A New Generation of Alkoxyl Radical Precursors – Preparation and Properties of *N*-(Alkoxy)-4-arylthiazole-2(3*H*)-thiones

Jens Hartung,*[a] Michaela Schwarz,[a] Ingrid Svoboda,[b] Hartmut Fuess,[b] and Maria Teresa Duarte[c]

Dedicated to Prof. Dr. Klaus Hafner on the occasion of his 70th birthday

Keywords: Alkoxyl radical / Cyclizations / Radicals / Tetrahydrofuran / Thiazolethione / Thiazolethione

N-(Hydroxy)thiazole-2(3*H*)-thiones **6–10** have been prepared in a short and efficient synthesis from *p*-substituted acetophenones. Alkylation of heterocycles **6–10** in the form of their potassium or tetraalkylammonium salts **11–15** affords *N*-alkoxy-4-arylthiazole-2(3*H*)-thiones **16–20** in good to satisfactory yields. The hitherto unknown thiones **16–20** have been subjected to a detailed structural investigation (NMR spectroscopy and X-ray crystallography) and furthermore to a mechanistic study in order to explore their utility as sources of oxygen-centered radicals in solution. From the results of these studies, the following conclusions can be drawn: (i) X-ray analyses of the *p*-chlorophenyl-substituted acid **9**, of the *O*-alkyl derivatives **19c**, **19f**, and of the *O*-mixed anhydride **19k** indicate short C–S bonds [C2–S2 = 1.637(5)–1.684(2) Å] and long N–O connectivities [N3–O1 = 1.369(3)–1.379(2) Å] in the thiohydroxamate functionalities. Furthermore, *O*-alkyl- or *O*-acyl substituents at O1 are twisted out of the thiazolethione plane by ca. 90°, which points to lone-pair repulsion between nitrogen and oxygen atom as the underlying structural motif of the cyclic thiohydroxamate derivatives. (ii) Alkylation of ambidentate thiohydroxamate anions (salts **11–15**; oxygen and sulfur nucleophiles) affords almost exclusively *O*-esters **16–20** (alkylation at the oxygen atom). (iii) Based on the results of X-ray diffraction studies and on the ^{1}H- and ^{13}C-NMR spectra, guidelines for the characterization of *N*-(alkoxy)thiazolethiones **16–20** and 2-(alkylsulfanyl)thiazole *N*-oxides **21–25**, i.e. the products of *S*-alkylation of thiohydroxamate salts **11–15**, could be derived. (iv) Photolyses of substituted *N*-(4-pentenoxy)-4-arylthiazolethiones **16–20** in general and in particular of *p*-chloro derivatives **19** were carried out in the presence of the hydrogen donor Bu_3SnH, and afforded substituted tetrahydrofurans **31** or tetrahydropyrans **32** as major products in good yields. The observed stereo- and regioselectivities of ethers **31** and **32** point to alkoxyl radicals **30** as reactive intermediates, which add intramolecularly by selective 5-*exo-trig* or 6-*endo-trig* pathways to the olefinic double bonds. In terms of synthetic access and ease of handling of the radical precursors, the *p*-chlorophenyl-substituted thiazolethiones **9** and **19** exhibit significant advantages over all the other thiones used in this study and are considered as excellent substitutes for the pyridinethiones as efficient sources of *free* alkoxyl radicals. Consequently, the present compounds may be of use in both mechanistic and synthetic studies.

Introduction

The study of alkoxyl radicals[1] in synthetic organic chemistry has received considerably less attention than transformations involving carbon-[2–4] or nitrogen-centered[5] radicals. However, alkoxyl radicals have served as useful intermediates in several selective transformations such as ring-closure reactions,[1a,6–8] hydrogen-atom abstractions,[9] and remote functionalizations of non-activated carbon−hydrogen bonds,[10] as well as for ring expansions of cycloaliphatic compounds.[11] Our own interest in this field of research is related to the stereoselective synthesis of substituted tetrahydrofurans by means of alkoxyl radical cyclizations.[1a,6–8] Previous work has shown that pyridinethione-derived *O*-esters of cyclic thiohydroxamic acids [e.g. *N*-(alkenoxy)pyridine-2(1*H*)-thiones, Figure 1] afford oxygen-centered radicals upon photolysis, which undergo fast and irreversible ring closures. Cyclized tetrahydrofurylmethyl radicals have been trapped by hydrogen or by heteroatom donors to furnish functionalized tetrahydrofurans. Considering the current progress in this field, it is very likely that alkoxyl radical cyclizations will soon play a role in concise syntheses of tetrahydrofuran-derived natural products, which are of considerable interest in contemporary research.[12]

In previous studies, cyclic thiohydroxamic acid *O*-esters such as *N*-(alkoxy)pyridine-2(1*H*)-thiones[8e] have served as useful sources of oxygen-centered radicals. The utility of these compounds in radical chain reactions is based on

---

[a] Institut für Organische Chemie, Universität Würzburg,
Am Hubland, D-97074 Würzburg, Germany
Fax: (internat.) + 49(0)931/888-4606
E-mail: hartung@chemie.uni-wuerzburg.de

[b] Fachbereich Materialwissenschaft, Fachgebiet Strukturforschung, Technische Universität Darmstadt,
Petersenstraße 23, D-64287 Darmstadt, Germany
Fax: (internat.) + 49(0)6151/166-023
E-mail: deOs@hrzpub.tu-darmstadt.de

[c] Centro de Química Estrutural, Complexo I, Instituto Superior Técnico,
Av. Rovisco Pais, P-1096 Lisboa Codex, Portugal
Fax: (internat.) + 351-1/8419282
E-mail: qteresa@beta.ist.utl.pt

1434−193X/99/0606−1275 $ 17.50+.50/0

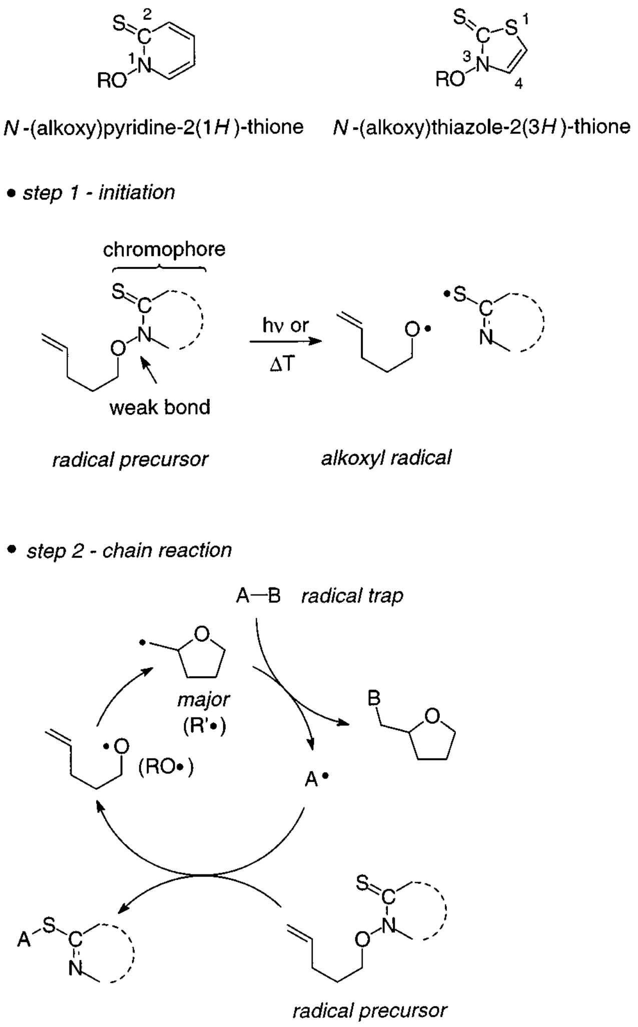
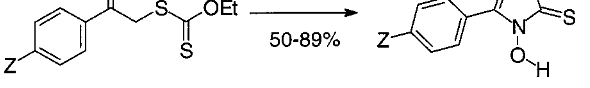


Figure 1. Key steps in the synthesis of cyclic ethers from thiohydroxamate *O*-esters [e.g. *N*-(alkoxy)pyridine-2(1*H*)-thione] by alkoxyl radical ring closures; A−**B** [Bu_3Sn−**H**, 2-$C_{10}H_8S$−**H**, $(Me_3Si)_3$-Si−**H**, Cl_3C−**Cl**, Cl_3C−**Br**, I_2CH−**I**]

three facts (Figure 1): (i) A thiohydroxamate group, i.e. a thiocarbonyl function in the vicinity of a hydroxylamine moiety, can be cleaved homolytically at the N−O bond either by photochemical excitation (incandescent or long-wavelength UV light) or by thermolysis to afford O radicals under mild conditions. (ii) The sulfur atom of a thiocarbonyl group is an excellent radical trap.[13][14] In one of the crucial steps in a radical chain reaction (Figure 1), carbon, silicon, sulfur, or phosphorus radicals $A^•$ readily add to thiocarbonyl groups at the sulfur atom to form rather strong S−A single bonds at the expense of a weak C−S π bond.[14] (iii) If a thiohydroxamate group is part of a heterocyclic compound that has formally 4*n* π electrons (*n* = 1,2), addition of $A^•$ to the *radicophilic* thiocarbonyl sulfur atom induces homolysis of an adjacent weak N−O bond (Figure 1). Subsequently, a new C−N π bond is formed, which constitutes part of a heteroaromatic compound. If resonance stabilization of this newly formed heteroaromatic molecule is sufficiently high, the generation of alkoxyl radicals ($RO^•$) from cyclic thiohydroxamic acid *O*-esters can be favoured by a good overall driving force. 4-Penten-1-oxyl radicals generated from precursors will undergo a stereoselective intramolecular 5-*exo-trig* cyclization to afford tetrahydrofurylmethyl radicals ($R'^•$) besides a minor amount of 3-tetrahydropyranyl radicals.[8] Carbon radicals $R'^•$ will be further trapped either by hydrogen or by heteroatom donors A−**B** [Bu_3Sn−**H**, 2-$C_{10}H_7S$−**H**, $(Me_3Si)_3Si$−**H**, Cl_3C−**Cl**, Cl_3C−**Br**, I_2CH−**I**] to afford substituted tetrahydrofurans as target molecules.[1a,6,7,8e]

Drawbacks associated with the use of *N*-(alkoxy)pyridinethiones in this type of reaction are not related to their efficiency in radical chain reactions (Figure 1), but rather to a number of unfavourable physical properties. Thus, they are typically obtained as thermally labile yellow oils. Several pyridinethiones decompose simply upon storage at temperatures below 5°C, while others rearrange to afford thermodynamically more stable 2-(alkylsulfanyl)pyridine *N*-oxides,[6][7] which can no longer be used as alkoxyl radical precursors. Thus, the availability of novel sources of alkoxyl radicals, combining the properties of *N*-alkoxypyridinethiones [points (i)−(iii), above] with more advantageous physical characteristics as well as a sufficient shelf-life, would represent significant progress in this field; these factors stimulated the present study.

In view of Barton's findings that *O*-acyl derivatives of *N*-(hydroxy)-4-phenylthiazole-2(3*H*)-thione (**8**) and its 4-methyl derivative[15] are less sensitive to visible light than the respective *N*-(acyloxy)pyridine-2(1*H*)-thiones, our attention was drawn to *N*-(hydroxy)thiazole-2(3*H*)-thiones.[16] Acids **6**−**10** fulfilled our requirements of having a thiohydroxamate functionality incorporated into an unsaturated, non-aromatic heterocycle, and a chromophore other than the pyridinethione group, combined with a seemingly straightforward synthetic access.[12][15] Moreover, the strategy for preparation of thiazole derivatives **6**−**10** would allow introduction of different groups Z at the *para* position of the aryl group simply by using the respective aryl methyl ketones as starting materials. Donor substituents (Z = OMe, Me) or acceptor groups (Z = Cl, NO_2) might serve as auxochromes for *tuning* the photochemical behaviour of compounds **6**−**10** as well as of the derived *O*-esters **16**−**20** (see below).



1 - 5

6 - 10

Z	compounds		Yield **6 - 10**
OCH_3	**1**	**6**	60%
CH_3	**2**	**7**	74%
H	**3**	**8**	50%[15]
Cl	**4**	**9**	89%
NO_2	**5**	**10**	57%

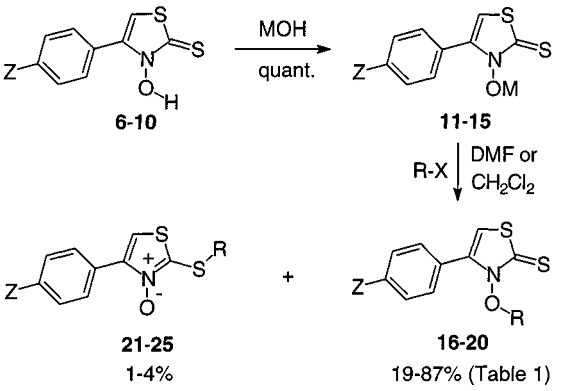
Scheme 1. Synthesis of thiazole-derived thiohydroxamic acids **6**−**10**

Results and Discussion

Preparation and Properties of 4-Aryl-Substituted *N*-(Hydroxy)-, *N*-(Alkoxy)-, and *N*-(Acyloxy)thiazole-2(3*H*)-thiones

The syntheses of *N*-(hydroxy)-4-arylthiazole-2(3*H*)-thiones **6−10** were started from commercially available *para*-substituted acetophenones, which were treated with bromine according to literature procedures to afford ω-bromo ketones in high yields.[15−17] The ω-bromo ketones were then treated with an excess of hydroxylamine hydrochloride in methanol in the absence of a base[16] to afford *p*-substituted phenacyl bromide oximes that have been described previously.[15][17] In a third step, the oximino bromides were treated with potassium ethyl xanthate in acetone to afford oximino dithiocarbonates **1−5**. Treatment of **1−5** with anhydrous $ZnCl_2$ afforded acids **6−10** in 50−89% yield (Scheme 1). Several procedures for $ZnCl_2$-mediated conversion of **1−5** into thiazolethiones **6−10** were explored. The best and most reliable conditions involved simple addition of commercially available anhydrous solid $ZnCl_2$ (3 equiv., 5 M) to a slurry of the appropriate dithiocarbonate **1−5** in diethyl ether. The initially formed viscous brown solutions solidified towards the end of the reaction (ca. 14 h). This precipitate, which presumably consisted of zinc derivatives of thiazolethiones **6−10**, redissolved upon addition of dilute aqueous HCl. Within a few minutes, a new precipitate consisting of the compounds **6−10** separated, which was isolated by suction filtration and purified by recrystallization. This method proved to be superior to the use of a commercially available solution of $ZnCl_2$ in diethyl ether (1 M). However, upon addition of further solid $ZnCl_2$ to a 1 M ethereal solution of $ZnCl_2$, yields of thiazolethiones **6−10** increased and reached values close to the figures quoted in Scheme 1. These findings indicated that concentration of the Lewis acid was critical in order to obtain good yields of heterocycles **6−10**. Efforts to increase the yields of thiazolethiones **6−10** using other, probably more efficient Lewis acids instead of $ZnCl_2$, such as $BF_3 \cdot OEt_2$, $CrCl_3$, $SnCl_4$, or $SbCl_5$ led either to complete failure of the ring closure **4** → **9** or to decomposition of the starting material **4**. Likewise, a change of solvent from diethyl ether to methyl *tert*-butyl ether (MTB) caused a sharp drop in the yield of **9**.

Acids **6−10** were neutralized using 1 equiv. of KOH in MeOH to afford potassium salts **11a−15a** (M = K) in quantitative yields. Likewise, tetraethylammonium salts **11b−15b** (M = NEt_4) were obtained as tan-coloured hygroscopic powders and tetrabutylammonium salts **11c−15c** (M = NBu_4) as tan oils from acids **6−10** and commercially available solutions of the tetraalkylammonium hydroxides in methanol (Scheme 2). Salts **11−15** were thoroughly freeze-dried and then treated with alkyl chlorides, benzyl chlorides, or alkyl tosylates, preferably in DMF solution, to give mainly the thiazolethione-derived *O*-esters **16−20** in good to satisfactory yields besides minor amounts of 2-(alkylsulfanyl)-4-arylthiazole *N*-oxides **21−25** (Table 1).



