S-Thioacyldithiophosphates in the Synthesis of Thiohydroxamic Acids and *O*-Thioacylhydroxylamines

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Received 15 February 2002

Abstract: *S*-Thioacyldithiophosphates proved to be excellent thioacylating agents. They are easily available from carboxylic acids. Due to their low reactivity towards oxygen nucleophiles and high reactivity towards nitrogen ones they found application in the synthesis of thiohydroxamic acids directly from hydroxylamines without protection on the hydroxy group. However, in cases of steric hindrance *O*-thioacyl hydroxylamines are formed and can be isolated with high yield.

Key words: thiohydroxamic acids, hydroxylamines, acylations, phosphates, chemoselectivity

Thiohydroxamic acids (being thioacyl derivatives of hydroxylamines) are a class of compounds containing significantly different neighboring atoms, ie nitrogen, oxygen, sulfur, and a carbon atom in sp^2 hybridization. The specific bond system causes thiohydroxamic acids to be excellent double dentate ligands capable of complexing cations of different metals. These bioligands are being used in nature for transport of numerous cations. They are also used in analytical chemistry for the quantitative determination of numerous metals. Moreover, in the past 25 years *O*-acyl derivatives of thiohydroxamic acids have found wide application as a source of efficiently generated carbon, sulfur, nitrogen, or phosphorus radicals. The derivatives of thiohydroxamic acids and their metal complexes are widespread in nature and already have found application in medicine and technology.[1]

Thioacyl derivatives might be obtained using two main approaches. One is a step by step method based on the synthesis of acyl derivatives and their subsequent thionation with thionating agents such as diphosphorus decasulfide or Lawessons' reagent.[2–4] However, although hydroxamic acids (being acyl derivatives of hydroxylamines) are easily available, their direct sulfuration with diphosphorus decasulfide yields complicated mixture of products, whereas the expected thiohydroxamic acids are present in only small quantities.[5,6] Moreover, recently Przychodzen[7] has shown that in the reaction of *N*-alkylhydroxamic acids with Lawessons' Reagent, thiohydroxamic acids, amides, and thioamides are formed. Hence, direct formation of hydroxamic acids cannot be classified as a good synthetic method for thiohydroxamic acids. On the other hand Rzepa[8] et al. proposed a method of hydroxamic acid transformation to thiohydroxamic acids based on *O*-acetylation of the hydroxamic acid, followed by thionation of the *O*-acetyl derivative with Lawessons' reagent, followed by deprotection of the hydroxy group. However, this multi-step procedure does not guarantee high yields (10–50%).

A second approach to the synthesis of thioacyl derivatives is based on preparing an active derivative of thiocarboxylic acid and the reaction of nucleophiles with the thus obtained thioacylating agent.[2,9–13] However, there is a shortage of stable and easily available thioacylating reagents (especially because most of them can only be prepared from dithiocarboxylic acids, which scarcely are commercial reagents and are hard to obtain or to handle in pure form). In the chemical literature many methods of thioacylation of hydroxylamines have been described, however most of them require protection of the hydroxy group in hydroxylamine. Consequently overall yields were low.[1]

We have recently described[14] a convenient method for the conversion of carboxylic acids into thioacyl dithiophosphates **6**, excellent thioacylating reagents (see Scheme 1). The method is based on isomerisation of acyl dithophosphates **3** to *O*-thioacyl monothiophosphates **4**. The mixture of isomers **3** and **4** treated with dithiophosphoric acid yields *S*-thioacyl dithiophosphates **6** exclusively. These reagents are easy to obtain, and they do not have to be isolated prior to thioacylation, although in many cases isolation is simple and provides stable crystalline reagents. The title compounds react much faster with nitrogen or sulfur nucleophiles than with oxygen ones. This can be applied to direct synthesis of hydroxythioamides and hydroxydithioesters. Here we would like to present the application of our method to the synthesis of thiohydroxamic acids by direct thioacylation of *N*-alkylhydroxylamines (without protection of hydroxy group).

Studying the scope and limitations of the new thioacylation method, we treated *S*-thioacyl dithiophosphates **6** with *N*-alkylhydroxylamines in the presence of triethylamine in chloroform (Scheme 2). From such a reaction mixture we isolated *N*-alkyl thiohydroxamic acids with moderate to very good yields. The results of this set of experiments are collected in Table 1.

