the phenyl fragment to the center of the thiophene cycle is 2.63 Å. The shortest C···H distance between the C(17)···H(25) atoms equal to 2.90 Å and that between C(19)···H(25) equal to 2.90 Å indicate the existence of weak hydrogen bonds of the C–H···π type [22], which link the molecules of compound **III** into chains along the crystallographic axis *a* (Fig. 4b).

The results of the studies of the antimicrobial properties of compounds **I**–**III** are presented in Tables 4 and 5.

The results obtained show that compound **II** is characterized by both bactericidal and fungicidal effects against all test cultures of the microorganisms used. Compound **I** manifested stronger fungicidal properties than those of compound **II** and weakly bactericidal properties against *Staphylococcus aureus* and *Escherichia coli*. Compound **III** has the lowest antimicrobial effect (nonfungicidal and nonbactericidal) and exhibited only weakly bactericidal properties against the *Staphylococcus aureus* culture.

The modern industrial biocidal drugs are applied in the concentrations from 0.05 to 3%. Compounds **I** and **II** synthesized in this work taken in a concentration of 1% are comparable with the industrial drugs in biocidal activity.

Thus, three new organoselenium compounds were synthesized and characterized by NMR spectroscopy, high-resolution mass spectrometry, and

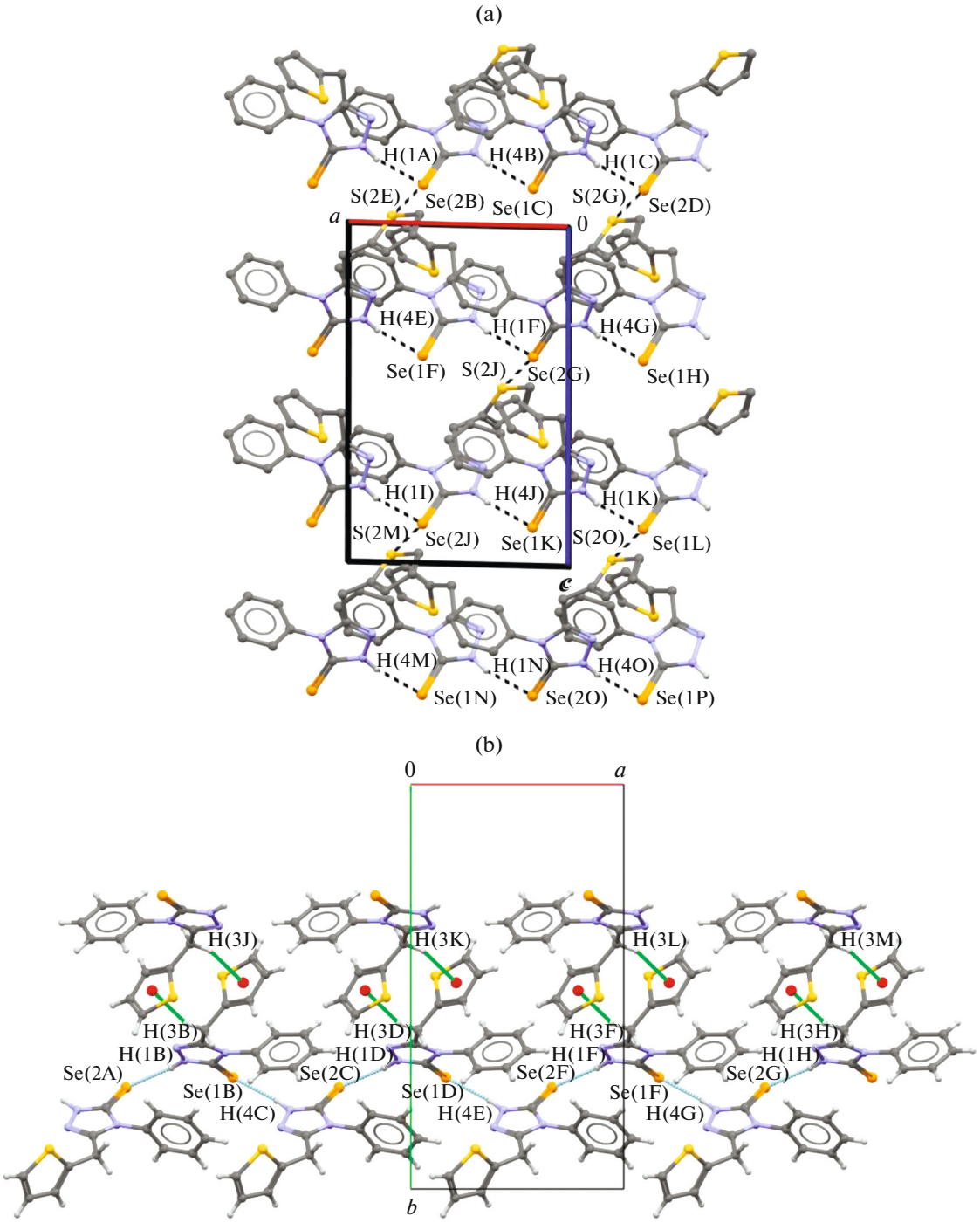


Fig. 2. Fragment of the crystal structure of compound **II** projected onto the planes (a) *a*0*c* and (b) *ab*0. Dashed lines show (a) hydrogen bonds N–H···Se and nonvalent interactions Se···S and (b) intermolecular hydrogen bonds N–H···Se and C–H···π.