Z	compounds		
OCH_3	11	16	21
CH_3	12	17	22
H	13	18	23
Cl	14	19	24
NO_2	15	20	25

11 - 15	M
a	K
b	NEt_4
c	NBu_4

Z = NO_2, Cl, H, Me, OMe

R = alkyl, allyl, benzyl, acyl

Scheme 2. Alkylation and *O*-acylation of thiohydroxamate salts **11−15** (Table 1)

The use of tetrabutylammonium salts **11c−15c** (Table 1, M = NBu_4) generally led to an increase in the yields of thiones **16−20**. Thus, **11c−15c** proved superior to the corresponding tetraethylammonium salts **11b−15b** (M = NEt_4), while the latter were superior to the potassium salts (M = K). On the other hand, the syntheses of the mixed anhydrides **19k** and **19m** were facilitated by the fact that potassium chloride precipitated from the reaction mixtures upon treatment of the potassium salt **14a** with the appropriate acid chlorides in CH_2Cl_2. The salt was filtered off, the respective filtrates were concentrated in vacuo, and the crude materials were recrystallized to afford pure compounds **19k** and **19m**. This method avoided the use of column chromatography, which led to considerable decomposition of these anhydrides.

Yields of the *O*-alkylthiazolethiones **16−20** ranged from 19 to 87%. There were no obvious correlations of our data with either the steric size of alkyl residues R or with the leaving group abilities of X of the alkylating reagents (i.e. sulfonate or halide). It is likely that both factors came into play and rendered primary alkyl tosylates almost as effective as alkylating reagents (entries 9 and 13, Table 1) as secondary derivatives (entries 14−15, Table 1). Secondary benzylic chlorides afforded higher yields (entries 1−5, Table 1) than benzyl chloride or 2-methallyl chloride (entries 16−17, Table 1). Thus, it would seem that the effectiveness of an alkylating reagent in the synthesis of *N*-(alkoxy)thiazolethiones **16−20** reflects a compromise between steric demand of the incoming electrophile, which has to approach the sterically more congested N−O face of the thiohydroxamate anion, and the reactivity of the C−X bond in electrophiles R−X. This explanation cannot, however, account for the 42% yield of allyloxythiazolethione **19j** which is still

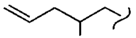
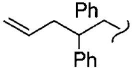
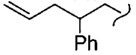
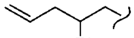
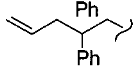
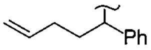
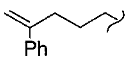
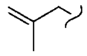
entry	R	X	Z	M	16 - 20	yield
1	PhCHCH$_3$	Cl	OCH$_3$	NBu$_4$	**16a**	47%
2	PhCHCH$_3$	Cl	CH$_3$	NBu$_4$	**17a**	50%
3	PhCHCH$_3$	Cl	H	NBu$_4$	**18a**	65%
4	PhCHCH$_3$	Cl	Cl	NBu$_4$	**19a**	67%
5	PhCHCH$_3$	Cl	NO$_2$	NBu$_4$	**20a**	64%
6		OTos	OCH$_3$	NBu$_4$	**16b**	21%
7		OTos	CH$_3$	NBu$_4$	**17b**	19%
8		OTos	H	NBu$_4$	**18b**	59%
9		OTos	Cl	NEt$_4$	**19b**	45%
10		OTos	NO$_2$	NEt$_4$	**20b**	46%
11		Cl	Cl	NBu$_4$	**19c**	51%
12		OTos	Cl	NEt$_4$	**19d**	62%
13	n-C$_5$H$_{11}$	OTos	Cl	NEt$_4$	**19e**	53%
14	CH(CH$_3$)$_2$	OTos	Cl	NEt$_4$	**19f**	51%
15	c-C$_5$H$_9$	OTos	Cl	NEt$_4$	**19g**	57%
16	C$_6$H$_5$CH$_2$	Cl	Cl	NBu$_4$	**19h**	40%
17		Cl	Cl	NBu$_4$	**19j**	42%
18	CH$_3$CO	Cl	Cl	NEt$_4$	**19k**	80%
19	(H$_3$C)$_3$CCO	Cl	Cl	NEt$_4$	**19m**	87%

Table 1. Yields of N-(alkoxy)- and N-(acyloxy)thiazolethiones **16–20**

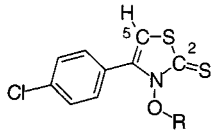
very promising considering the yields offered by other available syntheses of O-allyl thiohydroxamates.[18] O-Acyl derivatives **19k** and **19m** of N-(hydroxy)thiazolethione **9** were formed almost quantitatively and were isolated after purification in 80–87% yield.

With the exception of the p-nitrophenyl-substituted thiazolethiones **20** (yellow crystals) and methoxy-substituted 2-phenylpentenyl ester **16b** (oil), all other O-esters **16–19** were obtained as colorless, crystalline compounds that could be stored without any detectable decomposition (TLC) in standard glassware (Duran) without a need for any special protection from daylight. Whereas in former studies S-alkylation of pyridinethione-derived thiohydroxamate salts generally consumed between 20 and 70% of the alkylating reagents, 2-alkylsulfanylthiazole N-oxides **21–25** were fortunately formed in only minor amounts (1–4%). Only in a few cases was sufficient material collected to allow full characterization of these side products. For instance, reaction of the p-(chlorophenyl)thiazolethione salt **14b** and α-methallyl chloride afforded 2-(2-methyl-2-propenyl-1-sulfanyl)thiazole N-oxide (**24j**) in 4% yield. The structure of **24j** was characterized by significantly different chemical shifts (^{1}H, ^{13}C) compared to those of its thione isomer **19j**; the signals of 5-H, α-H, C-2, and C-5 are transposed compared to the corresponding signals of O-ester **19j** (see below, Table 2).

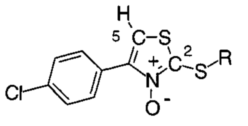
Spectroscopic Properties of 4-Aryl-Substituted N-Hydroxythiazole-2(3H)-thiones and Derivatives Thereof

The p-chlorophenyl-N-hydroxythiazolethione **9** shows simple ^{1}H- and ^{13}C-NMR spectra in CDCl$_3$, which is advantageous if structurally complex alkyl esters are considered for investigation. A characteristic singlet at δ = 6.68 (5-H) as well as distinctive ^{13}C-NMR data are consistent with a thione structure for possible thione–thiol tautomers of **9** (Scheme 1). Thus, C-2 resonates at δ = 179.2 (C=S) and C-5 at δ = 106.4 (Table 2). The hydroxy proton usually gives rise to a broad singlet (δ ≈ 12), which is sometimes difficult to locate. Minor changes are seen in the ^{1}H- and ^{13}C-NMR signals of the thiazolethione unit upon deprotonation of acid **9** with NEt$_4$OH in MeOH. Thus, with the exception of a marked highfield shift of C-2 (Δδ = −14.7), NMR data relating to the thiazolethione subunits of acid **9** and the derived tetraethylammonium salt **14b** are comparable. Likewise, chemical-shift values (^{1}H, ^{13}C) for O-alkyl derivatives **16–20** of N-(hydroxy)thiazole-2(3H)-thiones and for mixed anhydride **19k**, including the resonances of C-2 (δ = 180–185), correspond to data obtained for the parent acids **6–10**. Comparison of selected chemical shift values (5-H, α-H, C-2, C-5, or C-α) of 4-(p-chlorophenyl)-substituted N-(alkoxy)thiazolethiones, e.g. **19j**, with data obtained for 2-(alkylsulfanyl)thiazole N-oxide **24j** allowed an unambiguous identification of both isomers (Table 2).

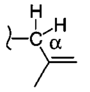
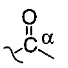
Table 2. Selected ^{1}H- and ^{13}C-NMR chemical shifts of (chlorophenyl)thiazolethiones **9**, **14a**, **19j**, **19k**, and 4-(p-chlorophenyl)-2-(2-methyl-2-propenyl-1-sulfanyl)thiazole N-oxide (**24j**)



9,14,19



24

entry	compound	solvent	5-H	α-H	C-2	C-5	C-α
					δ [ppm]		
1	**9**	CDCl$_3$	6.68$^{[a]}$	-	179.2	106.4	-
2	**14b**	[D$_6$]DMSO	6.53	-	164.5	104.1	-
3	**19j**	CDCl$_3$	6.50	4.52	180.6	105.2	79.6
4	**19k**	CDCl$_3$	6.56	-	181.5	105.0	165.5
5	**24j**	CDCl$_3$	7.32	3.90	164.6	112.9	41.8
R	H	NEt$_4$					
compd.	**9**	**14b**	**19j, 24j**			**19k**	

[a] ^{1}H-NMR data referenced to residual protons in CDCl$_3$ solvent.

UV/Vis spectra of thiones **5−10** and especially of **16−20** provided information on excitation wavelengths, which would be a prerequisite for any photochemical activation of these compounds. The cross-conjugated π system of acid **9** gives rise to electronic transitions in ethanol at λ_{max} = 309 nm (lg ε = 4.16) and at 240 nm (4.20), which are blue-shifted compared to the corresponding absorptions of *N*-(hydroxy)pyridine-2(1*H*)-thione [λ_{max} = 362 nm (ε = 3.28), 295 (3.71), 251(3.99),[14] Table 3]. Moreover, absorption maxima of thione **9** in apolar solvents such as *c*-C_6H_{12} and THF are seen at similar wavelengths as those recorded in ethanol. UV absorptions of *O*-esters **16−20** are only slightly red-shifted by 15−20 nm compared to those of the parent thiones **6−10**.

Table 3. UV/Vis data of thiazolethiones **9**, **14a**, **16a−20a**, and **19k**

Entry	Compound	Solvent	λ_{max}[nm] (lg ε)[a]
1	**9**	EtOH	309 (4.16), 240 (4.20)
2	**9**	THF	312 (4.14), 242 (4.19)
3	**9**	*c*-C_6H_{12}	307 (4.21), 246 (4.31)
4	**14b**	EtOH	300 (3.86), 260 (3.97)
5	**16a**	EtOH	320 (3.94), 250 (3.95)
6	**17a**	EtOH	320 (4.07), 240 (4.04)
7	**18a**	EtOH	320 (4.15), 230 (4.13)
8	**19a**	EtOH	320 (3.96), 240 (3.95)
9	**19k**	EtOH	300 (3.94), 264 (4.11)
10	**20a**	EtOH	370 (3.70) sh, 325 (4.13), 255 (3.89)

[a] ε in L mol^{-1} cm^{-1}.

Investigation of *N*-(Hydroxy)- and *N*-(Alkoxy)-4-(*p*-chlorophenyl)thiazolethiones by X-ray Diffraction Analysis

4-(*p*-Chlorophenyl)thiazolethiones **9** and **19** were selected for more detailed study of their structural properties since the yields of acid **9** and of the derived *O*-esters **19** were the highest achieved in this study. Furthermore, photochemical studies (see below, Table 5) indicated thiones **19** to be excellent substitutes for *N*-(alkoxy)pyridine-2(1*H*)-thiones in many applications in alkoxyl radical chemistry. Suitable crystals of selected *p*-chlorophenylthiazolethiones (acid **9**, *O*-isopropyl ester **19f**, 1-phenyl-4-pentenyl ester **19c**, and *O*-acetyl derivative **19k**) were grown and subjected to X-ray diffraction analysis. The results of these studies are presented in Figure 2. Significant connectivities, bond and torsion angles of the selected compounds are summarized in Table 4.

The solid-state structure of 4-(*p*-chlorophenyl)-*N*-hydroxythiazolethione **9** features a planar heterocyclic core. The thiohydroxamate moiety consists of a short C2−S2 bond [1.684(2) Å] and a long N3−O1 bond [1.379(2) Å]. Heteroatoms, especially S1, cause a distortion of the five-membered heterocycle [C2−S1−C5 = 92.2(1)°, C2−S1 = 1.714(2) Å, S1−C5 = 1.711(3) Å]. The distance between N3 and its adjacent carbon atoms is shorter towards the thione group [N3−C2 = 1.339(3) Å] than to the olefinic double bond [N3−C4 = 1.395(3) Å, C4−C5 = 1.337(3) Å].

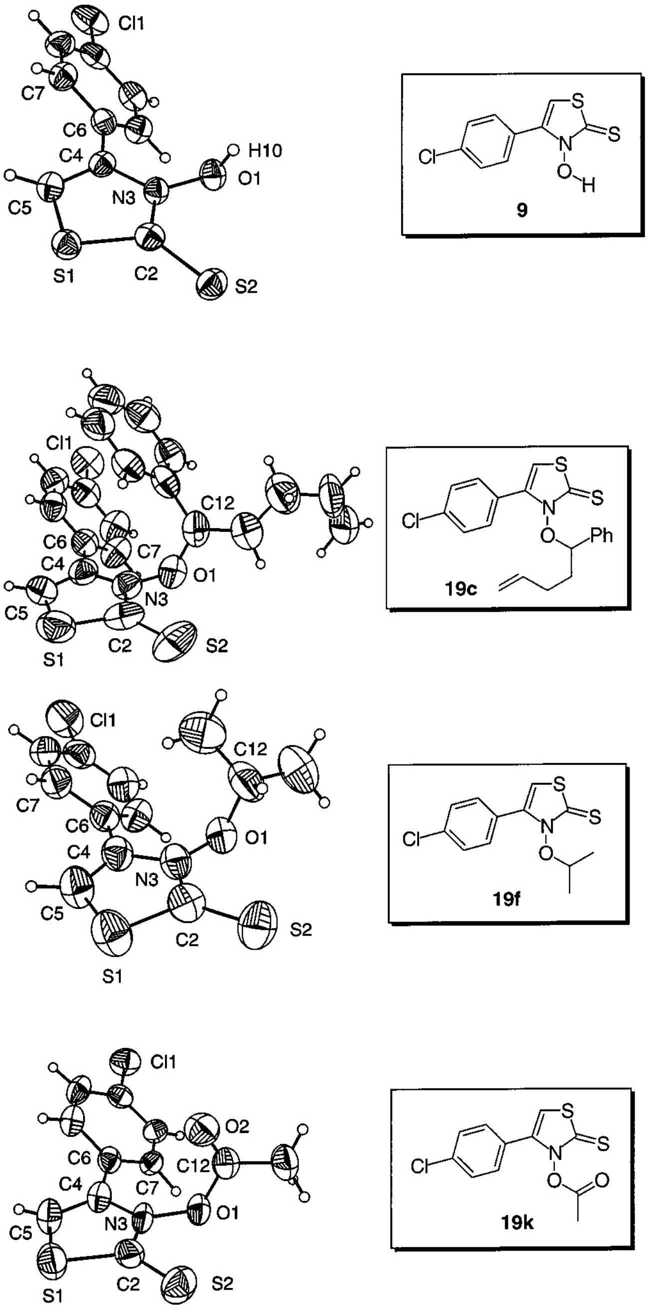


Figure 2. Views of (a) *N*-(hydroxy)thiazole-2(3*H*)-thione **9**, (b) *N*-(1-phenyl-4-penten-1-oxy)thiazole-2(3*H*)-thione **19c**, (c) *N*-(isopropyloxy)thiazole-2(3*H*)-thione **19f**, and (d) *N*-(acetoxy)thiazole-2(3*H*)-thione **19k** in the solid state, showing labelling of selected non-hydrogen atoms and H1O (see Table 4); thermal ellipsoids[31] are drawn at 50% probability levels; hydrogen atoms are depicted as small circles of arbitrary radius

The acidic hydrogen atom H1O was located on a difference Fourier map, from which it was established that it is bound to oxygen atom O1. Hydrogen atom H1O is involved in an intermolecular hydrogen bond to S2 of a neighbouring thione.[19] In the crystal, thiones **9** are arranged in π-stacked sheets. The *N*-hydroxythiazolethione moieties of **9** are rotated by 180° in adjacent molecules. The distances between the *p*-chlorophenyl rings are in the typical range for π-stacked aromatic compounds (ca. 3.8 Å).[20] This arrange-