Our method of thioacylation is very simple: thioacyl dithiophosphate is added to the solution or suspension of a nucleophile with one equivalent of a base (e.g. triethylamine). In most cases the reaction is finished immediate-

Synthesis 2002, No. 8, 04 06 2002. Article Identifier:
1437-210X,E;2002,0,08,1047,1052,ftx,en;P00502SS.pdf.
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ISSN 0039-7881

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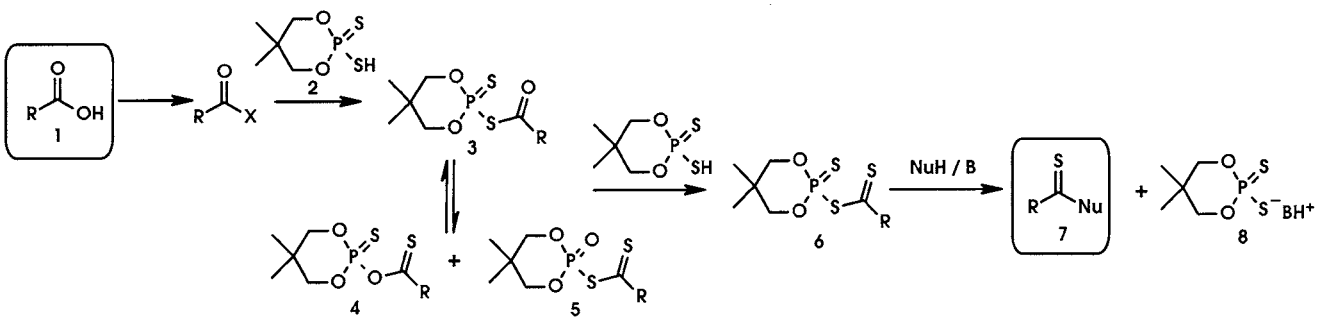
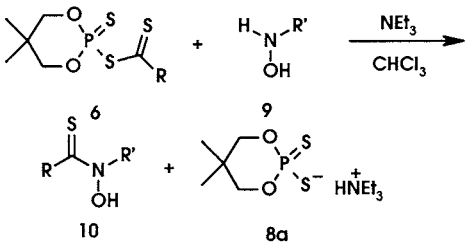


Scheme 1 Conversion of carboxylic acids into thioacylating reagents and their reaction with nucleophiles.



Scheme 2 Reaction of *S*-thioacyl dithiophosphates **6** with *N*-alkylhydroxylamines **9** possessing bulky or two substituents

Table 1 Synthesis of Thiohydroxamic Acids **10**

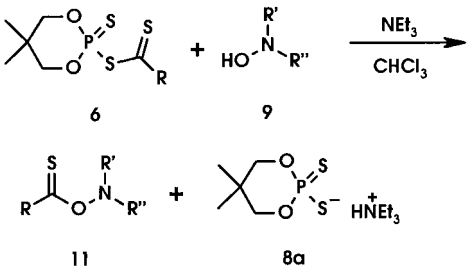
Entry	R	R′	Yield (%)
10a	*t*-Bu	Me	71
10b	Ph	Me	68
10c	Ph	*i*-Pr	73
10d	Ph	CH(Me)Ph	72
10e	Pr	Me	83
10f	Pr	*i*-Pr	80
10g	Pr	CH(Me)Ph	77
10h	Pr	*t*-Bu	57
10i	$MeOCO(CH_2)_4$	Me	91
10j	$MeOCO(CH_2)_4$	*i*-Pr	91
10k	$MeOCO(CH_2)_4$	CH(Me)Ph	94
10l	$MeOCO(CH_2)_4$	*t*-Bu	82

ly. Subsequent washing with water, drying and solvent evaporation yields crude product **10**.

It is important to mention that formation of water-soluble trialkylammonium phosphates **8** during thioacylation with thioacyl dithiophosphates is generally an advantage, because it simplifies isolation of the product. However, when obtaining water-soluble products it can be troublesome to isolate the product by water extraction. Then filtering the reaction mixture through a short pad of silica gel facilitates obtaining the crude product free of dithiophosphates and other strongly polar compounds.