XRD: *N*-phenyl-2-(2-thienylacetyl)hydrazinecarboselenoamide (**I**), 4-phenyl-5-(2-thienylmethyl)-2,4-dihydro-3*H*-1,2,4-triazole-3-selone (**II**), and 3,3'-di[4-phenyl-5-(2-thienylmethyl)-4*H*-1,2,4-triazolyl] diselenide (**III**). Selenotriazole **II** was revealed to exist as selone in both the crystal and solution (the C=Se distance in the crystal is 1.847(3) and 1.845(3) Å for two crystallographically independent molecules). Owing to the anomeric effect, crystalline diselenide **III** is characterized by the gauche conformation of the substituents at the Se–Se bond stabilized by the weak intramolecular hydrogen bond C–H···π. The antimicrobial activity of the synthesized compounds was studied. Compounds **I**

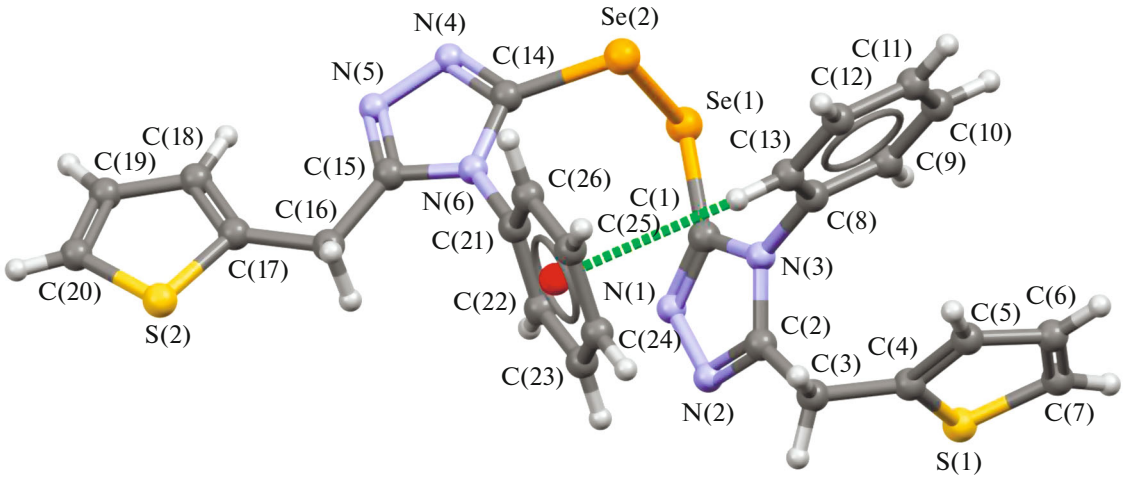


Fig. 3. Molecular structure of compound **III**. The weak intramolecular hydrogen bond C–H···π is shown by dash.

Table 3. Selected bond lengths and the bond and torsion angles in compound **III**

Bond	*d*, Å	Bond angle	ω, deg
Se(1)–Se(2)	2.346(8)	C(1)Se(1)Se(2)	100.03(15)
Se(1)–C(1)	1.888(5)	C(14)Se(2)Se(1)	97.37(14)
Se(2)–C(14)	1.898(5)	N(1)C(1)Se(1)	123.8(4)
N(1)–N(2)	1.390(6)	N(4)C(14)Se(2)	124.4(4)
N(1)–C(1)	1.318(6)	C(2)C(3)C(4)	112.3(4)
N(2)–C(2)	1.325(6)	C(15)C(16)C(17)	116.2(4)
N(3)–C(1)	1.377(6)	C(1)N(1)N(2)	107.0(4)
N(3)–C(2)	1.358(6)	C(2)N(2)N(1)	107.5(4)
C(2)–C(3)	1.488(7)	C(2)N(3)C(1)	105.3(4)
C(3)–C(4)	1.512(7)	C(14)N(4)N(5)	106.5(4)
N(3)–C(8)	1.445(6)	C(15)N(5)N(4)	107.6(4)
N(4)–N(5)	1.396(6)	C(14)N(6)C(15)	104.8(4)
N(4)–C(14)	1.306(6)	N(5)C(15)N(6)	109.6(4)
N(5)–C(15)	1.328(6)	Torsion angle	γ, deg
N(6)–C(14)	1.366(6)	C(1)Se(1)Se(2)C(14)	–83.5(2)
N(6)–C(15)	1.370(6)	C(2)C(3)C(4)C(5)	15.7(9)
N(6)–C(21)	1.442(6)	C(15)C(16)C(17)C(18)	106.6(7)
C(15)–C(16)	1.489(7)	C(1)N(3)C(8)C(13)	104.6(6)
C(16)–C(17)	1.517(6)	C(14)N(6)C(21)C(26)	70.9(7)