Table 4. Selected bond lengths [Å], bond angles [°], and torsion angles [°] in (*p*-chlorophenyl)thiazolethiones **9**, **19c**, **19f**, **19k**

Entry	Parameter	**9**	**19c**	**19f**	**19k**
1	C2−S2	1.684(2)	1.647(5)	1.658(3)	1.637(5)
2	N3−O1	1.379(2)	1.377(4)	1.369(3)	1.394(5)
3	S1−C2	1.714(2)	1.724(6)	1.730(3)	1.719(5)
4	S1−C5	1.711(3)	1.718(5)	1.717(3)	1.717(6)
5	C2−N3	1.339(3)	1.360(5)	1.353(3)	1.360(6)
6	N3−C4	1.395(3)	1.387(5)	1.395(3)	1.394(6)
7	C4−C5	1.337(3)	1.338(6)	1.338(4)	1.326(7)
8	N3−C2−S2	127.5(2)	127.6(4)	127.9(2)	127.1(4)
9	N3−C2−S1	108.0(2)	106.2(4)	107.2(2)	106.0(4)
10	C2−S1−C5	92.2(1)	93.0(2)	92.3(1)	92.7(3)
11	S1−C5−C4	112.4(2)	112.1(4)	112.6(2)	113.2(5)
12	C5−C4−N3	110.0(2)	110.0(4)	110.1(2)	108.8(5)
13	C4−N3−C2	117.4(2)	118.7(4)	117.8(2)	119.2(4)
14	C4−N3−O1	120.8(2)	121.1(3)	121.4(2)	121.1(3)
15	C2−N3−O1	121.8(2)	120.2(4)	120.7(2)	118.9(4)
16	N3-O1-C12,H1O	104(2)	111.7(3)	112.4(2)	113.2(4)
17	S2−C2−N3−C4	177.9(2)	177.5(4)	178.5(2)	−176.5(4)
18	S2−C2−N3−O1	−0.3(3)	0.0(6)	2.9(4)	7.7(7)
19	C2−N3−O1−C12,H1O	75.2(3)	−80.2(5)	−81.7(3)	−86.8(5)
20	N3−C4−C6−C7	−143.8(2)	44.5(6)	−138.6(3)	37.8(8)

ment resembles infinite double layers of π-stacked thiones. Both sulfur atoms of a given thione, i.e. S1 and S2, point towards the same edge of a double layer, which leads to the formation of sulfur-rich interfaces between two adjacent sheets of stacked thiazolethiones **9**. In this part of the crystal, short sulfur−sulfur distances are observed, which come close to, or are even less than, the sum of two sulfur van der Waals radii (1.85 ± 0.1 Å)[21] [S1−S1 = 3.78(1) Å, S1−S2 = 3.422(1) Å]. Intermolecular hydrogen bridges, as described above, are formed across the double layers of **9** from one stack to another. The fundamental connectivities of the thiohydroxamate group in *O*-esters **19c**, **19f** and in *O*-acetylthiazolethione **19k** are all of the same magnitude compared to data obtained for acid **9**. Bond lengths of the thiocarbonyl groups decrease slightly on going from acid **9** [C2−S2 = 1.684(2) Å] to *O*-esters **19c** and **19f** [**19c**: C2−S2 = 1.647(5) Å, **19f**: C2−S2 = 1.658(3) Å] and further to anhydride **19k** [C2−S2 = 1.637(5) Å]. On the other hand, N−O connectivities in thiones **9**, **19c**, and **19f** are comparable [**9**: N3−O1 = 1.379(2) Å, **19c**: N3−O1 = 1.377(4) Å, **19f**: N3−O1 = 1.369(3) Å], while the longest bond is observed in the *O*-acetyl derivative **19k** [N3−O1 = 1.394(5) Å]. In terms of magnitudes, these data are comparable to values obtained previously for 4-*tert*-butylcyclohexyl derivatives of *N*-(hydroxy)pyridine-2(1*H*)-thione.[20]

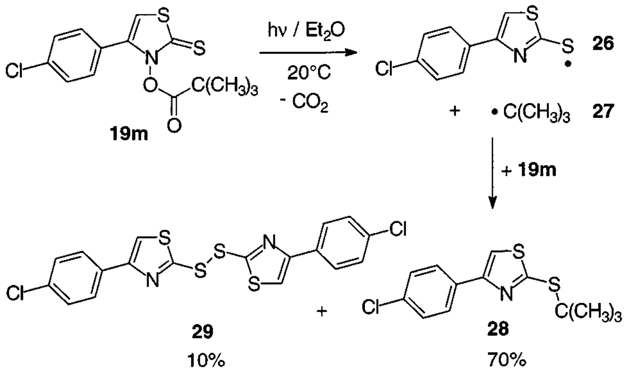
Substituents at O1 in compounds **19c**, **19f**, and in **19k** are twisted by between 80 and 87° out of the plane of the heterocycle (entry 19, Table 4). A similar structural motif has been observed in the pyridinethione series and was interpreted as a structural consequence of a minimization of lone pair repulsion on the adjacent nitrogen and oxygen atoms.[22] We feel that this picture also applies to thiazolethiones **19c**, **19f**, and **19k**. This phenomenon should in general lead to barriers to rotation about the N−O bonds,[23] which can be expected to be higher in 4-aryl-substituted thioazolethiones than in the respective pyridinethiones or pyridones.[24] However, steric congestion at the N−O face of **19f** due to the proximity of the thiocarbonyl group on one side and the twisted *p*-chlorophenyl group on the other is not sufficiently high such as to significantly slow the rate of rotation about the stereogenic N−O axis.[25] Thus, the resonances of the CH_3 group of the isopropoxy substituent are not split into two separate signals at T = 25°C.

Ellipsoid graphics of **9**, **19c**, **19f**, and **19k** in Figure 2 show that the *p*-chlorophenyl substituents are twisted from the planes of the *N*-substituted thiazolethione heterocycles by ca. ±40°. If the major conformers of esters **19**, and presumably also of derivatives **16**, **17**, **18**, and **20**, were to show similar torsional angles between the aryl and heteroaryl groups in solution, electronic interactions between the π-systems would be less than expected.

Generation of Alkoxyl Radicals from *N*-(Alkoxy)thiazolethiones 16−20

In an initial study, a yellowish solution of *O*-pivaloyl thiazolethione **19m** in diethyl ether was irradiated (Rayonet® chamber photoreactor equipped with 350-nm lamps) in order to probe the photochemical lability of thiones **19**. Anhydride **19m** was smoothly converted into thioether **28** (70% yield) with the loss of one equiv. of CO_2. That CO_2 had been produced was verified by passing a gentle stream of nitrogen first through the reaction mixture and then through an aqueous solution of $Ba(OH)_2$, which led to precipitation of $BaCO_3$ in the second chamber. The formation of minor amounts of bis(thiazyl) disulfide **29**[26] can be attributed to a combination of thiyl radicals **26** or to the addition of intermediate **26**, in competition with *tert*-butyl radical **27**, to thione **19m** as part of a radical chain reaction (Scheme 3; see also Figure 1).

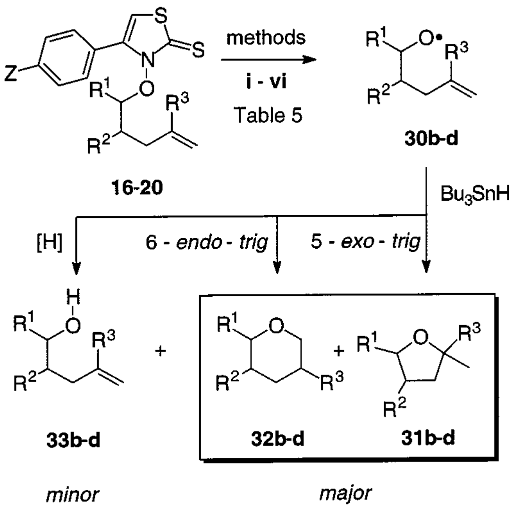
Next, *N*-(alkoxy)thiazolethiones **16**−**20** were investigated in order to evaluate their utility as sources of oxygen-cen-



Scheme 3. Decarboxylative rearrangement of *O*-pivaloyl thiazolethione **19m** into thioether **28**

tered free radicals. Previous work had indicated that at least three substituted 4-penten-1-oxyl radicals **30b−c** exist, which undergo distinctive cyclization reactions.[6] With regard to the stereo- and regioselectivity of the ring closures, these processes are markedly different from ionic processes[27]: (a) 2-Phenyl- and 1-phenyl-substituted 4-penten-1-oxyl radicals **30b** and **30c** undergo selective 5-*exo-trig* cyclizations to afford, after hydrogen trapping, substituted tetrahydrofurans **31** (**31b**: *cis*/*trans* = 88:12; **31c**: *cis*/*trans* = 50:50), along with a minor amount of tetrahydropyrans **32** (**31**/**32** ≈ 96:4 for **30b**; 98:2 for **30c**). (b) Ring-closure reactions of 4-phenyl-4-pentenyl-1-oxyl radicals **30d** proceed 6-*endo*-selectively and lead, after subsequent trapping with hydrogen donors such as Bu_3SnH, to 3-phenyltetrahydropyran (**32**) as the major product (**32b**/**31d** = 93:7).[6] Thus, 2-phenyl-4-penten-1-yl *O*-esters **16b−20b** (Z = OMe, Me, H, Cl, NO_2), *N*-(1-phenyl-4-penten-1-oxy)thiazolethione **19c**, and 4-phenyl-4-penten-1-yl ester **19d** were subjected to a series of photochemical and thermal transformations (Scheme 4, Table 5). Fundamental studies were carried out by irradiating 2-phenyl-4-pentenyl *O*-esters **16b−20b** in the presence of the hydrogen donor Bu_3SnH in a Rayonet® chamber photoreactor equipped with 350 nm lamps (Method i), as these conditions had been employed in preliminary studies.[16] Additionally, photochemical conversions using various light sources and Bu_3SnH as the radical trap (Methods i−v), as well as thermal reactions of *N*-(alkoxy)-*p*-(chlorophenyl)thiazolethiones **19b−d** and tri-*n*-butylstannane in the presence of 10% of the initiator AIBN (Method vi), were investigated. In a typical run, a degassed (Ar) solution of thione **16b−20b**, 10 equiv. of Bu_3SnH (c_o = 0.1 M)[6] in *tert*-butylbenzene (TBB) and an internal standard (n-$C_{14}H_{30}$) were subjected to photolysis. Immediately thereafter, the reaction mixture was subjected to GC analysis in order to determine product selectivities and yields. The identities of the products were established by co-elution with authentic samples[6] (Methods i−iv) or by isolating the major products **31** and **32** and subjecting them to ^1H-NMR analysis.

Photolysis of *N*-(alkoxy)thiazolethiones **16b−20b** and Bu_3SnH using 350 nm light (Method i) led to a smooth photodecomposition of the starting thiones and afforded cyclic ethers **31b** and **32b**. A minor amount of 2-phenylpentenol **33b** was detected, resulting from reduction of alkoxyl radicals **30b** prior to cyclization. The starting thiones **16b−19b** were usually consumed within 3 min at 20 °C, while 60 min of irradiation was required for complete photodecomposition of (*p*-nitrophenyl)thiazolethione **20b**. *cis*-4-Methyl-2-phenyltetrahydrofuran (*cis*-**31b**) was obtained as the major product (GC analysis, entries 1−10, Table 5; 32−62%). Typically, 1−3% of 3-phenyltetrahydropyran (**32b**) and 3−8% of 2-phenyl-4-pentenol (**33b**) were also detected. The *cis*/*trans* ratio of tetrahydrofuran **31b** (88:12) and the ratio of tetrahydrofuran **31b** to tetrahydropyran **32b** (96:4) were independent of the substituent Z on the starting thione. The observed product ratios pointed to the 2-phenyl-4-penten-1-oxyl radical (**30b**) as the reactive intermediate, which generally favours irreversible 5-*exo-trig* cyclization (*exo*/*endo* = 96:4) and, in particular, favours *cis*-5-*exo-trig* ring closure (**31b**: *cis*/*trans* = 88:12).[6,16] Thiazolethiones **16b−19b** (Z = OMe, Me, H, Cl) proved to be equally efficient sources of the alkoxyl radical **30b**, whereas the *p*-nitrophenyl derivative **20b** was less well suited for this purpose. Although thione **20b** was completely consumed in the photoreaction with Bu_3SnH, the conversion took significantly longer and the yields of cyclic ethers **31b** and **32b** were lower. Unfortunately, no additional products could be detected in this reaction mixture, which might have helped in delineating competing photoreaction pathways starting from **20b**.



30 - 33[a]	R1	R2	R3
b	H	Ph	H
c	Ph	H	H
d	H	H	Ph

[a] **32b** and **32d** are identical

Scheme 4. Preparation of cyclic ethers **31−32** from *N*-(alkoxy)thiazolethiones **16−20** by alkoxyl radical ring closures

In further mechanistic studies concerning *N*-(alkoxy)thiazolethiones we restricted ourselves to derivatives of 4-(*p*-chlorophenyl)-*N*-hydroxythiazole-2(3*H*)-thione (**9**) for three

Table 5. Yields of cyclic ethers **31−32** and alkenols **33** from photolyses and thermal reactions of thiazolethiones **16−20** and Bu_3SnH

Entry	**16−20**	R^1	R^2	R^3	Method[a]	**31**[b] (*cis*/*trans*)	**32**[b] (*exo*/*endo*)	**33**[b]
1	**16b**	H	Ph	H	**i**	62% (88:12)	3% (96:4)	6%
2	**17b**	H	Ph	H	**i**	59% (88:12)	2% (96:4)	3%
3	**18b**	H	Ph	H	**i**	61% (88:12)	3% (96:4)	4%
4	**19b**	H	Ph	H	**i**	57% (88:12)	2% (96:4)	4%
5	**19b**	H	Ph	H	**ii**	62% (88:12)	3% (95:5)	3%
6	**19b**	H	Ph	H	**iii**	57% (88:12)	2% (96:4)	4%
7	**19b**	H	Ph	H	**iv**	58% (88:12)	3% (96:4)	8%
8	**19b**	H	Ph	H	**v**	46% (87:13)	−	−
9	**19b**	H	Ph	H	**vi**	56% (83:17)	3% (95:5)	1%
10	**20b**[c]	H	Ph	H	**i**	32% (86:14)	2% (95:5)	7%
11	**19c**	Ph	H	H	**i**	67% (50:50)	4% (95:5)	13%
12	**19c**	Ph	H	H	**ii**	68% (50:50)	4% (95:5)	13%
13	**19c**	Ph	H	H	**iii**	74% (50:50)	2% (98:2)	10%
14	**19c**	Ph	H	H	**iv**	68% (50:50)	4% (95:5)	13%
15	**19c**	Ph	H	H	**v**	55% (50:50)	−	−
16	**19c**	Ph	H	H	**vi**	76% (50:50)	2% (98:2)	3%
17	**19d**	H	H	Ph	**i**	5%	63% (7:93)	7%
18	**19d**	H	H	Ph	**ii**	5%	67% (7:93)	1%
19	**19d**	H	H	Ph	**iii**	5%	60% (7:93)	5%
20	**19d**	H	H	Ph	**iv**	5%	69% (7:93)	8%
21	**19d**	H	H	Ph	**v**	−	47%	−
22	**19d**	H	H	Ph	**vi**	8%	73% (10:90)	−

Method	(i)	λ = 350 nm	(iv)	visible light (150-W, tungsten)
	(ii)	λ = 300nm	(v)	Method i preparative scale
	(iii)	visible light (250-W discharge lamp)	(vi)	T = 80°C/AIBN

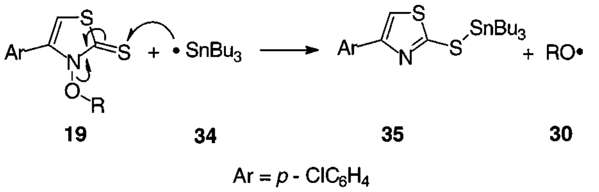
[a] All photoreactions, with the exception of Method (v) (benzene), were performed in *tert*-butylbenzene; Method (i): Rayonet® chamber photoreactor (350 nm); Method (ii): Rayonet® chamber photoreactor (300 nm); Method (iii): incandescent light (250-W discharge lamp); Method (iv): incandescent light (150-W tungsten); Method (v): preparative reaction, isolated yields; Method (vi): thermal reaction, T = 80°C, 45 min, 10 mol-% AIBN. − [b] GC yields other than data obtained using Method (v) (isolated yields); a detailed description of the analytical methods used is given in refs.[1a,6] − [c] 60 min photolysis; irradiation for 3 min afforded **31b** (17%, *cis*/*trans* = 86:14), **32b** (1%, *exo*/*endo* = 95:5), and **33b** (7%).

reasons: (i) Excellent synthetic access to acid **9** provided sufficient material not only for the present but also for future studies. (ii) *O*-Alkylation of (*p*-chlorophenyl)thiazolethione salts afforded *O*-esters **19**, which are convenient and safe to handle. Moreover, all *O*-esters **19** required for our study were available in good to satisfactory yields. (iii) The first set of photoreactions (Method i) had indicated *p*-chlorophenyl-*N*-(2-phenyl-4-penten-1-oxy)thiazolethione **19b** to be one of the most promising candidates in the synthesis of tetrahydrofuran **31b**. Thus, thiones **19b−c** were irradiated in a Rayonet chamber photoreactor using either 300-nm or 350-nm light, incandescent light (discharge lamp), or 150-W visible light (tungsten). In addition, the generation of alkoxyl radicals **30b−d** under thermal conditions from **19b−d** was investigated (Table 5).