As one can see from the data collected in Table 1, the method is efficient, and sterically hindered *N*-tertbutylhydroxylamine and *N*-phenetylhydroxylamine are also effectively thioacylated (Table 1, entries **10d**,**g**,**h**,**k**,**l**). Moreover, *S*-thiopivaloyl dithiophosphate (**6a**) as well as bifunctional 5-methoxycarbonylthiopentanoyl dithiophosphate (**6d**) appeared to be good thioacylating agents (Table 1, entries **10a**,**i**–**l**).

However, we found that *S*-thiopivaloyl dithiophosphate (**6a**), as well as thiobenzoyl dithiophosphate **6b** treated with hydroxylamines possessing a bulky substituent or two substituents on the nitrogen atom (*N*-tertbutylhydroxylamine, *N*-phenethylhydroxylamine, *N*-hydroxylmorpholine, *N*-isopropylbenzhydroxamic acid) in the presence of triethylamine yield *O*-thioacylhydroxylamines **11** efficiently (Scheme 3, Table 2).



Scheme 3 Reaction of *S*-thioacyl dithiophosphates **6** with *N*-alkylhydroxylamines **9** possessing bulky or two substituents

Table 2 Synthesis of *O*-Thioacylhydroxylamines **11**

Entry	R	R′	R″	Yield (%)
11m	*t*-Bu	*t*-Bu	H	96
11n	*t*-Bu	CH(Me)Ph	H	95
11o	*t*-Bu	$CH_2CH_2OCH_2CH_2$		71
11p	*t*-Bu	*i*-Pr	PhCO	95[a]
11r	Ph	*t*-Bu	H	74

[a] DBU was applied as a base instead of Et_3N; reaction time 24 h

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Hydroxylamines are known as ambident nucleophiles but the results of our previous experiments showed very poor reactivity of thioacyl dithiophosphates **6** towards oxygen nucleophiles. Reversed reactivity observed in this set of experiments can be explained by supernucleophilic properties of oxygen in hydroxylamines comparing to common alcohols as well as the lower thermodynamic stability of the *N*-thioacylated product due to steric hindrance compared to the *O*-thioacylated product (see also base-catalyzed isomerization of sterically hindered hydroxamic acids to *O*-acyl hydroxylamines[15,16] and papers of Lobo[17–21] et al. on *N*- and *O*-acylation of hydroxylamines with different acylating agents).

In conclusion we have elaborated a very simple strategy of thioacylation with the use of thioacyl dithiophosphates. The thioacylation of hydroxylamines generally yields thiohydroxamic acids. However, in cases of higher steric hindrance or *N*,*N*-disubstituted hydroxylamines, *O*-thioacyl hydroxylamines are formed and can be isolated with high yield. It is important to mention that both kinds of products are hardly available using other methods. Moreover, to our best knowledge, *O*-thioacyl hydroxylamines have not yet been described in chemical literature.

All reactions were carried out under an argon atmosphere in anhyd solvents (benzene and THF dried over benzophenone ketyl, CH_2Cl_2 dried over CaH_2, $CHCl_3$ dried over P_2O_5 hexane and cyclohexane dried over potassium). Chromatography was carried out on Silica Gel 60 (0.15–0.3 mm) Machery Nagel®. NMR was preformed on Vaarian Gemini 500 MHz (all *J* values are given in Hz); IR on a Bruker IFS66 (liquids from film and solids from KBr tablet); MS were acquired on a MASPEC II system [II32/99D9] in EI mode and if necessary liquid SIMS technique was applied.

Acyl 2-(5,5-Dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) Sulfides 3; General Procedure

AcCl (3 mmol) was added to a solution of 5,5-dimethyl-2-thiolo-2-thiono-1,3,2-dioxaphosphorinane (**2**) (0.594 g, 3 mmol) in benzene (10 mL). Subsequently, Et_3N (0.303 g, 3 mmol) or pyridine (0.237 g, 3 mmol) was added dropwise to the ice-cold solution. Immediately $Et_3N{\cdot}HCl$ precipitated. After 15 min the reaction mixture was filtered through a short pad of silica gel. After solvent evaporation pure product was obtained.

Pivaloyl 2-(5,5-Dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) Sulfide (3a)

Yield: 96%; mp 112–113 ºC.

IR (KBr): 1703 (C=O), 1046 (*P*OC), 997 (PO*C*), 686 (P=S) cm^{-1}.