Table 4. Bactericidal effect of compounds **I**–**III**

Compound	*Staphylococcus aureus*		*Escherichia coli*	
	D zones of growth inhibition, mm (ignoring well diameter)	characteristic of bactericidity	*D* zones of growth inhibition, mm (ignoring well diameter)	characteristic of bactericidity
I	8	Weakly bactericidal	4	Nonbactericidal
II	10	Bactericidal	10	Bactericidal
III	6	Weakly bactericidal	0	Nonbactericidal

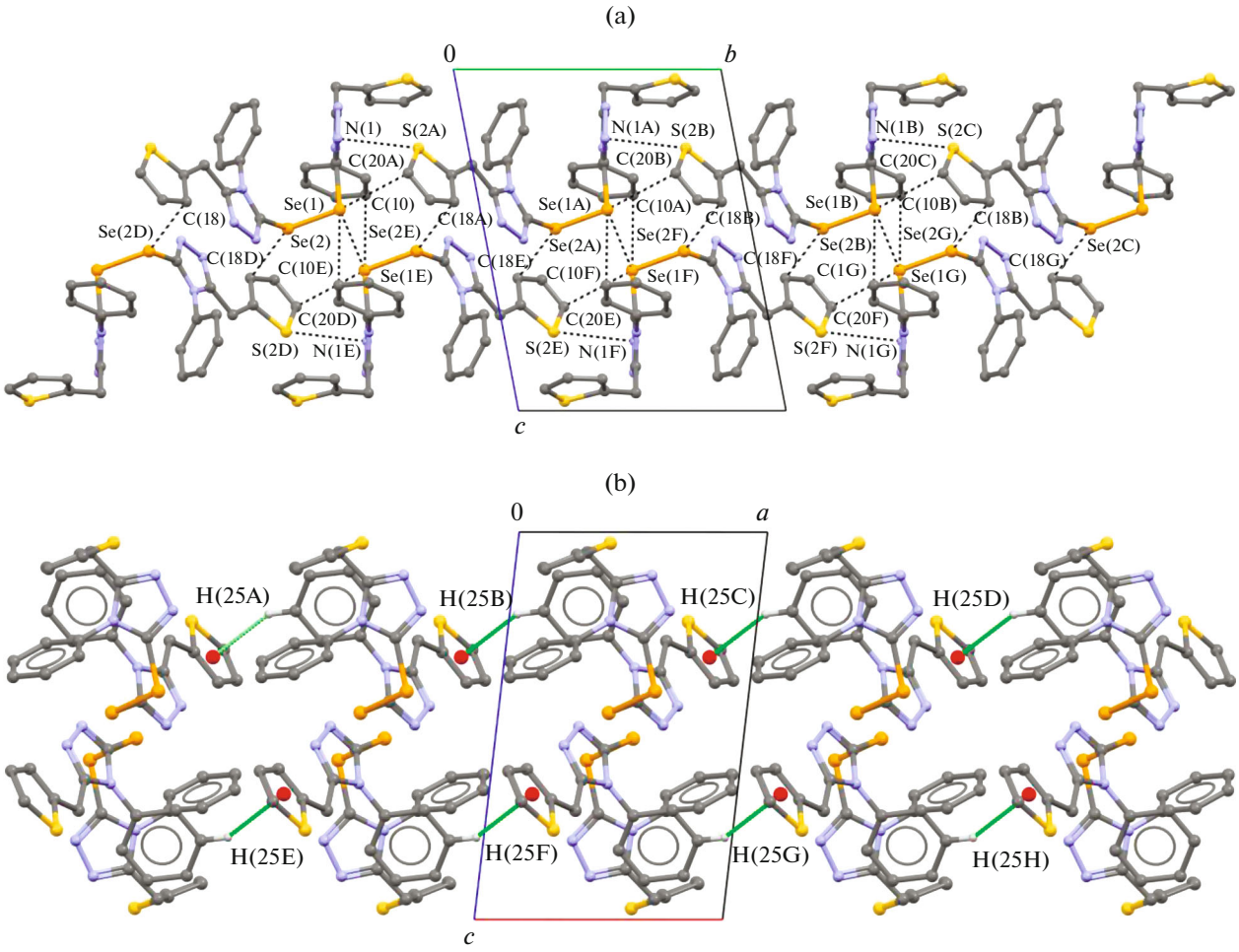


Fig. 4. Fragment of the crystal packing of compound **III** projected onto the planes (a) *b*0*c* and (b) *a*0*c*. Hydrogen atoms that are not involved in intermolecular hydrogen bonds are omitted for clarity. Dashed lines show (a) contacts Se···C, Se···Se, and S···N and (b) hydrogen bonds C–H···π.

Table 5. Fungicidal effect of compounds **I**–**III**

Compound	*D* zones of growth inhibition, mm (ignoring well diameter)	Characteristic of fungicidity
I	16	Fungicidal
II	10	Fungicidal
III	No inhibition zone	Nonfungicidal

and **II** were found to possess bactericidal and fungicidal activity.

REFERENCES

1. Banerjee, B. and Koketsu, M., *Coord. Chem. Rev.*, 2017, vol. 339, p. 104.
2. Zhang, S., Wang, Z., Hu, Z., et al., *Chem. Med. Chem.*, 2017, vol. 12, no. 3, p. 235.
3. Álvarez-Pérez, M., Ali, W., Marć, M.A., et al., *Molecules*, 2018, vol. 23, p. 628.
4. Miao, Q., Xu, J., Lin, A., et al., *Curr. Med. Chem.*, 2018, vol. 25, no. 17, p. 2009. https://doi.org/10.2174/0929867325666171129220544
5. Ninomiya, M., Garud, D.R., and Koketsu, M., *Coord. Chem. Rev.*, 2011, vol. 255, p. 2968.
6. Garud, D.R., Koketsu, M., and Ishihara, H., *Molecules*, 2007, vol. 12, p. 504.