Photoreaction of 1-phenyl-substituted ester **19c** and Bu_3SnH afforded 5-methyl-2-phenyltetrahydrofuran (**31c**) in 67−74% yield as the major product (*cis*/*trans* = 50:50; isolated yield 55%), along with 2−4% of 2-phenyltetrahydropyran (**32c**) and 10−13% of 1-phenylpentenol **33c**. In general, compounds **31c−33c** accounted for 84−86% of products derived from starting thione **19c** and, much to our surprise, the relative amounts were almost independent of the method used to initiate the radical chain reaction. Ratios of tetrahydrofuran **31c** to tetrahydropyran **32c** varied only from 95:5 to 98:2.

In addition to data obtained from photolysis of 2-phenyl-4-pentenyl ester **19b** and Bu_3SnH using a Rayonet® photoreactor equipped with 350-nm lamps (Method i), further photochemical and thermal reactions (Methods ii−vi) were carried out. Again, neither the yields nor the selectivities of products **31b−32b** seemed to be dependent on the method employed and 4-methyl-*cis*-2-phenyltetrahydrofuran (**31b**) was invariably favoured as the major product (*cis*/*trans* = 88:12). 3-Phenyltetrahydropyran (**32b**) was obtained as a side product (**31b**/**32b** = 96:4), along with 3−7% of pentenol **33b**.

Finally, (4-phenyl-4-pentenoxy)thiazolethione **19d** and Bu_3SnH were irradiated using four different sources of light (Methods i−v). These components were also heated in TBB (Method vi, 80°C, 10% AIBN). In all experiments, the major product was 3-phenyltetrahydropyran (**32b**) (60−73%; isolated yield 47%) besides 5% of 2-methyl-2-phenyltetrahydrofuran (**31d**) (**32b**/**31d** = 93:7) and 1−8% of 4-phenyl-4-pentenol (**33d**). Repeated chromatography of a non-polar fraction, obtained following photoreactions of phenylpentenyl esters **19b** and **19d** on a larger scale (Method v), afforded a new product as a colorless oil, which was identified as the tri-*n*-butyltin-substituted thiazole **35** (56%). The formation of organotin compound **35** can be rationalized in terms of the addition of stannyl radical **34** to the double bond of thione **19**, which corresponds to addition of $A^\bullet$ to a radical precursor, as outlined in Figure 1 and Scheme 5. Thus, thiazole derivative **35** represents an important *link*, providing evidence to support our mechanistic rationale of the photochemical synthesis of cyclic ethers from thiohydroxamic acid esters, e.g. **19** (Figure 1, Scheme 5).



Scheme 5. Proposed mechanism for the formation of stannylsulfanyl-substituted thiazolethione **35**

From the data relating to radical reactions involving *N*-(alkoxy)thiazolethiones (selectivities and yields) compiled in Table 5, it is clear that a number of useful methods (i−vi) exist for the transformation of thiazolethiones **19** via alkoxyl radical intermediates **30** into cyclic ethers. These findings should provide sufficient information for those who wish to use *N*-(alkoxy)-(*p*-chlorophenyl)thiazolethiones **19** in synthesis. Our choice to restrict our studies to chloro-substituted thiones **19** was made considering the overall advantages of **19** compared to derivatives **16**−**18**, **20**. Finally, we have listed a number of pros and cons of thiazole derivatives **19** compared to the corresponding *N*-(alkoxy)pyridinethiones[1a,8e] in Table 6. Although the advantages of *N*-(alkoxy)-(*p*-chlorophenyl)thiazolethiones **19** are obvious from Table 6, *N*-alkoxypyridine-2(1*H*)-thiones are still comparable to **19** with regard to their efficiency as sources of *O*-radicals.

Table 6. Comparison of properties of *N*-(alkoxy)-(*p*-chlorophenyl)-thiazole-2(3*H*)-thiones **19** with those of the corresponding *N*-(alkoxy)pyridine-2(1*H*)-thiones[a]

Criterion	*N*-(Alkoxy)-(*p*-chlorophenyl)-thiazole-2(3*H*)-thiones **19**	*N*-(Alkoxy)pyridine-2(1*H*)-thiones
Thiohydroxamic acid	Convenient large-scale synthesis	Sodium salt commercially available
Synthesis (yields)	+	+
Storage and handling	++	◇
Stability of *N*-benzyloxy derivatives	++	−
Efficiency as *O*-radical precursor	++	++

[a] ++ excellent, + good, ◇ satisfactory, − less than satisfactory.

Conclusion

N-Alkoxy-4-arylthiazolethiones **16**−**20** have been prepared in good yields and in useful quantities from *p*-substituted acetophenones. Based on the results of a detailed study of the physical (X-ray crystallography, NMR, and UV/Vis spectroscopy) and chemical properties of thiones **16**−**20**, *p*-chlorophenyl derivatives **19** were selected for further exploration of their utility as precursors of oxygen-centered radicals. Colorless crystalline esters **19** are sufficiently stable to allow storage in standard glassware without special protection from sunlight. On the other hand, thiazolethiones **19** efficiently liberate *free* alkoxyl radicals **30** upon irradiation or heating in the presence of Bu$_3$SnH as a radical trap. Reactive intermediates **30** undergo cyclization reactions, which have been used for the selective construction of tetrahydrofurans **31b**−**c** or tetrahydropyran **32b** in good yields. The convenience of thiazolethiones **19** in terms of ease of access, handling, and application in alkoxyl radical chemistry represents a considerable improvement when compared to the formerly used pyridinethiones (Table 6).

Experimental Section

General: Tri-*n*-butyltin hydride was purchased from Fluka (purum, 98%) and was used as received. The purity of the reagent was checked by NMR. *N*-Hydroxy-4-phenylthiazole-2(3*H*)-thione (**8**) was prepared as described previously.[15] Petroleum ether refers to the fraction boiling in the range 40−60°C. All solvents and reagents were purified according to standard procedures.[28] − Unless otherwise noted, NMR spectra were recorded in CDCl$_3$ solution. − UV spectra were measured in ethanol in 1-cm quartz cuvettes, while IR spectra were recorded in CCl$_4$ in NaCl cuvettes (0.5 mm) except where noted otherwise; the abbreviation CSNO denotes absorptions assigned to vibrations of the thiohydroxamate groups. − Melting (m.p.) or decomposition points (dec.) of thiazolethiones **6**−**10** and **16**−**20** were determined by differential thermal analysis (DTA) using a DuPont Thermal Analyzer 9000 at a scanning rate of 10°C min^{-1}; individual samples were sealed in metal containers under nitrogen. − GC analyses: Carlo Erba GC 6000 (Vega Series), FID, connected to Spectra Physics integrator 4290. Helium at a flow rate of 2 mL min^{-1} (equal to 80 kPa pressure) was used as carrier gas; injector and detector temperature 240°C; DB-225 column from J. & W. Scientific. − Photoreactions were carried out in Duran® glassware using a Rayonet® chamber photoreactor (RPR-100, Southern New England Ultraviolet, RPR 3500-Å and 3000-Å light lamps), 250-W visible-light discharge lamp (Osram Power Star HQI/D), or incandescent light (Philips 150-W Spotline® R80). − *N*-(Alkoxy)thiazolethiones **16**−**20** were found to be freely soluble in halogenated solvents (CH$_2$Cl$_2$, CHCl$_3$) and in THF, less soluble in aromatic solvents (benzene, toluene), and only sparingly soluble in diethyl ether, methyl *tert*-butyl ether (MTB) and hydrocarbons. Acids **6**−**10** show similar solubility characteristics, except that they are less soluble in halogenated solvents (CH$_2$Cl$_2$, CHCl$_3$). The *N*-hydroxy compounds **6**−**10** also dissolve in aqueous bases with the formation of salts (e.g. **11**−**15**). Addition of trifluoroacetic acid (1 equiv.) to a solution of (*p*-chlorophenyl)-*N*-hydroxythiazolethione **9** in CDCl$_3$ at 20°C did not lead to a measurable change in the chemical shifts (^{1}H and ^{13}C NMR) that might have indicated protonation of the thione. − Differential thermal analysis (DTA) showed thiazolethiones **16**−**20** to be thermally moderately stable. In general, solid samples of **16**−**20** subjected to DTA showed an exothermic signal (decomposition) immediately after melting (endothermic): 102 ± 2°C (**16a**, Z = OMe), 92 ± 2°C (**17a**, Z = Me), 46 ± 2°C (**18a**, Z = H). Thus, the melting points of thiazolethiones **16**−**20** served as useful guides for estimating their thermal stabilities as neat compounds. However, some thiones, e.g. **19a** (Z = Cl, dec. 121 ± 2°C), **20a** (Z = NO$_2$, dec. 151 ± 2°C) decomposed without melting.

1. Preparation of *O*-Ethyl *S*-(2-Aryl-2-oximinoethyl) Dithiocarbonates 1−5: A solution of the appropriate *p*-substituted ω-bromoacetophenone oxime[12,13,15−17] (33.9 mmol) in acetone (50 mL) was added dropwise to an ice-cooled suspension of potassium *O*-ethyl dithiocarbonate (5.98 g, 37.3 mmol) in acetone (40 mL). The reaction mixture was stirred for 4 h at 20°C and then concentrated to dryness. The residue was taken up in a minimum of diethyl ether and water. The yellow organic layer was washed with water, dried ($MgSO_4$), and the solvent was removed in vacuo to afford dithiocarbonate **1−5**, which was pure on the basis of NMR analysis. Analytical samples were obtained by recrystallization from toluene/*n*-pentane.

***O*-Ethyl *S*-[2-(*p*-Methoxyphenyl)ethyl-2-oximino] Dithiocarbonate (1):** Yield 8.01 g (88%), yellow solid, m.p. 85−90°C. − IR: $\tilde{\nu}$ = 3591 cm^{-1} (O−H), 3285 (=C−H), 2936, 2838 (C−H), 1608 (C=C). − ^1H NMR (250 MHz): δ = 1.40 (t, *J* = 7.3 Hz, 3 H, OCH_2CH_3), 3.84 (s, 3 H, $ArOCH_3$), 4.50 (s, 2 H, CH_2S), 4.66 (q, *J* = 7.3 Hz, 2 H, OCH_2CH_3), 6.90 (m_c, 2 H, Ar-H), 7.58 (m_c, 2 H, Ar-H). − ^{13}C NMR (100 MHz): δ = 13.7, 29.6, 55.5, 70.4, 114.3, 126.6, 127.9, 153.4, 161.0, 213.7. − MS (70 eV, EI); *m/z* (%): 285 (4) [M^+], 268 (20) [M^+ − OH], 224 (6) [$H_3CO(C_6H_4)C_3H_3NS_2^+$], 179 (40) [$H_3CO(C_6H_4)C_2H_2NS^+$], 164 (25) [$H_3CO(C_6H_4)C_2HS^+$], 133 (100) [$H_3CO(C_6H_4)CN^+$]. − $C_{12}H_{15}NO_3S_2$ (285.4): calcd. C 50.50, H 5.30, N 4.91, S 22.47; found C 50.70, H 5.34, N 4.91, S 22.35.

***O*-Ethyl *S*-[2-(*p*-Methylphenyl)ethyl-2-oximino] Dithiocarbonate (2):** Yield 8.42 g (87%), yellow solid, m.p. 105−109°C. − IR: $\tilde{\nu}$ = 3590 cm^{-1} (O−H), 3296 (=CH), 2982, 2928, 2866 (C−H), 1640 (C=C). − ^1H NMR (250 MHz): δ = 1.37 (t, *J* = 7.3 Hz, 3 H, OCH_2CH_3), 2.37 (s, 3 H, $ArCH_3$), 4.51 (s, 2 H, CH_2S), 4.65 (q, *J* = 7.3 Hz, 2 H, OCH_2CH_3), 7.20 (m_c, 2 H, Ar-H), 7.59 (m_c, 2 H, Ar-H). − ^{13}C NMR (100 MHz): δ = 13.7, 21.4, 29.8, 70.4, 126.2, 128.1, 129.4, 140.0, 154.0, 213.6. − MS (70 eV, EI); *m/z* (%): 269 (3) [M^+], 252 (43) [M^+ − OH], 208 (17) [$H_3C(C_6H_4)C_3H_3NS_2^+$], 163 (100) [$H_3C(C_6H_4)C_2H_2NS^+$], 118 (81) [$H_3C(C_6H_4)CHN^+$], 91 (53) [$H_3C(C_6H_4)^+$]. − $C_{12}H_{15}NO_2S_2$ (269.4): calcd. C 53.50, H 5.61, N 5.20, S 23.80; found C 53.24, H 5.63, N 5.21, S 23.66.

***O*-Ethyl *S*-[2-(*p*-Chlorophenyl)ethyl-2-oximino] Dithiocarbonate (4):** Yield 9.53 g (97%), yellow solid, m.p. 122−124°C. − IR: $\tilde{\nu}$ = 3587 cm^{-1} (O−H), 3298 (=C−H), 2934 (C−H), 1637 (C=C). − ^1H NMR (250 MHz): δ = 1.40 (t, *J* = 7.3 Hz, 3 H, OCH_2CH_3), 4.50 (s, 2 H, CH_2S), 4.65 (q, *J* = 7.3 Hz, 2 H, OCH_2CH_3), 7.36 (m_c, 2 H, Ar-H), 7.59 (m_c, 2 H, Ar-H), 8.40 (br. s, 1 H, OH). − ^{13}C NMR (100 MHz): δ = 13.7, 29.7, 70.6, 128.0, 128.9, 132.6, 136.0, 153.4, 213.3. − MS (70 eV, EI); *m/z* (%): 289 (3) [M^+], 272 (28) [M^+ − OH], 228 (21) [$ClC_6H_4C_3H_3NS_2^+$], 183 (46) [$ClC_6H_4C_2H_2NS^+$], 168 (20) [$ClC_6H_4C_2HS^+$], 138 (100) [$ClC_6H_4CHN^+$], 111 (38) [$ClC_6H_4^+$]. − $C_{11}H_{12}ClNO_2S_2$ (289.8): calcd. C 45.59, H 4.17, N 4.83, S 22.13; found C 45.81, H 4.11, N 4.77, S 21.93.