^1H NMR ($CDCl_3$): δ = 4.23 (2 H, dd, J_{H-H} = 11, J_{P-H} = 4.8), 3.95 (2 H, dd, J_{H-H} = 11, J_{P-H} = 25.3), 1.31 (3 H, s), 1.26 (9 H, s), 0.91 (3 H, s).

^{13}C NMR ($CDCl_3$): δ = 199.7, 78.77 (d, J_{P-C} = 9.9), 49.45, 32.69 (d, J_{P-C} = 7.4), 27.23, 22.7, 21.03.

^{31}P NMR ($CDCl_3$): δ = 70.8.

HRMS: *m*/*z* Calcd for $C_{10}H_{19}O_3PS_2$: 282.05132. Found: 282.05046.

Benzoyl 2-(5,5-Dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) Sulfide (3b)

Yield: 98%; mp 114–115 ºC.

IR (KBr): 1679 (C=O), 1591, 1579, 1474, 1447 (C=C_{Ar}), 1043 (*P*OC), 985 (PO*C*), 668 (P=S) cm^{-1}.

^1H NMR ($CDCl_3$): δ = 7.97 (2 H, d, *J* = 7.8), 7.64 (1 H, t, *J* = 7.3), 7.49 (2 H, t, *J* = 7.3), 4.38 (2 H, dd, J_{H-H} = 10.7, J_{P-H} = 3.9), 4.02 (2 H, dd, J_{H-H} = 10.7, J_{P-H} = 25.9), 1.38 (3 H, s), 0.93 (3 H, s).

^{13}C NMR ($CDCl_3$): δ = 185.97, 136.61, 134.91, 129.18, 128.62, 79.1 (d, J_{P-C} = 9.9), 32.73 (d, J_{P-C} = 7.6), 22.79, 20.99.

^{31}P NMR ($CDCl_3$): δ = 69.1.

HRMS: *m*/*z* Calcd for $C_{12}H_{15}O_3PS_2$ (M^+): 302.02002. Found: 302.01975.

Butyryl 2-(5,5-Dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) Sulfide (3c)

Yield: 92%; mp 98–99 ºC.

IR (KBr): 1744 (C=O), 1043 (*P*OC), 988 (PO*C*), 678 (P=S) cm^{-1}.

^1H NMR ($CDCl_3$): δ = 4.24 (2 H, dd, J_{H-H} = 10.3, J_{P-H} = 3.9), 3.95 (2 H, dd, J_{H-H} = 10.3, J_{P-H} = 25.4), 2.72 (2 H, dt, J_{H-H} = 7.3, J_{P-H} = 1.9), 1.71 (2 H, tq, J_1, J_2 = 7.3), 1.32 (3 H, s), 0.97 (3 H, t, J_{H-H} = 7.3), 0.91 (3 H, s).

^{13}C NMR ($CDCl_3$): δ = 192.72 (d, J_{P-C} = 3.5), 78.81 (d, J_{P-C} = 9.6), 48.72 (d, J_{P-C} = 2.5), 32.69 (d, J_{P-C} = 7.1), 22.66, 20.98, 18.78, 13.55.

^{31}P NMR ($CDCl_3$): δ = 70.1.

HRMS: *m*/*z* Calcd for $C_9H_{17}O_3PS_2$ (M^+): 268.03568. Found: 268.03562.

5-Carbomethoxypentanoyl 2-(5,5-Dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) Sulfide (3d)

Yield: 100%; mp ~ 25 ºC.

IR (KBr): 1734 (C=O), 1046 (*P*OC), 995 (PO*C*), 679 (P=S) cm^{-1}.

^1H NMR ($CDCl_3$): δ = 4.25 (2 H, dd, J_{H-H} = 11, J_{P-H} = 4.8), 3.97 (2 H, dd, J_{H-H} = 11, J_{P-H} = 25.3), 2.79 (2 H, dt, J_1 = 7, J_2 = 1.5), 3.67 (3 H, s), 2.34 (2 H, t, *J* = 7), 1.7 (4 H, m), 1.33 (3 H, s), 0.92 (3 H, s).

^{13}C NMR ($CDCl_3$): δ = 192.2 (d, J_{P-C} = 3.4), 173.47, 78.69 (d, J_{P-C} = 10.3), 51.64, 46.26 (d, J_{P-C} = 3.4), 33.55, 32.52 (d, J_{P-C} = 6.8), 24.35, 23.99, 22.48, 20.79.