7. Heimgartner, H., Zhou, Y., Plamen, K., et al., *Phosphorus, Sulfur, Silicon Relat. Elem.*, 2008, vol. 183, p. 840.
8. Karabanovich, G., Roh, J., Padelkova, Z., et al., *Tetrahedron*, 2013, vol. 69, p. 8798.

9. Sommen, G.L., Linden, A., and Heimgartner, H., *Helv. Chim. Acta*, 2007, vol. 90, p. 641.
10. Favero, F., Sommen, G.L., Linden, A., and Heimgartner, H., *Heterocycles*, 2006, vol. 67, p. 749.
11. Pieczonka, A.M., Ciepielowski, K., Cebulska, Z., et al., *Helv. Chim. Acta*, 2013, vol. 96, p. 397.
12. Zakrzewski, J., Huras, B., and Kiełczewska, A., *Synthesis*, 2016, vol. 48, p. 85.
13. Lazarenko, V.A., Dorovatovskii, P.V., Zubavichus, Y.V., et al., *Crystals*, 2017, vol. 7, no. 11, p. 325.
14. Battye, T.G.G., Kontogiannis, L., Johnson, O., et al., *Acta Crystallogr., Sect. D: Biol. Crystallogr.*, 2011, vol. 67, p. 271.
15. Evans, R., *Acta Crystallogr., Sect. D: Biol. Crystallogr.*, 2006, vol. 2, p. 72.
16. Sheldrick, G.M., *Acta Crystallogr., Sect. C: Struct. Chem.*, 2015, vol. 71, p. 3.
17. Shtefan, E.D. and Vvedenskii, V.Yu., *Usp. Khim.*, 1995, vol. 65, p. 326.
18. Akkurt, M., Ozturk, S., Servi, S., et al., *Acta Crystallogr., Sect. E: Struct. Rep. Online*, 2004, vol. 60, p. 1507.
19. Fleischhauera, J., Beckerta, R., Horniga, D., et al., *Z. Naturforsch., B: J. Chem. Sci.*, 2008, vol. 63, p. 415.
20. Bondi, A., *J. Phys. Chem.*, 1964, vol. 68, p. 441.
21. Rowland, R.S. and Taylor, R., *J. Phys. Chem.*, 1996, vol. 100, p. 7384.
22. Christoph, J., *Dalton Trans.*, 2000, p. 3885.
23. Piccotti, E., DE Patent 2148633, 1972.
24. Brown, J.C., Fry, D.J., and Keogh, P.J., DE Patent 2162856, 1972.
25. Dyke, J.M., DE Patent 2331220, 1974.

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