***O*-Ethyl *S*-[2-(*p*-Nitrophenyl)ethyl-2-oximino] Dithiocarbonate (5):** A solution of *p*-nitrophenacyl bromide oxime (11.6 g, 44.8 mmol) in dichloromethane (150 mL) was added to a suspension of potassium *O*-ethyl dithiocarbonate (7.91 g, 49.3 mmol) in dichloromethane (60 mL). The reaction was conducted and worked up as described in Section 1. Yield: 12.8 g (94%), yellow solid, m.p. 116−117°C. − ^1H NMR (250 MHz): δ = 1.41 (t, *J* = 7.2 Hz, 3 H, OCH_2CH_3), 4.56 (s, 2 H, CH_2S), 4.66 (q, *J* = 7.2 Hz, 2 H, OCH_2CH_3), 7.84 (m_c, 2 H, Ar-H), 8.24 (m_c, 2 H, Ar-H), 8.56 (br. s, 1 H, OH). − ^{13}C NMR (63 MHz): δ = 13.7, 29.5, 70.9, 123.8, 127.4, 140.0, 148.4, 152.8, 212.9. − MS (70 eV, EI); *m/z* (%): 300 (1) [M^+], 283 (37) [M^+ − OH], 195 (43) [$O_2N(C_6H_4)C_2H_3NS^+$], 149 (100) [$O_2N(C_6H_4)CHN^+$]. − $C_{11}H_{12}N_2O_4S_2$ (300.4): calcd. C 43.99, H 4.03, N 9.33, S 21.35; found C 44.11, H 3.89, N 9.20, S 20.98.

2. Preparation of 4-Aryl-*N*-Hydroxythiazole-2(3*H*)-thiones 6−10: A suspension of the appropriate dithiocarbonate **1−5** (15.0 mmol) in diethyl ether (9 mL) was cooled to 0°C. Anhydrous $ZnCl_2$ (6.15 g, 45.1 mmol) was then added in small portions and the brown reaction mixture was stirred for 14 h at 20°C, whereupon the viscous solution solidified. After the addition of a mixture of conc. aq. HCl (6.2 mL) and water (4.9 mL) and vigorous stirring at 20°C, the brown solid dissolved and a new precipitate of thione **6−10** formed within a few minutes. Stirring was continued for 1 h at 20°C, then the product was collected on a Buchner funnel and washed with cold diethyl ether (9 mL) to afford thione **6−10** as a tan-coloured powder. Unless otherwise noted, analytical samples of thiohydroxamic acids **6−10** were obtained by recrystallization from methanol.

***N*-Hydroxy-4-(*p*-methoxyphenyl)thiazole-2(3*H*)-thione (6):** Yield 2.18 g (60%), tan solid, m.p. 99 ± 2°C. − UV/Vis: λ_{max} (lg ε) = 309 sh (3.72), 263 nm (4.21). − IR: $\tilde{\nu}$ = 3298 cm^{-1} (=C−H), 3127, 2938, 2839 (C−H), 1612 (C=C), 1505 (C−N), 1299, 1254, 1179 (CSNO). − ^1H NMR (200 MHz): δ = 3.87 (s, 3 H, $ArOCH_3$), 6.57 (s, 1 H, 5-H), 7.00 (m_c, 2 H, Ar-H), 7.61 (m_c, 2 H, Ar-H), 10.05 (br. s, 1 H, OH). − ^{13}C NMR (100 MHz): δ = 55.4, 102.5, 114.4, 120.3, 129.5, 138.9, 161.2, 171.8. − MS (70 eV, EI); *m/z* (%): 239 (65) [M^+], 223 (32) [M^+ − O], 164 (100) [$H_3CO(C_6H_4)C_2HS^+$], 135 (24) [$H_3CO(C_6H_4)CH_2N^+$], 121 (17) [$H_3CO(C_6H_4)CH_2^+$]. − $C_{10}H_9NO_2S_2$ (239.3): calcd. C 50.19, H 3.79, N 5.85, S 26.80; found C 49.90, H 3.73, N 5.82, S 26.69.

***N*-Hydroxy-4-(*p*-methylphenyl)thiazole-2(3*H*)-thione (7):** Yield 2.48 g (74%), tan solid, dec. 164 ± 2°C. − UV/Vis: λ_{max} (lg ε) = 309 (4.10), 240 nm (4.17). − IR: $\tilde{\nu}$ = 3296 cm^{-1} (=C−H), 2927, 2855 (−C−H), 1640 (C=C), 1498 (C−N), 1298, 1220, 1166 (CSNO). − ^1H NMR (250 MHz): δ = 2.42 (s, 3 H, $ArCH_3$), 6.64 (s, 1 H, 5-H), 7.29 (m_c, 2 H, Ar-H), 7.52 (m_c, 2 H, Ar-H), 10.03 (br. s, 1 H, OH). − ^{13}C NMR (100 MHz, [D_6]DMSO): δ = 20.6, 104.8, 125.8, 127.9, 128.8, 138.9, 141.3, 178.9. − MS (70 eV, EI); *m/z* (%): 223 (63) [M^+], 207 (25) [M^+ − O], 206 (11) [M^+ − OH], 148 (100) [$H_3C(C_6H_4)C_2HS^+$], 147 (30) [$H_3C(C_6H_4)C_2S^+$]. − $C_{10}H_9NOS_2$ (223.3): calcd. C 53.78, H 4.06, N 6.27, S 28.72; found C 53.96, H 4.02, N 6.17, S 28.76.

4-(*p*-Chlorophenyl)-*N*-hydroxythiazole-2(3*H*)-thione (9): Yield 3.25 g (89%), yellow-green solid, dec. 138 ± 2°C. − UV/Vis: λ_{max} (lg ε) = 309 (4.16), 240 nm (4.20). − IR: $\tilde{\nu}$ = 3580 cm^{-1} (O−H), 3297 (=C−H), 3124, 2942 (C−H), 1638 (C=C), 1488 (C−N), 1301, 1214, 1174 (CSNO). − ^1H NMR (250 MHz): δ = 6.68 (s, 1 H, 5-H), 7.47 (m_c, 2 H, Ar-H), 7.62 (m_c, 2 H, Ar-H), 11.72 (br. s, 1 H, OH). − ^{13}C NMR (100 MHz, [D_6]DMSO): δ = 106.4, 127.6, 128.7, 130.1, 134.4, 140.3, 179.2. − MS (70 eV, EI); *m/z* (%): 243 (80) [M^+], 226 (13) [M^+ − OH], 191 (25) [M^+ − OH − Cl], 168 (100) [$ClC_6H_4C_2HS^+$]. − $C_9H_6ClNOS_2$ (243.7): calcd. C 44.35, H 2.48, N 5.75, S 26.31; found C 44.35, H 2.47, N 5.74, S 26.39.

***N*-Hydroxy-4-(*p*-nitrophenyl)thiazole-2(3*H*)-thione (10):** An analytical sample of **10** was recrystallized from toluene: Yield 2.60 g (57%), yellow solid. − UV/Vis: λ_{max} (lg ε) = 400 (3.28) sh, 322 (4.29), 242 nm (4.19). − IR: $\tilde{\nu}$ = 3580 cm^{-1} (O−H), 3296 (=C−H), 2931, 2850, 2356 (C−H), 1638 (C=C), 1543 (N=O), 1461 (C−N), 1349 (N=O), 1302, 1214 (CSNO). − ^1H NMR (250 MHz): δ = 6.93 (s, 1 H, 5-H), 7.94 (m_c, 2 H, Ar-H), 8.35 (m_c, 2 H, Ar-H). − ^{13}C NMR (63 MHz, [D_6]DMSO): δ = 109.1, 123.7, 129.3, 134.4, 139.3, 147.5, 179.4. − MS (70 eV, EI); *m/z* (%): 254 (92) [M^+], 238 (100) [M^+ − O], 191 (62). − $C_9H_6N_2O_3S_2$ (254.3): calcd. C 42.51, H 2.38, N 11.02, S 25.22; found C 42.48, H 2.53, N 10.86, S 24.65. − HRMS: *m/z* calcd. 253.9820; found 253.9824.

3. Preparation of 4-Aryl-*N*-hydroxythiazole-2(3*H*)-thione Salts 11−15: Equimolar amounts of the appropriate acid **6−10** (2.2 mmol) and tetraethylammonium hydroxide [1.5 mL, 2.2 mmol, 25% solution in methanol, (*w*/*w*), Fluka], tetrabutylammonium hydroxide [2.8 mL, 2.2 mmol, 25% solution in methanol, (*w*/*w*), Fluka] or potassium hydroxide (120 mg, 2.2 mmol) were stirred in methanol (total volume 10 mL) for 1 h at 20°C. The solvent was then removed in vacuo and the remaining brown residue was freeze-dried for 3−4 d (10^{-3} mbar) to afford the respective thiohydroxamate salt **11−15** in quantitative yield.

***N*-Hydroxy-4-(*p*-methoxyphenyl)thiazole-2(3*H*)-thione Tetrabutylammonium Salt (11c):** ^{1}H NMR (200 MHz): δ = 0.95 (t, J = 7.2 Hz, 12 H), 1.36 (m_c, 8 H), 1.46−1.67 (m, 8 H), 3.30 (m_c, 8 H), 3.79 (s, 3 H), 6.54 (s, 1 H), 6.87 (m_c, 2 H), 7.84 (m_c, 2 H). − ^{13}C NMR (100 MHz): δ = 13.5, 19.6, 24.0, 55.2, 58.8, 102.4, 113.4, 123.5, 129.5, 143.3, 159.9, 162.5. − $C_{26}H_{44}N_2O_2S_2$ (480.77).

***N*-Hydroxy-4-(*p*-methylphenyl)thiazole-2(3*H*)-thione Tetrabutylammonium Salt (12c):** ^{1}H NMR (200 MHz): δ = 0.96 (t, J = 7.2 Hz, 12 H), 1.39 (m_c, 8 H), 1.53−1.68 (m, 8 H), 2.34 (s, 3 H), 3.31 (m_c, 8 H), 6.67 (s, 1 H), 7.16 (m_c, 2 H), 7.74 (m_c, 2 H). − ^{13}C NMR (50 MHz): δ = 13.2, 19.1, 20.9, 23.4, 58.1, 103.2, 127.1, 127.6, 128.3, 138.2, 142.7, 161.6. − $C_{26}H_{44}N_2OS_2$ (464.8).

***N*-Hydroxy-4-phenylthiazole-2(3*H*)-thione Tetrabutylammonium Salt (13c):** ^{1}H NMR (200 MHz): δ = 0.94 (t, J = 7.2 Hz, 12 H), 1.37 (m_c, 8 H), 1.51−1.66 (m, 8 H), 3.33 (m_c, 8 H), 6.54 (s, 1 H), 7.32 (m_c, 3 H), 7.85 (m_c, 2 H). − ^{13}C NMR (100 MHz): δ = 13.5, 19.6, 24.0, 58.7, 103.0, 127.9, 128.1, 128.6, 130.0, 143.0. − $C_{25}H_{42}N_2OS_2$ (450.7).

4-(*p*-Chlorophenyl)-*N*-hydroxythiazole-2(3*H*)-thione Potassium Salt (14a): ^{1}H NMR (250 MHz, [D$_6$]DMSO): δ = 6.98 (s, 1 H), 7.43 (m_c, 2 H), 8.00 (m_c, 2 H). − ^{13}C NMR (100 MHz, CDCl$_3$/[D$_6$]DMSO): δ = 103.8, 127.4, 129.2, 129.6, 132.6, 141.6, 169.2. − $C_9H_5ClKNOS_2$ (281.8).

4-(*p*-Chlorophenyl)-*N*-hydroxythiazole-2(3*H*)-thione Tetraethylammonium Salt (14b): ^{1}H NMR (250 MHz): δ = 1.21 (t, J = 7.2 Hz, 12 H), 3.28 (q, J = 7.2 Hz, 8 H), 6.53 (s, 1 H), 7.26 (m_c, 2 H), 7.77 (m_c, 2 H). − ^{13}C NMR (50 MHz): δ = 7.3, 52.3, 104.1, 127.9, 129.2, 129.5, 133.8, 142.6, 164.5. − UV/Vis: λ_{max} (lg ε) = 300 (3.86), 260 nm (3.97). − $C_{17}H_{25}ClN_2OS_2$ (373.0).

4-(*p*-Chlorophenyl)-*N*-hydroxythiazole-2(3*H*)-thione Tetrabutylammonium Salt (14c): ^{1}H NMR (200 MHz): δ = 0.95 (t, J = 7.2 Hz, 12 H), 1.38 (m_c, 8 H), 1.52−1.67 (m, 8 H), 3.31 (m_c, 8 H), 6.62 (s, 1 H), 7.27 (m_c, 2 H), 7.85 (m_c, 2 H). − ^{13}C NMR (100 MHz): δ = 13.8, 20.0, 24.4, 59.2, 104.4, 128.4, 129.5, 129.7, 134.8, 142.4, 163.6. − $C_{25}H_{41}ClN_2OS_2$ (485.2).

***N*-Hydroxy-4-(*p*-nitrophenyl)thiazole-2(3*H*)-thione Tetrabutylammonium Salt (15c):** ^{1}H NMR (200 MHz): δ = 0.96 (t, J = 7.2 Hz, 12 H), 1.42 (m_c, 8 H), 1.49−1.73 (m, 8 H), 3.35 (m_c, 8 H), 6.77 (s, 1 H), 8.17 (s, 4 H). − ^{13}C NMR (50 MHz): δ = 13.5, 19.6, 23.9, 58.6, 106.7, 123.0, 128.5, 136.7, 141.0, 147.0. − $C_{25}H_{41}N_3O_3S_2$ (495.74).

4. Preparation of *N*-Alkoxy-4-arylthiazole-2(3*H*)-thiones 16−20: A flame-dried, round-bottomed flask was charged with the appropriate 4-aryl-*N*-hydroxythiazole-2(3*H*)-thione tetrabutylammonium salt **11c−15c** (2.20 mmol) and a solution of 1-chloro-1-phenylethane (309 mg, 2.20 mmol) in anhydrous DMF (11 mL) under argon. The reaction mixture was stirred for 4−7 d in the dark, then poured into water (40 mL), and extracted with diethyl ether (2 × 40 mL). The organic layer was washed with 2 N aqueous sodium hydroxide (30 mL) and dried (MgSO$_4$). The solvent was removed in vacuo at 40°C to afford a brown oil, which, unless noted otherwise, was purified by column chromatography (SiO$_2$) with dichloromethane as eluent.

***N*-(1-Ethoxy-1-phenyl)-4-(*p*-methoxyphenyl)thiazole-2(3*H*)-thione (16a):** Yield: 355 mg (47%); colourless solid, m.p. 102 ± 2°C, R_f = 0.47 diethyl ether/petroleum ether, 1:1 (*v*/*v*)]. − UV/Vis: λ_{max} (lg ε) = 320 (3.94), 250 nm (3.95). − IR: $\tilde{\nu}$ = 3300 cm^{-1} (=C−H), 3067, 3038, 2986, 2935, 2838 (C−H), 1613 (C=C), 1505 (C−N), 1302 (CSNO), 1286 (C−O), 1252, 1177 (CSNO). − ^{1}H NMR (200 MHz): δ = 1.52 (d, J = 6.6 Hz, 3 H, 2-H), 3.86 (s, 3 H, Ar-OCH$_3$), 6.16 (q, J = 6.6 Hz, 1 H, 1-H), 6.17 (s, 1 H, 5′-H), 6.81−7.23 (m, 9 H, Ar-H). − ^{13}C NMR (100 MHz): δ = 18.4, 55.4, 82.4, 103.0, 113.8, 121.7, 128.1, 128.2, 128.9, 130.0, 137.2, 142.7, 160.5, 180.7. − MS (70 eV, EI); *m*/*z* (%): 343 (1) [M^{+}], 239 (3) [M^{+} − C_8H_8], 223 (8) [M^{+} − C_8H_8O], 164 (4) [$H_3CO(C_6H_4)C_2HS^{+}$], 120 (37) [$PhC_2H_3O^{+}$], 105 (100) [$PhCO^{+}$], 77 (73) [$C_6H_5^{+}$]. − $C_{18}H_{17}NO_2S_2$ (343.5): calcd. C 62.95, H 4.99, N 4.08, S 18.67; found C 62.70, H 4.93, N 4.16, S 18.86.