^{31}P NMR ($CDCl_3$): δ = 69.2.

HRMS (LSIMS): *m*/*z* Calcd for $C_{12}H_{22}O_5PS_2$ ($M + H^+$): 341.06463. Found: 341.06308.

Thioacyl 2-(5,5-Dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) Sulfides 6; Typical Procedure

The solution of acyl 2-(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) sulphide **3** (5 mmol) and 5,5-dimethyl-2-thiolo-2-thiono-1,3,2-dioxaphosphorinane (**2**) (1.98 g, 10 mmol) in benzene (35 mL) was heated under reflux for 2–4 h (until the starting material disappeared completely). Subsequently phosphoric thioacids were removed by washing with aq Na_2CO_3 and then H_2O. Next, the organic layer was dried ($MgSO_4$) and the solvent was evaporated. The crude product was used for thioacylation without further purification, or if necessary was purified by means of silica gel chromatography or crystallization.

Thiopivaloyl 2-(5,5-Dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) Sulfide (6a)

Reaction time: 4 h. Before washing with aq $NaHCO_3$, the reaction mixture was diluted with $CHCl_3$, because the product started to precipitate. Crystallization from benzene.

Yield: 95%; mp 153–154 ºC.

IR (KBr): 1209 (C=S), 1045 (*P*OC), 992 (PO*C*), 678 (P=S) cm^{-1}.

^1H NMR ($CDCl_3$): δ = 4.19 (2 H, d, J_{H-H} = 10.7, J_{P-H} = 3.9), 3.94 (2 H, dd, J_{H-H} = 10.7, J_{P-H} = 25.9), 1.45 (9 H, s), 1.34 (3 H, s), 0.89 (3 H, s).

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^{13}C NMR ($CDCl_3$): δ = 241.86 (d, $J_{P–C}$ = 4.2), 78.67 (d, J_{P150C} = 10.1), 32.61 (d, $J_{P–C}$ = 7.1), 31.29, 22.62 (d, $J_{P–C}$ = 4.2), 20.99.

^{31}P NMR ($CDCl_3$): δ = 70.7.

HRMS: m/z Calcd for $C_{10}H_{19}O_2PS_3$ (M^+): 298.02853. Found: 298.02848.

Thiobenzoyl 2-(5,5-Dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) Sulfide (6b)
Reaction time: 2 h; eluent: benzene; yield 94%; mp 95–97 °C.

IR (KBr): 1181 (C=S), 1587, 1479, 1442 (C=C_{Ar}), 1042 (*P*OC), 985 (PO*C*), 678 (P=S) cm^{-1}.

^{1}H NMR ($CDCl_3$): δ = 8.04 (2 H, d, *J* = 8.3), 7.59 (1 H, t, *J* = 7.8), 7.4 (2 H, t, *J* = 7.8), 4.29 (2 H, dd, $J_{H–H}$ = 10.7, $J_{P–H}$ = 3.4), 3.98 (2 H, dd, $J_{H–H}$ = 10.7, $J_{P–H}$ = 25.9), 1.37 (3 H, s), 0.9 (3 H, s).

^{13}C NMR ($CDCl_3$): δ = 219.44, 145.56 (d, $J_{P–C}$ = 5.5), 133.6, 128.73, 127.32, 78.91 (d, $J_{P–C}$ = 9.6), 32.65 (d, $J_{P–C}$ = 7.3), 22.64, 20.96.

^{31}P NMR ($CDCl_3$): δ = 68.6.

HRMS: *m*/*z* Calcd for $C_{12}H_{15}O_2PS_3$ (M^+): 317.99718. Found: 317.99997.

Thioacylation of Hydroxylamines with Thioacyl 2-(5,5-Dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) Sulfides (6); General Procedure
To the solution of hydroxylamine (or suspension of hydroxylamine hydrochloride or oxalate) (1 mmol) in $CHCl_3$ (2 mL), Et_3N (1, 2 or 3 mmol, respectively) was added. Next, the solution of thioacyl 2-(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) sulfide (1 mmol) in $CHCl_3$ (4 mL) was added dropwise. [If the thioacyl dithiophosphate was crude (after only washing with aq $NaHCO_3$), then a 25% excess was used.] After 15 min, the reaction mixture was filtered through a short pad of silica gel. After solvent removal residue was purified by means of either:

1) chromatography; or

2) extraction (only for thiohydroxamic acids): the residue was diluted with $CHCl_3$ and extracted with 1 M aq NaOH. Next the water layer was acidified with 6 M aq HCl and extracted with $CHCl_3$. The resulting organic layer was dried ($MgSO_4$). Solvent evaporation yielded pure product.

For chromatography of thiohydroxamic acids, low metal content silica gel is beneficial. Thus, silica gel was washed with aq sodium EDTA, MeOH and dried on a rotary evaporator.

NMR, MS and IR data for *N*-thioacyl and *O*-thioacyl hydroxylamines **10, 11** are collected in Table 3.

***N*-Methyl-*N*-thiopivaloylhydroxamic Acid (10a)**
N-Methylhydroxylamine hydrochloride was used; instead of $CHCl_3$, CH_2Cl_2 was the solvent; eluent: $CHCl_3$.

***N*-Methylthiobenzhydroxamic Acid (10b)**
N-Methylhydroxylamine hydrochloride was used; eluent: *t*-BuOMe–hexane, 10:3.

***N*-Isopropylothiobenzhydroxamic Acid (10c)**
N-Isopropylhydroxylamine oxalate was used; eluent: benzene.

***N*-(1-Phenylethyl)thiobenzhydroxamic Acid (10d)**
Extraction.

***N*-Methyl-*N*-thiobutyrylhydroxylamine (10e)**
N-Methylhydroxylamine hydrochloride was used and crude thiobutyryl 2-(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) sulfide (**6c**); eluent: benzene–hexane, 1:1.

***N*-Isopropyl-*N*-thiobutyrylhydroxylamine (10f)**
N-Isopropylhydroxylamine oxalate was used and crude thiobutyryl 2-(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) sulfide (**6c**); extraction.

***N*-(1-Phenylethyl)-*N*-thiobutyrylhydroxylamine (10g)**
Crude thiobutyryl 2-(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) sulfide (**6c**) was used; eluent: benzene–hexane, 1:2.

***N*-*tert*-Butyl-*N*-thiobutyrylhydroxylamine (10h)**
Crude thiobutyryl 2-(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) sulfide (**6c**) was used; extraction.

***N*-(5-Carbomethoxythiopentanoyl)-*N*-methylhydroxylamine (10i)**
N-Methylhydroxylamine hydrochloride was used and crude 5-carbomethoxythiopentanoyl 2-(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) sulfide (**6d**); eluent: CH_2Cl_2.

***N*-(5-Carbomethoxythiopentanoyl)-*N*-isopropylhydroxylamine (10j)**
N-Isopropylhydroxylamine oxalate was used and crude 5-carbomethoxythiopentanoyl 2-(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) sulfide (**6d**); eluent: CH_2Cl_2.

***N*-(1-Phenylethyl)-*N*-(5-carbomethoxythiopentanoyl)hydroxylamine (10k)**
Crude 5-carbomethoxythiopentanoyl 2-(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) sulfide (**6d**) was used; eluent: CH_2Cl_2.

***N*-*tert*-Butyl-*N*-(5-carbomethoxythiopentanoyl)hydroxylamine (10l)**
Crude 5-carbomethoxythiopentanoyl 2-(5,5-dimethyl-2-thiono-1,3,2-dioxaphosphorinanyl) sulfide (**6d**) was used; eluent: CH_2Cl_2.

***N*-*tert*-Butyl-*O*-thiopivaloylhydroxylamine (11n)**
Eluent: $CHCl_3$.

***N*-(1-Phenylethyl)-*O*-thiopivaloylhydroxylamine (11o)**
Eluent: $CHCl_3$.

***O*-Thiopivaloyl-*N*-hydroxymorpholine (11p)**
Eluent: $CHCl_3$.

***N*-Benzoyl-*N*-isopropyl-*O*-thiopivaloylhydroxylamine (11r)**
Instead of Et_3N, 1,8-diazabicyclo[5.4.0]undec-7-ene was used; the reaction was carried out in darkness (reaction flask covered tightly with aluminum foil) due to the photochemical instability of the product; reaction time: 24 h; eluent: benzene.