***N*-(1-Ethoxy-1-phenyl)-4-(*p*-methylphenyl)thiazole-2(3*H*)-thione (17a):** Yield: 360 mg (50%), colourless solid, m.p. 92 ± 2°C, R_f = 0.35 (CH$_2$Cl$_2$). − UV/Vis: λ_{max} (lg ε) = 320 (4.07), 240 nm (4.04). − IR: $\tilde{\nu}$ = 3302 cm^{-1} (=C−H), 3116, 3006, 3034, 2981, 2935, 2868 (C−H), 1640 (C=C), 1505 (C−N), 1312 (CSNO), 1300 (C=O), 1218, 1166 (CSNO). − ^{1}H NMR (400 MHz): δ = 1.50 (d, J = 6.6 Hz, 3 H, 2-H), 2.40 (s, 3 H, ArCH$_3$), 6.14 (q, J = 6.6 Hz, 1 H, 1-H), 6.21 (s, 1 H, 5′-H), 6.90−7.24 (m, 9 H, Ar-H). − ^{13}C NMR (100 MHz): δ = 18.4, 21.3, 82.5, 103.6, 126.2, 128.1, 128.2, 128.4, 128.9, 137.1, 139.4, 142.9, 180.7. − MS (70 eV, EI); *m*/*z* (%): 327 (2) [M^{+}], 223 (30) [M^{+} − C_8H_8], 207 (41) [M^{+} − C_8H_8O], 148 (38) [$H_3C(C_6H_4)C_2HS^{+}$], 120 (12) [$PhC_2H_3O^{+}$], 105 (100) [$PhCO^{+}$], 77 (42) [$C_6H_5^{+}$]. − $C_{18}H_{17}NOS_2$ (327.5): calcd. C 66.02, H 5.23, N 4.28, S 19.58; found C 66.16, H 5.17, N 4.28, S 19.49.

***N*-(1-Ethoxy-1-phenyl)-4-phenylthiazole-2(3*H*)-thione (18a):** Yield: 448 mg (65%), colourless solid, m.p. 46 ± 2°C, R_f = 0.42 (CH$_2$Cl$_2$). − UV/Vis: λ_{max} (lg ε) = 320 (4.15), 230 nm (4.13). − IR: $\tilde{\nu}$ = 3298 cm^{-1} (=C−H), 3066, 3037, 2986, 2935 (C−H), 1637 (C=C), 1492 (C−N), 1299, 1213, 1166 (CSNO). − ^{1}H NMR (200 MHz): δ = 1.53 (d, J = 6.6 Hz, 3 H, 2-H), 6.14 (q, J = 6.6 Hz, 1 H, 1-H), 6.25 (s, 1 H, 5′-H), 6.90−7.35 (m, 10 H, Ph-H). − ^{13}C NMR (100 MHz): δ = 18.4, 82.6, 104.1, 128.1, 128.2, 128.2, 128.5, 128.9, 129.2, 137.0, 142.9, 180.8. − MS (70 eV, EI); *m*/*z* (%): 313 (2) [M^{+}], 209 (24) [M^{+} − C_8H_8], 193 (27) [M^{+} − C_8H_8O], 134 (29) [PhC_2HS^{+}], 120 (10) [$PhC_2H_3O^{+}$], 105 (100) [$PhCO^{+}$], 77 (44) [$C_6H_5^{+}$]. − $C_{17}H_{15}NOS_2$ (313.4): calcd. C 65.14, H 4.82, N 4.47, S 20.46; found C 65.32, H 4.84, N 4.47, S 20.21.

4-(*p*-Chlorophenyl)-*N*-(1-ethoxy-1-phenyl)thiazole-2(3*H*)-thione (19a): Yield: 513 mg (67%), colourless solid, dec. 121 ± 2°C, R_f = 0.66 (CH$_2$Cl$_2$). − UV/Vis: λ_{max} (lg ε) = 320 (3.96), 240 nm (3.95). − IR: $\tilde{\nu}$ = 3296 cm^{-1} (=C−H), 3117, 3067, 3037, 2987, 2936, 2868 (C−H), 1639 (C=C), 1487 (C−N), 1300 (CSNO), 1296 (C=O), 1213, 1166 (CSNO). − ^{1}H NMR (200 MHz): δ = 1.57 (d, J = 6.6 Hz, 3 H, 2-H), 6.12 (q, J = 6.6 Hz, 1 H, 1-H), 6.23 (s, 1 H, 5′-H), 6.89−7.24 (m, 9 H, Ar-H). − ^{13}C NMR (100 MHz): δ = 18.3, 82.8, 104.3, 126.5, 127.4, 128.2, 128.5, 129.1, 129.7, 135.4, 136.8, 141.7, 180.8. − MS (70 eV, EI); *m*/*z* (%): 347 (1) [M^{+}], 243 (14) [M^{+} − C_8H_8], 227 (30) [M^{+} − C_8H_8O], 168 (15) [$ClC_6H_4C_2HS^{+}$], 120 (12) [$PhC_2H_3O^{+}$], 105 (100) [$PhCO^{+}$]. − $C_{17}H_{14}ClNOS_2$ (347.9): calcd. C 58.69, H 4.06, N 4.03, S 18.43; found C 58.43, H 4.16, N 4.00, S 18.79.

4-(*p*-Chlorophenyl)-2-(1-phenylethyl-1-sulfanyl)thiazole *N*-Oxide (24a): Yield: 15.0 mg (2%), colourless solid, m.p. 153 ± 2°C, R_f = 0.91 (CH$_2$Cl$_2$). − UV/Vis: λ_{max} (lg ε) = 293 (3.82) sh, 255 nm (4.31). − IR: $\tilde{\nu}$ = 3245 cm^{-1} (=C−H), 2977, 2928, 2867 (C−H), 1638 (C=C), 1486 (C−N), 1261 (N−O). − ^{1}H NMR (250 MHz): δ = 1.72 (d, J = 7.0 Hz, 3 H, CH$_3$), 5.12 (q, J = 7.0 Hz, 1 H, 1-H), 7.28−7.37 (m, 6 H, Ph-H, 5′-H), 7.44 (m_c, 2 H, Ar-H), 7.86 (m_c, 2 H, Ar-H). − ^{13}C NMR (100 MHz): δ = 21.5, 45.6, 114.6, 127.4, 127.9, 128.7, 128.8, 129.5, 135.9, 141.5, 146.0. − MS (70 eV, EI); *m/z* (%): 331 (1) $[M^+ - OH]$, 227 (12) $[M^+ - C_8H_8O]$, 139 (31) $[ClC_6H_4CHN^+]$, 105 (100) $[PhCO^+]$. − $C_{17}H_{14}ClNOS_2$ (347.9): calcd. C 58.69, H 4.06, N 4.03, S 18.43; found C 58.43, H 4.29, N 3.97, S 17.98.

***N*-(1-Ethoxy-1-phenyl)-4-(*p*-nitrophenyl)thiazole-2(3*H*)-thione (20a):** A solution of tetrabutylammonium salt **15c** (982 mg, 1.98 mmol) and 1-chloro-1-phenylethane (278 mg, 1.98 mmol) in anhydrous DMF (10 mL) was reacted a described in Section 4, with the sole modification that dichloromethane was used to extract the product instead of diethyl ether. Yield: 504 mg (64%), yellow solid, dec. 151 ± 2°C, $R_f = 0.41$ (CH_2Cl_2). − UV/Vis: λ_{max} (lg ε) = 370 (3.70) sh, 325 (4.13), 255 nm (3.89). − IR: $\tilde{\nu} = 3299\ cm^{-1}$ (=C−H), 2927, 2855 (C−H), 1528 (N=O), 1459 (C−N), 1348 (N=O), 1302, 1208, 1165 (CSNO). − ^1H NMR (200 MHz): δ = 1.64 (d, *J* = 6.7 Hz, 3 H, 2-H), 6.12 (q, *J* = 6.7 Hz, 1 H, 1-H), 6.37 (s, 1 H, 5′-H), 6.85−7.25 (m, 7 H, Ar-H), 8.13 (m_c, 2 H, Ar-H). − ^{13}C NMR (63 MHz): δ = 18.0, 83.0, 106.5, 123.3, 128.3, 129.0, 129.4, 134.4, 136.2, 140.4, 147.6, 180.7. − MS (70 eV, EI); *m/z* (%): 238 (4) $[M^+ - C_8H_8O]$, 120 (32) $[PhC_2H_3O^+]$, 105 (100) $[PhCO^+]$. − $C_{17}H_{14}N_2O_3S_2$ (358.4): calcd. C 56.97, H 3.94, N 7.82, S 17.89; found C 56.62, H 4.00, N 7.80, S 17.56.

5. Preparation of 4-Aryl-*N*-(2-Phenyl-4-penten-1-oxy)thiazole-2(3*H*)-thiones 16b−20b: The appropriate anhydrous tetrabutylammonium salt **11c−15c** (2.40 mmol) was dissolved in dry DMF (10 mL) and treated with 2-phenyl-4-penten-1-yl tosylate (759 mg, 2.40 mmol) at 25°C under argon in the absence of moisture. The reaction mixture was stirred for 4−7 d in the dark, then poured into water (40 mL), and extracted with diethyl ether (2 × 40 mL). The combined organic phases were washed with 2 N aqueous sodium hydroxide (30 mL), dried ($MgSO_4$), and concentrated in vacuo at 40°C to afford a brown oil, which, unless otherwise noted, was purified by column chromatography (SiO_2) with dichloromethane as eluent. Analytical samples of thiones **16−20** were obtained by recrystallization from diethyl ether/*n*-pentane.

4-(*p*-Methoxyphenyl)-*N*-(2-phenyl-4-penten-1-oxy)thiazole-2(3*H*)-thione (16b): Yield: 193 mg (21%), tan-coloured oil, $R_f = 0.38$ diethyl ether/petroleum ether, 1:1 (*v*/*v*)]. − UV/Vis: λ_{max} (lg ε) = 320 (4.11), 252 nm (4.13). − IR: $\tilde{\nu} = 3300\ cm^{-1}$ (=C−H), 3066, 3031, 2934, 2838 (C−H), 1642 (C=C), 1505 (C−N), 1305 (CSNO), 1288 (C=O), 1254, 1178 (CSNO). − ^1H NMR (250 MHz): δ = 2.33 (dt, J_d = 14.0 Hz, J_t = 5.8 Hz, 1 H, 3-H), 2.56 (dt, J_d = 14.0 Hz, J_t = 7.0 Hz, 1 H 3-H), 3.13 (m_c, 1 H, 2-H), 3.88 (s, 3 H, $ArOCH_3$), 4.15 (t, *J* = 7.0 Hz, 1 H, 1-H), 4.33 (t, *J* = 7.0 Hz, 1 H, 1-H), 4.92−5.00 (m, 2 H, 5-H), 5.62 (ddt, J_d = 10.1, 16.9 Hz, J_t = 7.0 Hz, 1 H, 4-H), 6.39 (s, 1 H, 5′-H), 6.82 (m_c, 2 H, Ar-H), 7.05−7.09 (m, 2 H, Ph-H), 7.24−7.36 (m, 5 H, Ph-H, Ar-H). − ^{13}C NMR (50 MHz): δ = 36.7, 44.1, 55.3, 78.8, 103.6, 114.1, 116.8, 120.8, 126.7, 127.9, 128.3, 129.6, 135.4, 140.4, 140.8, 160.7, 180.4. − MS (70 eV, EI); *m/z* (%): 223 (2) $[M^+ - C_{11}H_{12}O]$, 160 (3) $[C_{11}H_{12}O^+]$, 131 (100) $[C_{10}H_{11}{}^+]$, 103 (11) $[C_8H_7{}^+]$, 91 (88) $[C_7H_7{}^+]$. − $C_{21}H_{21}NO_2S_2$ (383.5): calcd. C 65.76, H 5.52, N 3.65, S 16.72; found C 64.71, H 5.48, N 3.51, S 15.51.

4-(*p*-Methylphenyl)-*N*-(2-phenyl-4-penten-1-oxy)thiazole-2(3*H*)-thione (17b): Yield 168 mg (19%), colourless solid, m.p. 74 ± 2°C, $R_f = 0.58$ (CH_2Cl_2). − UV/Vis: λ_{max} (lg ε) = 320 (4.11), 240 nm (4.09). − IR: $\tilde{\nu} = 3296\ cm^{-1}$ (=C−H), 3066, 3031, 2978, 2933 (C−H), 1641 (C=C), 1505 (C−N), 1313 (CSNO), 1301 (C=O), 1220, 1167 (CSNO). − ^1H NMR (400 MHz): δ = 2.28 (dt, J_d = 15.3 Hz, J_t = 7.4 Hz, 1 H, 3-H), 2.39 (s, 3 H, $ArCH_3$), 2.51 (dt, J_d = 15.3 Hz, J_t = 6.9 Hz, 1 H, 3-H), 3.07 (m_c, 1 H, 2-H), 4.12 (t, *J* = 6.9 Hz, 1 H, 1-H), 4.29 (t, *J* = 6.9 Hz, 1 H, 1-H), 4.89−4.94 (m, 2 H, 5-H), 5.57 (ddt, J_d = 17.1, 10.1 Hz, J_t = 6.9 Hz, 1 H, 4-H), 6.40 (s, 1 H, 5′-H), 7.01−7.33 (m, 9 H, Ar-H). − ^{13}C NMR (50 MHz): δ = 21.4, 36.7, 44.1, 78.9, 104.3, 116.8, 125.0, 126.7, 127.9, 128.0, 128.3, 129.4, 135.4, 140.0, 140.3, 141.1, 180.6. − MS (70 eV, EI); *m/z* (%): 368 (1) $[M^+]$, 223 (8) $[M^+ - C_{11}H_{12}]$, 207 (100) $[M^+ - C_{11}H_{12}O]$, 91 (51) $[C_7H_7{}^+]$. − $C_{21}H_{21}NOS_2$ (367.5): calcd. C 68.63, H 5.76, N 3.81, S 17.45; found C 68.36, H 5.93, N 3.51, S 17.31.

4-Phenyl-*N*-(2-phenyl-4-penten-1-oxy)thiazole-2(3*H*)-thione (18b): Yield: 500 mg (59%), colourless solid, m.p. 38 ± 2°C, $R_f = 0.45$ (CH_2Cl_2). − UV/Vis: λ_{max} (lg ε) = 320 (4.03), 230 nm (4.00). − IR: $\tilde{\nu} = 3300\ cm^{-1}$ (=C−H), 3065, 3031, 2979, 2870 (C−H), 1641 (C=C), 1491 (C−N), 1318 (CSNO), 1300 (C=O), 1214, 1168 (CSNO). − ^1H NMR (400 MHz): δ = 2.28 (dt, J_d = 14.7 Hz, J_t = 7.4 Hz, 1 H, 3-H), 2.51 (dt, J_d = 14.7 Hz, J_t = 7.0 Hz, 1 H, 3-H), 3.06 (m_c, 1 H, 2-H), 4.15 (t, *J* = 7.3 Hz, 1 H, 1-H), 4.27 (t, *J* = 7.3 Hz, 1 H, 1-H), 4.88−4.94 (m, 2 H, 5-H), 5.54 (ddt, J_d = 10.3, 16.9 Hz, J_t = 7.0 Hz, 1 H, 4−H), 6.44 (s, 1 H, 5-H), 7.01−7.46 (m, 9 H, Ar-H). − ^{13}C NMR (100 MHz): δ = 36.7, 44.2, 79.0, 104.8, 116.8, 126.8, 127.9, 128.3, 128.4, 128.8, 129.9, 135.4, 140.3, 141.1, 180.7. − MS (70 eV, EI); *m/z* (%): 209 (4) $[M^+ - C_{11}H_{12}]$, 131 (100) $[C_{10}H_{11}{}^+]$, 91 (89) $[C_7H_7{}^+]$. − $C_{20}H_{19}NOS_2$ (353.5): calcd. C 67.95, H 5.42, N 3.96, S 18.14; found C 67.69, H 5.48, N 3.91, S 18.17.