***N*-*tert*-Butyl-*O*-thiobenzoylhydroxylamine (11s)**
Eluent: benzene–cyclohexane, 1:1.

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Table 3 Analytical Data for Compounds **10**, **11**

Entry	^{1}H NMR ($CDCl_3$, 500 MHz) δ, *J* (Hz)	^{13}C NMR ($CDCl_3$, 125 MHz) δ	HRMS (EI), M observed (calculated)	Molecular Formula	IR (NaCl, film) (cm^{-1})
10a[a]	11.39 (1 H, s), 3.72 (3 H, s), 1.38 (9 H, s)	192.72, 41.74, 40.22, 30.45	147.07199 (147.07179)	$C_6H_{13}NOS$	3298 (OH), 2963, 2874 (CH), 1221 (C=S)
10b	11 (1 H, br s), 7 (5 H, m), 3.4 (3 H, s)[22]				
10c	9.75 (1 H, s), 6.9 (5 H, s), 4.15 (1 H, m), 1.2 (6 H, d, *J* = 6)[7]				
10d	10.95 (1 H, br s), 7.39 (10 H, m), 5.43 (1 H, q, *J* = 6.9), 1.77 (3 H, d, *J* = 6.9)	182.35, 138.26, 138.45, 130.05, 128.91, 128.53, 126.91, 126.88, 62.26, 18.86	257.08752 (257.08744)	$C_{15}H_{15}NOS$	3334 (OH), 3030, 2983, 2937 (CH), 1205 (C=S)
10e	10.82 (1 H, s), 3.56 (3 H, s), 2.67 (2 H, t, *J* = 7.8), 1.78 (2 H, tq, $J_1 = J_2$ = 7.8), 0.97 (3 H, t, *J* = 7.8),	184.45, 40.74, 38.53, 22.27, 13.82	133.05652 (133.05614)	$C_5H_{11}NOS$	3280 (OH), 2965, 2934, 2874 (CH), 1214 (C=S)
10f	10.75 (1 H, br s), 4.56 (1 H, sept, *J* = 6.5), 2.68 (2 H, m), 1.69 (2 H, m), 1.36 (6 H, d, *J* = 6.5), 0.96 (3 H, t, *J* = 7.7)	182.59, 54.14, 40.85, 22.88, 20.42, 14.13	161.08715 (161.08744)	$C_7H_{15}NOS$	3271 (OH), 2967, 2936, 2874 (CH), 1211 (C=S)
10g	11.7 (1 H, br s), 7.15 (5 H, m), 5.03 (1 H, q, *J* = 7.3) 2.4 (2 H, m), 1.55 (5 H, m), 0.67 (3 H, t, *J* = 7.3)	184.4, 138.7, 129.1, 126.6, 60.9, 40.7, 22.7, 19.5, 14.0	223.10398 (223.10309)	$C_{12}H_{17}NOS$	3278 (OH), 2965, 2932, 2873 (CH), 1210 (C=S)
10h	11.36 (1 H, s), 2.83 (2 H, m), 1.85 (2 H, m), 1.61 (9 H, s), 0.98 (3 H, t, *J* = 7.4)	185.24, 67.22, 41.7, 30.4, 24.31, 14.24	175.10290 (175.10309)	$C_8H_{17}NOS$	3306 (OH), 2965, 2933, 2874 (CH), 1224 (C=S)
10i	10.77 (1 H, s), 3.65 (3 H, s), 3.59 (3 H, s), 2.69 (2 H, t, *J* = 7.8), 2.34 (2 H, t, *J* = 7.3), 1.79 (2 H, m), 1.69 (2 H, m)	183.89, 173.94, 51.82, 38.56, 38.37, 33.78, 28.12, 24.45	205.07790 (205.07727)	$C_8H_{15}NO_3S$	2950, 2868, (CH), 1735 (C=O), 1199 (C=S), 1045, 995 (CO)
10j	10.77 (1 H, s), 4.56 (1 H, sept, *J* = 6.3), 3.65 (3 H, s), 2.75 (2 H, t, *J* = 7.8), 2.35 (2 H, t, *J* = 7.3), 1.77 (2 H, m), 1.71 (2 H, m), 1.39 (6 H, d, *J* = 6.3)	181.84, 173.88, 53.97, 51.83, 38.24, 33.78, 28.52, 24.54, 20.19	233.10811 (233.10857)	$C_{10}H_{19}NO_3S$	3294 (OH), 2979, 2949, 2872 (CH), 1737 (C=O), 1237 (C=S), 1037 (CO)
10k	10.88 (1 H, br s), 7.35 (5 H, m), 5.55 (1 H, q, *J* = 6.8), 3.65 (3 H, s), 2.75 (2 H, m), 2.32 (2 H, t, *J* = 7.3), 1.77 (2 H, m), 1.67 (2 H, m), 1.8 (3 H, d, *J* = 6.8)	183.89, 173.9, 138.66, 129.15, 128.6, 126.59, 61, 51.84, 38.25, 33.77, 28.51, 24.55, 19.56	296.13164 (296.13204)	$C_{15}H_{22}NO_3S$ (M + H)[c]	3285 (OH), 2949, 2870 (CH), 1736 (C=O), 1235 (C=S), 1027, 977 (CO)
10l	11.34 (1 H, s), 3.65 (3 H, s), 2.87 (2 H, t, *J* = 7.8), 2.35 (2 H, t, *J* = 7.3), 1.86 (2 H, m), 1.7 (2 H, m), 1.62 (9 H, s)	184.42, 173.94, 67.05, 51.82, 39.2, 33.91, 30.16, 30.02, 24.73	247.12472 (247.12422)	$C_{11}H_{21}NO_3S$	3302 (OH) 2986, 2950, 2871 (CH), 1737 (C=O), 1203 (C=S), 1027 (CO)
11m[b]	2.9 (1 H, s), 1.22 (9 H, s), 1.08 (9 H, s)	211.73, 55.2, 45.15, 28.76, 27.1	189.11926 (147.07179)	$C_6H_{13}NOS$	3298 (NH), 2968, 2934, 2907, 2870 (CH), 1204 (C=S)
11n	7.3 (5 H, m), 3.92 (1 H, q), 3.25 (1 H, br s), 1.45 (3 H, d), 1.2 (9 H, s)	213, 144.5, 128.9, 127.6, 60.88, 45.31, 27.15, 23.6	237.11825 (237.11873)	$C_{13}H_{19}NOS$	3309 (OH), 2967, 2931 (CH), 1118 (C=S)

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Table 3 Analytical Data for Compounds **10**, **11** (continued)

Entry	^{1}H NMR ($CDCl_3$, 500 MHz) δ, *J* (Hz)	^{13}C NMR ($CDCl_3$, 125 MHz) δ	HRMS (EI), M observed (calculated)	Molecular Formula	IR (NaCl, film) (cm^{-1})
11o	3.59 (4 H, m), 3.16 (4 H, m), 1.1 (9 H, s)	212.35, 68.22, 54.41, 45.51, 27.07	203.09856 (203.09800)	$C_9H_{17}NO_2S$	2988, 2966, 2930, 2860 (CH), 1186 (C=S), 1048 (CO)
11p	7.57 (2 H, dt, J_1 = 7, J_2 = 1.5), 7.44 (1 H, tt, J_1 = 7.3, J_2 = 1.5), 7.38 (2 H, tt, J_1 = 7.3, J_2 = 1.5), 4.54 (1 H, m), 1.32 (3 H, d, 6.6), 1.31 (9 H, s), 1.25 (3 H, d, *J* = 7)	227.33, 170.44, 134.86, 131.02, 128.42, 127.8, 54.22 46.93, 30.03, 20.43, 19.54	279.12955 (279.12930)	$C_{15}H_{21}NO_2S$	2975, 2933 (CH), 1672 (C=O), 1176 (C=S)
11r	7.91 (2 H, d, *J* = 7.3), 7.58 (1 H, t, *J* = 7.8), 7.46 (2 H, t, *J* = 7.8), 3.17 (1 H, br s), 1.19 (9 H, s)	197.4, 135.49, 133.75, 129.03, 126.89, 55.66, 29.02	209.08758 (209.08744)	$C_{11}H_{15}NOS$	3304 (NH), 2968 (CH), 1207 (C=S)

[a] All thiohydroxamic acids gave a positive Fe^{3+} test.
[b] All *O*-thioacylhydroxylamines gave negative Fe^{3+} test.
[c] LSIMS method.

Acknowledgements

We gratefully acknowledge the Polish State Committee for Scientific Research for financial support (Grant No. 3 T09A 061 16).

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