4-(*p*-Chlorophenyl)-*N*-(2-phenyl-4-penten-1-oxy)thiazole-2(3*H*)-thione (19b): Yield: 419 mg (45%), dec. 88 ± 2°C, colourless solid, $R_f = 0.54$ (CH_2Cl_2). − UV/Vis: λ_{max} (lg ε) = 320 (4.20), 235 nm (4.13). − IR: $\tilde{\nu} = 3297\ cm^{-1}$ (=C−H), 3066, 3031, 2931 (C−H), 1641 (C=C), 1487 (C−N), 1307 (CSNO), 1289 (C−O), 1214, 1168 (CSNO). − ^1H NMR (200 MHz): δ = 2.30 (dt, J_d = 14.4 Hz, J_t = 6.5 Hz, 1 H, 3-H), 2.49 (dt, J_d = 14.4 Hz, J_t = 7.2 Hz, 1 H, 3-H), 3.09 (m_c, 1 H, 2-H), 4.05 (t, *J* = 7.0 Hz, 1 H, 1-H), 4.40 (dd, *J* = 1.5, 7.0 Hz, 1 H, 1-H), 4.95−5.00 (m, 2 H, 5-H), 5.60 (ddt, J_d = 10.4, 16.9 Hz, J_t = 6.5 Hz, 1 H, 4-H), 6.44 (s, 1 H, 5′-H), 6.98−7.30 (m, 9 H, Ar-H). − ^{13}C NMR (100 MHz): δ = 36.6, 44.0, 79.0, 105.1, 116.9, 126.0, 126.8, 127.7, 128.4, 128.7, 129.0, 129.3, 135.2, 139.8, 140.3, 180.7. − MS (70 eV, EI); *m/z* (%): 227 (5) $[M^+ - C_{11}H_{12}O]$, 131 (100) $[C_{10}H_{11}{}^+]$, 91 (99) $[C_7H_7{}^+]$. − $C_{20}H_{18}ClNOS_2$ (388.0): calcd. C 61.92, H 4.68, N 3.61, S 16.53; found C 61.74, H 4.77, N 3.75, S 16.39.

4-(*p*-Nitrophenyl)-*N*-(2-phenyl-4-penten-1-oxy)thiazole-2(3*H*)-thione (20b): Thione **20b** was prepared as described in Section 5, with the sole modification that dichloromethane was used to extract the product instead of diethyl ether. Yield: 497 mg (52%), dec. 96 ± 2°C, yellow solid, $R_f = 0.48$ (CH_2Cl_2). − UV/Vis: λ_{max} (lg ε) = 370 sh (3.61), 320 (4.03), 254 nm (3.87). − IR: $\tilde{\nu} = 3300\ cm^{-1}$ (=C−H), 2930, 2849 (C−H), 1638 (C−N), 1527 (N=O), 1348 (N=O), 1304, 1214, 1165 (CSNO). − ^1H NMR (200 MHz): δ = 2.40 (m_c, 2 H, 3-H), 3.09 (m_c, 1 H, 2-H), 4.00 (t, *J* = 7.4 Hz, 1 H, 1-H), 4.53 (dd, *J* = 5.0, 7.4 Hz, 1 H, 1′-H), 4.92−5.01 (m, 2 H, 5-H), 5.62 (ddt, J_d = 10.0, 17.0 Hz, J_t = 7.0 Hz, 1 H, 4-H), 6.62 (s, 1 H, 5′-H), 6.96−7.26 (m, 5 H, Ph-H), 7.44 (m_c, 2 H, Ar-H), 7.99 (m_c, 2 H, Ar-H). − ^{13}C NMR (100 MHz): δ = 36.5, 44.0, 79.3, 107.4, 117.4, 123.8, 127.0, 127.7, 128.4, 128.6, 133.1, 135.0, 138.5, 140.5, 148.0, 180.8. − MS (70 eV, EI); *m/z* (%): 208 (4) $[C_9H_6NOS_2{}^+]$, 131 (78) $[C_{10}H_{11}{}^+]$, 103 (47) $[C_8H_7{}^+]$, 91 (100) $[C_7H_7{}^+]$, 77 (30) $[C_6H_5{}^+]$. − $C_{20}H_{18}N_2O_3S_2$ (398.5): calcd. C 60.28, H 4.55, N 7.03, S 16.09; found C 59.94, H 4.51, N 7.27, S 16.15.

4-(*p*-Chlorophenyl)-*N*-(1-phenyl-4-penten-1-oxy)thiazole-2(3*H*)-thione (19c): Thiazolethione **19c** was prepared from tetrabutylammonium salt **14c** (2.55 g, 5.26 mmol) and 5-chloro-5-phenyl-1-pentene (950 mg, 5.26 mol) as described in Section 4. Yield: 1.04 g

(51%), m.p. 64 ± 2°C, colourless solid, R_{f} = 0.21 [CH_2Cl_2/petroleum ether, 3:2 (*v*/*v*)]. − UV/Vis: $\lambda_{\max}$ (lg ε) = 320 (4.12), 240 nm (4.14). − IR: $\tilde{\nu}$ = 3298 cm^{-1} (=C−H), 3079, 2942, 2861 (C−H), 1640 (C−N), 1488 (C−N), 1300 (CSNO), 1284 (C−O), 1212, 1165 (CSNO). − ^{1}H NMR (250 MHz): δ = 1.90 (m_{c}, 1 H, 2-H) 2.08 (m_{c}, 2 H, 3-H), 2.30 (m_{c}, 1 H, 2-H), 4.92−5.00 (m, 2 H, 5-H), 5.80 (ddt, J_{d} = 9.7, 17.7 Hz, J_{t} = 6.4 Hz, 1 H, 4-H), 6.01 (dd, *J* = 6.6, 7.8 Hz, 1 H, 1-H), 6.18 (s, 1 H, 5′-H), 6.80−7.27 (m, 9 H, Ar-H). − ^{13}C NMR (63 MHz): δ = 29.6, 31.4, 86.1, 104.4, 115.2, 127.3, 127.6, 128.2, 128.4, 128.8, 129.2, 129.6, 135.3, 137.2, 141.7, 180.5. − MS (70 eV, EI); *m*/*z* (%): 160 (3) [$C_{11}H_{12}O^+$], 105 (100) [$C_6H_5CO^+$], 77 (32) [$C_6H_5^+$]. − $C_{20}H_{18}ClNOS_2$ (388.0): calcd. C 61.92, H 4.68, N 3.61, S 16.53; found C 61.69, H 4.44, N 3.74, S 16.18.

4-(*p*-Chlorophenyl)-*N*-(4-phenyl-4-penten-1-oxy)thiazole-2(3*H*)-thione (19d): Thiazolethione **19d** was obtained from tetraethylammonium salt **14b** (1.17 g, 3.15 mmol) and 4-phenyl-4-penten-1-yl tosylate (1.00 g, 3.15 mmol) as described in Section 5. Yield: 763 mg (62%), m.p. 88 ± 2°C, colourless solid, R_{f} = 0.55 (CH_2Cl_2). − UV/Vis: $\lambda_{\max}$ (lg ε) = 316 (4.15), 236 nm (4.35). − IR: $\tilde{\nu}$ = 3298 cm^{-1} (=C−H), 3084, 2948, 2332 (C−H), 1632 (C=C), 1488 (C−N), 1306, 1213, 1168 (CSNO). − ^{1}H NMR (250 MHz): δ = 1.70 (quint, *J* = 6.5 Hz, 2 H, 2-H), 2.46 (t, *J* = 7.5 Hz, 2 H, 3-H), 4.07 (t, *J* = 6.4 Hz, 2 H, 1-H), 4.89 (s, 1 H, 5-H), 5.17 (s, 1 H, 5-H), 6.46 (s, 1 H, 5′-H), 7.22−7.28 (m, 5 H, Ph-H), 7.37 (m_{c}, 2 H, Ar-H), 7.47 (m_{c}, 2 H, Ar-H). − ^{13}C NMR (100 MHz): δ = 26.1, 31.3, 76.0, 105.3, 112.7, 126.0, 126.7, 127.5, 128.4, 129.6, 136.4, 140.0, 140.7, 147.1, 180.8. − MS (70 eV, EI); *m*/*z* (%): 168 (4) [$ClC_6H_4C_2HS^+$], 160 (18) [$C_{11}H_{12}O^+$], 118 (100) [$C_9H_{10}^+$]. − $C_{20}H_{18}ClNOS_2$ (388.0): calcd. C 61.92, H 4.68, N 3.61, S 16.53; found C 61.72, H 4.53, N 3.65, S 16.15.

4-(*p*-Chlorophenyl)-*N*-(1-pentyloxy)thiazole-2(3*H*)-thione (19e): *n*-Pentyl *O*-ester **19e** was prepared from tetraethylammonium salt **14b** (1.90 g, 5.10 mmol) and *n*-pentyl tosylate (1.24 g, 5.10 mmol) as described in Section 5. The reaction took 6 d to reach completion. Yield: 845 mg (53%), m.p. 69 ± 2°C, colourless solid, R_{f} = 0.28 [toluene/diethyl ether, 10:1 (*v*/*v*)]. − UV/Vis: $\lambda_{\max}$ (lg ε) = 338 (4.19), 240 nm (4.20). − IR: $\tilde{\nu}$ = 3298 cm^{-1} (=C−H), 2958, 2869 (C−H), 1637 (C=C), 1487 (C−N), 1306, 1213, 1169 (CSNO). − ^{1}H NMR (250 MHz): δ = 0.83 (m_{c}, 3 H, 5-H), 1.20 (m_{c}, 4 H, 3-H, 4-H), 1.57 (m_{c}, 2 H, 2-H), 4.07 (t, *J* = 6.7 Hz, 2 H, 1′-H), 6.51 (s, 1 H, 5′-H), 7.49 (m_{c}, 4 H, Ar-H). − ^{13}C NMR (63 MHz): δ = 13.7, 22.1, 27.3, 27.5, 76.3, 105.4, 126.6, 129.1, 129.6, 136.2, 139.9, 180.6. − MS (70 eV, EI); *m*/*z* (%): 313 (10) [M^+], 243 (26) [$M^+ - C_5H_{10}$], 227 (94) [$M^+ - C_5H_{10}O$], 168 (50) [$ClC_6H_4C_2HS^+$], 44 (100). − $C_{14}H_{16}ClNOS_2$ (313.9): calcd. C 53.57, H 5.14, N 4.46, S 20.43; found C 53.25, H 5.05, N 4.34, S 20.15.

4-(*p*-Chlorophenyl)-*N*-(isopropyloxy)thiazole-2(3*H*)-thione (19f): Isopropyl ester **19f** was obtained from tetraethylammonium salt **14b** (2.10 g, 5.63 mmol) and 2-propyl tosylate (1.21 g, 5.63 mmol) as described in Section 5. Yield: 819 mg (51%), m.p. 95 ± 2°C, colourless solid, R_{f} = 0.32 [petroleum ether/ethyl acetate, 4:1 (*v*/*v*)]. − UV/Vis: $\lambda_{\max}$ (lg ε) = 318 (4.18), 238 nm (4.19). − IR: $\tilde{\nu}$ = 3298 cm^{-1} (=C−H), 3117, 2935, 2872 (C−H), 1638 (C=C), 1487 (C−N), 1305 (CSNO), 1295 (C−O), 1213, 1169 (CSNO). − ^{1}H NMR (200 MHz): δ = 1.04 (d, *J* = 6.1 Hz, 6 H, CH_3), 5.08 (sept, *J* = 6.1 Hz, 1 H, CH), 6.52 (s, 1 H, 5-H), 7.48 (m_{c}, 4 H, Ar-H). − ^{13}C NMR (100 MHz): δ = 20.2, 79.4, 105.2, 127.4, 128.9, 129.7, 135.9, 141.3, 181.1. − MS (70 eV, EI); *m*/*z* (%): 285 (16) [M^+], 243 (12) [$M^+ - C_3H_6O$], 227 (25) [$M^+ - C_3H_6O$] 168 (100) [$ClC_6H_4C_2HS^+$]. − $C_{12}H_{12}ClNOS_2$ (285.8): calcd. C 50.43, H 4.23, N 4.90, S 22.44; found C 50.70, H 4.23, N 4.96, S 22.15.

4-(*p*-Chlorophenyl)-*N*-(cyclopentyloxy)thiazole-2(3*H*)-thione (19g): Thione **19g** was synthesized from tetraethylammonium salt **14b** (806 mg, 2.16 mmol) and cyclopentyl tosylate (523 mg, 2.16 mmol) according to the procedure given in Section 5. The reaction took 7 d to reach completion. Yield: 385 mg (57%), m.p. 118 ± 2°C, colourless solid, R_{f} = 0.64 [petroleum ether/diethyl ether, 4:1 (*v*/*v*)]. − UV/Vis: $\lambda_{\max}$ (lg ε) = 320 (4.11), 238 nm (4.09). − IR: $\tilde{\nu}$ = 3298 cm^{-1} (=C−H), 2967, 2875 (C−H), 1638 (C=C), 1487 (C−N), 1295 (CSNO), 1293 (C−O), 1212, 1163 (CSNO). − ^{1}H NMR (250 MHz): δ = 1.18−1.44 (m, 4 H, CH_2), 1.48−1.74 (m, 4 H, CH_2), 5.42 (quint, *J* = 2.8 Hz, 1 H, 1-H), 6.50 (s, 1 H, 5′-H), 7.47 (m_{c}, 4 H, Ar-H). − ^{13}C NMR (63 MHz): δ = 23.2, 31.0, 89.5, 105.4, 127.3, 129.0, 129.8, 136.0, 141.3, 181.1. − MS (70 eV, EI); *m*/*z* (%): 311 (12) [M^+], 243 (52) [$M^+ - C_5H_8$], 227 (69) [$M^+ - C_5H_8O$], 168 (100) [$ClC_6H_4C_2HS^+$]. − $C_{14}H_{14}ClNOS_2$ (311.9): calcd. C 53.92, H 4.52, N 4.49, S 20.56; found C 53.80, H 4.45, N 4.54, S 20.18.

***N*-(Benzyloxy)-4-(*p*-chlorophenyl)thiazole-2(3*H*)-thione (19h):** Benzyl chloride (254 mg, 2.01 mmol) and tetrabutylammonium salt **14c** (975 mg, 2.01 mmol) were dissolved in DMF (10 mL) and converted into benzyl ester **19h** within 7 d according to the procedure given in Section 4. Yield: 271 mg (40%), dec. 120 ± 2°C, colourless solid, R_{f} = 0.47 (CH_2Cl_2). − UV/Vis: $\lambda_{\max}$ (lg ε) = 318 (3.97), 241 nm (3.93). − IR: $\tilde{\nu}$ = 3296 cm^{-1} (=C−H), 3069, 3039, 2946, 2864 (C−H), 1637 (C=C), 1483 (C−N), 1305 (CSNO), 1295 (C−O), 1213, 1164 (CSNO). − ^{1}H NMR (200 MHz): δ = 5.08 (s, 2 H, 1′-H), 6.34 (s, 1 H, 5-H), 7.00−7.30 (m, 9 H, Ar-H). − ^{13}C NMR (63 MHz): δ = 77.4, 104.8, 126.7, 128.5, 128.8, 129.5, 129.6, 130.4, 132.2, 135.9, 140.6, 180.6. − MS (70 eV, EI); *m*/*z* (%): 333 (2) [M^+], 227 (25) [M^+ − PhCHO], 168 (21) [$ClC_6H_4C_2HS^+$], 105 (69) [$PhCO^+$], 91 (71) [$C_7H_7^+$], 77 (100) [$C_6H_5^+$]. − $C_{16}H_{12}ClNOS_2$ (333.9): calcd. C 57.56, H 3.62, N 4.20, S 19.21; found C 57.32, H 3.69, S 4.09, N 18.95.

4-(*p*-Chlorophenyl)-*N*-(2-methyl-2-propen-1-oxy)thiazole-2(3*H*)-thione (19j): Tetrabutylammonium salt **14c** (1.01 g, 2.08 mmol) and 1-chloro-2-methyl-2-propene (188 mg, 2.08 mmol) were allowed to react for 7 d in DMF (10 mL). The reaction mixture was subsequently worked up as described in Section 4. Yield: 257 mg (42%), m.p. 92 ± 2°C, colourless solid, R_{f} = 0.36 (CH_2Cl_2). − UV/Vis: $\lambda_{\max}$ (lg ε) = 318 (4.13), 237 nm (4.12). − IR: $\tilde{\nu}$ = 3310 cm^{-1} (=C−H), 3112, 3083, 2983, 2944, 2875 (C−H), 1640 (C=C), 1482 (C−N), 1305 (CSNO), 1296 (C−O), 1213, 1168 (CSNO). − ^{1}H NMR (250 MHz): δ = 1.60 (dd, *J* = 0.9, 1.5 Hz, 3 H, CH_3), 4.52 (s, 2 H, 1-H), 4.93 (m_{c}, 1 H, 3-H), 4.97 (quint, *J* = 1.5 Hz, 1 H, 3-H), 6.50 (s, 1 H, 5-H), 7.44 (m_{c}, 2 H, Ar-H), 7.53 (m_{c}, 2 H, Ar-H). − ^{13}C NMR (63 MHz): δ = 20.0, 79.6, 105.2, 118.6, 126.7, 129.1, 129.8, 136.2, 137.7, 140.2, 180.6. − MS (70 eV, EI); *m*/*z* (%): 297 (12) [M^+], 227 (85) [$M^+ - C_4H_6O^+$], 192 (29) [$C_9H_6NS_2^+$], 168 (100) [$ClC_6H_4C_2HS^+$], 70 (35) [$C_4H_6O^+$], 55 (30) [$C_4H_7^+$], 41 (90) [$C_3H_5^+$]. − $C_{13}H_{12}ClNOS_2$ (297.8): calcd. C 52.43, H 4.06, N 4.70, S 21.53; found C 52.50, H 4.16, N 4.69, S 21.38.

2-(2-Methyl-2-propenyl-1-sulfanyl)thiazole *N*-Oxide (24j): Yield: 35.0 mg (4%), tan oil, R_{f} = 0.86 (CH_2Cl_2). − IR: $\tilde{\nu}$ = 3308 cm^{-1} (=C−H), 2859 (C−H), 1644 (C=C), 1595, 1514, 1469 (C−N), 1429, 1398, 1375, 1308, 1285, 1263 (N−O). − ^{1}H NMR (250 MHz): δ = 1.89 (dd, *J* = 0.9, 1.5 Hz, 3 H, CH_3), 3.90 (d, *J* = 0.9 Hz, 2 H, 1-H), 4.92 (quint *J* = 1.5 Hz, 1 H, 3-H), 5.04 (m_{c}, 1 H, 3-H), 7.32 (s, 1 H, 5′-H), 7.37 (m_{c}, 2 H, Ar-H), 7.81 (m_{c}, 2 H, Ar-H). − ^{13}C NMR (63 MHz): δ = 21.2, 41.8, 112.9, 115.2, 127.5, 128.8, 132.6, 133.9, 139.9, 154.1, 164.6. − $C_{13}H_{12}ClNOS_2$ (297.8): calcd. C 52.43, H 4.06, N 4.70, S 21.53; found C 55.20, H 4.54, N 4.34, S 20.03.

6. Preparation of *N*-Acyloxy-4-arylthiazole-2(3*H*)-thiones 19k−m: To a suspension of the potassium salt **14a** (564 mg, 2.00 mmol) in dry dichloromethane (20 mL) was added 1 equiv. of the neat acyl chloride at 20°C in the dark. The reaction mixture was stirred for 30 min and the precipitated potassium chloride was filtered off by suction (Buchner funnel). The filtrate was concentrated at 40°C in vacuo to afford an orange oil, which crystallized upon treatment with *n*-pentane.

***N*-Acetoxy-4-(*p*-chlorophenyl)thiazole-2(3*H*)-thione (19k):** Yield: 457 mg (80%), dec. 103 ± 2°C, tan solid. − UV/Vis: λ_{max} (lg ε) = 300 nm (3.94), 264 (4.11). − IR: $\tilde{\nu}$ = 3300 cm^{-1} (=C−H), 2959, 2927, 2867 (C−H), 1823 (C=O), 1637 (C=C), 1488 (C−N), 1301, 1214, 1177 (CSNO). − ^{1}H NMR (250 MHz): δ = 2.25 (s, 3 H, CH_3), 6.56 (s, 1 H, 5-H), 7.41 (m_c, 4 H, Ar-H). − ^{13}C NMR (63 MHz): δ = 18.0, 105.0, 126.2, 129.3, 129.4, 136.5, 140.0, 165.5, 181.5. − MS (70 eV, EI); *m*/*z* (%): 285 (33) [M$^+$], 243 (100) [M$^+$ − C_2H_2O], 227 (52), [M$^+$ − $C_2H_2O_2$]. − $C_{11}H_8ClNO_2S_2$ (285.8): calcd. C 46.23, H 2.82, N 4.90, S 22.44; found C 46.52, H 2.90, N 4.80, S 22.22.

***N*-*tert*-Butylcarbonyloxy-4-(*p*-chlorophenyl)thiazole-2(3*H*)-thione (19m):** Yield: 571 mg (87%), dec. 94 ± 2°C, tan solid. − UV/Vis: λ_{max} (lg ε) = 316 (4.10), 230 nm (4.08). − IR: $\tilde{\nu}$ = 3300 cm^{-1} (=C−H), 3117, 2979, 2935, 2906, 2874 (C−H), 1801 (C=O), 1657 (C=C), 1487 (C−N), 1307 (CSNO), 1299 (C=O), 1213, 1167 (CSNO). − ^{1}H NMR (200 MHz): δ = 1.24 (s, 9 H, CH_3), 6.54 (s, 1 H, 5-H), 7.42 (m_c, 4 H, Ar-H). − ^{13}C NMR (100 MHz): δ = 26.9, 38.4, 104.9, 126.4, 129.0, 129.9, 136.5, 140.2, 173.1, 181.5. − MS (70 eV, EI); *m*/*z* (%): 327 (7) [M$^+$], 283 (6) [M$^+$ − CO_2], 227 (87) [M$^+$ − $C_5H_8O_2$], 168 (27) [$ClC_6H_4C_2HS^+$], 57 (100) [$(H_3C)_3C^+$]. − $C_{14}H_{14}ClNO_2S_2$ (327.9): calcd. C 51.29, H 4.30, N 4.27, S 19.56; found C 50.97, H 4.10, N 4.56, S 19.57.

7. Photolyses of Thiohydroxamic Acid Esters 16−20: In a typical run, ester 16−20 (18.0 μmol) was dissolved in *tert*-butylbenzene (2.0 mL, TBB) in a small Schlenk flask. A precise amount of olefin-free *n*-tetradecane (Fluka, GC standard) was added, the reaction vessel was sealed with a rubber septum, wrapped in aluminum foil, and cooled to liquid-nitrogen temperature. After thorough evacuation, the flask was flushed with argon and 50 μL of tri-*n*-butylstannane was added. The reaction mixture was degassed by means of a freeze-pump-thaw cycle and was then thermostatted in a water bath at 18°C. The solution was photolyzed for 3 min. in a Rayonet® chamber photoreactor equipped with 350-nm lamps and was immediately subjected to GC analysis.

8. Preparation of the Tetrahydrofurans 31b−c or Tetrahydropyran 32d:[6] A Schlenk flask was charged with a solution of *N*-alkoxy-4-(*p*-chlorophenyl)thiazole-2(3*H*)-thione (1.03 mmol) in benzene (21 mL). The flask was sealed with a rubber septum, wrapped in aluminum foil, and cooled to liquid-nitrogen temperature. The flask was attached to a vacuum line for 5 min, then flushed with argon, and tri-*n*-butylstannane (1.0 mL, 3.8 mmol) was added. The mixture was degassed by means of 2 consecutive freeze-pump-thaw cycles and then thermostatted in a water bath at 18°C. The reaction mixture was photolysed for 45 min in a Rayonet® chamber photoreactor equipped with 350-nm lamps. Potassium fluoride (3.9 g, 67.2 mmol) and water (1.9 mL) were added and the resulting slurry was stirred for 14 h at 20°C. Further water (5 mL) was then added to dissolve the salts. The organic layer was separated, dried ($MgSO_4$), and concentrated in vacuo to afford a yellow oil, which

Table 7. Crystallographic data and data collection parameters for thiazolethiones **9**, **19c**, **19f**, **19k**[a]

	9	**19c**	**19f**	**19k**
Empirical formula	$C_9H_6ClNOS_2$	$C_{20}H_{18}ClNOS_2$	$C_{12}H_{12}ClNOS_2$	$C_{11}H_8ClNO_2S_2$
Formula weight	243.72	387.92	285.82	285.77
Temperature [K]	293(2)	298(2)	300(2)	299(2)
Wavelength [Å]	0.71069	0.71093	0.71093	0.71093
Crystal system	orthorhombic	monoclinic	orthorhombic	monoclinic
Space group	*Pbca*	*P*21/*c*	*Pbca*	*P*21/*c*
a [Å]	7.234(2)	9.059(2)	18.445(4)	10.898(2)
b [Å]	11.777(4)	7.580(2)	12.969(3)	7.987(2)
c [Å]	23.067(4)	28.423(4)	11.662(5)	14.339(2)
β [°]	90	89.93(1)	90	94.59(1)
V [Å^3]	1965.2(9)	1951.7(7)	2790(2)	1244.1(4)
Z	8	4	8	4
$\rho_{calcd.}$ [g cm^{-3}]	1.647	1.320	1.361	1.526
μ(Mo-K_α)/mm^{-1}	0.738	0.407	0.543	0.619
F (000)	992	808	1184	584
Crystal size [mm]	0.40 × 0.35 × 0.08	0.45 × 0.30 × 0.10	0.75 × 0.40 × 0.33	0.22 × 0.08 × 0.03
θ range [°]	1.77−22.97	1.43−22.97	2.21−25.99	1.88−22.97
Index ranges	$-7 \le h \le 7$ $-1 \le k \le 12$ $-25 \le l \le 25$	$-9 \le h \le 7$ $0 \le k \le 8$ $-31 \le l \le 31$	$-22 \le h \le 0$ $-15 \le k \le 0$ $-14 \le l \le 1$	$-11 \le h \le 1$ $-8 \le k \le 0$ $-15 \le l \le 15$
Reflections collected	5651	5099	2854	1963
Independent reflections	1358	2692	2735	1714
Data/restraints/parameters	1357/0/132	2692/0/235	2735/0/173	1713/0/178
Goodness-of-fit on F^2	1.102	1.075	1.000	1.041
Final *R* indices [$I > 2\sigma(I)$]	$R1 = 0.0294$ $wR2 = 0.0667$	$R1 = 0.0598$ $wR2 = 0.1527$	$R1 = 0.0451$ $wR2 = 0.1240$	$R1 = 0.0405$ $wR2 = 0.0776$
R indices (all data)	$R1 = 0.0385$ $wR2 = 0.0709$	$R1 = 0.0806$ $wR2 = 0.1693$	$R1 = 0.0694$ $wR2 = 0.1424$	$R1 = 0.1575$ $wR2 = 0.1071$
Largest diff. peak and hole [eÅ^{-3}]	0.228, −0.177	0.443, −0.392	0.444, −0.260	0.260, −0.235

[a] Data were collected with Enraf-Nonius Turbo-CAD4 (**9**) and Enraf-Nonius CAD4 (**19c**, **19f**, **19k**) four-circle diffractometers using Mo-K_α radiation; no absorption corrections were applied; structures were solved using SHELXS-86[29] and SHELXL-93;[30] with the exception of H1O in thiazolethione **9** (difference Fourier map), all hydrogen atoms were positioned geometrically; thermal ellipsoid graphics were obtained using Xtal 3.2[31]

was purified by column chromatography [SiO_2, petroleum ether/diethyl ether, 5:1 (v/v)] and subsequent kugelrohr distillation.

4-(*p*-Chlorophenyl)-2-(tri-*n*-butylstannylsulfanyl)thiazole (**35**) was isolated following photolysis of 4-(*p*-chlorophenyl)-*N*-(2-phenyl-4-pentenyl-1-oxy)thiazole-2(3*H*)-thione **19b** and Bu_3SnH. Yield: 300 mg (56%); colourless oil. – IR: $\tilde{\nu}$ = 3300 cm^{-1} (=C–H), 2960, 2926, 2874, 2850 (C–H), 1638 (C=C), 1473 (C–N). – ^1H NMR (250 MHz): δ = 0.87 (t, J = 7.1 Hz, 9 H, 4′-H), 1.25–1.38 (m_c, 12 H, 3′-H, 2′-H), 1.56–1.67 (m_c, 6 H, 1′-H), 7.18 (s, 1 H, 5-H), 7.35 (m_c, 2 H, Ar-H), 7.79 (m_c, 2 H, Ar-H). – ^{13}C NMR (63 MHz): δ = 13.6, 15.9, 27.0, 28.6, 113.4, 127.3, 128.8, 132.8, 133.5, 153.2, 165.8. – MS (70 eV, EI); m/z (%): 462 (6), 460 (12), 458 (9) [$M^+ - C_4H_8^+$], 348 (3), 346 (11), 344 (7) [$M^+ - C_{12}H_{26}$], 149 (38) [$C_8H_4ClN^+$], 91 (100) [$C_7H_7^+$]. – $C_{21}H_{32}ClNS_2Sn$ (516.8): calcd. C 48.81, H 6.24, N 2.71, S 12.41; found C 49.08, H 6.17, N 2.71, S 12.18.

9. Photolysis of Thiohydroxamic Anhydride 19m: A solution of the *O*-pivaloylthiazolethione **19m** (728 mg, 2.22 mmol) in dry diethyl ether (30 mL) was photolyzed at 15°C in a Rayonet® chamber photoreactor equipped with 350-nm lamps and an external water cooler. After evaporation of the solvent, the remaining yellow solid was purified by chromatography (SiO_2, CH_2Cl_2).

***2-tert*-Butylsulfanyl-4-(*p*-chlorophenyl)thiazole** (**28**): Yield: 440 mg (70%), m.p. 83 ± 2°C, tan solid, R_f = 0.91 (CH_2Cl_2). – UV/Vis: λ_{max} (lg ε) = 267 (4.20), 227 nm (4.03) sh. – IR: $\tilde{\nu}$ = 3294 cm^{-1} (=C–H), 2966, 2921, 2854, 2350 (C–H), 1638 (C=C), 1471 (C–N). – ^1H NMR (250 MHz): δ = 1.52 (s, 9 H, CH_3), 7.39 (m_c, 2 H, Ar-H), 7.47 (s, 1 H, 5-H), 7.86 (m_c, 2 H, Ar-H). – ^{13}C NMR (63 MHz): δ = 30.9, 49.9, 115.9, 127.6, 128.9, 132.6, 134.0, 155.2, 161.1. – MS (70 eV, EI); m/z (%): 283 (8) [M^+], 227 (100) [$ClC_6H_4C_3H_2NS_2^+$], 168 (15) [$ClC_6H_4C_2HS^+$]. – $C_{13}H_{14}ClNS_2$ (285.8): calcd. C 55.01, H 4.97, N 4.93, S 22.59; found C 54.59, H 4.66, N 4.90, S 22.30.

10. X-ray Crystallographic Studies:[29–32] Suitable crystals of thiones **9**, **19c**, **19f**, and **19k** were obtained from saturated solutions in diethyl ether, which were stored under an atmosphere saturated with *n*-pentane vapour.

Acknowledgments

This work was generously supported by the Deutsche Forschungsgemeinschaft, the Fonds der Chemischen Industrie, and the Deutscher Akademischer Austauschdienst (DAAD) within the Accoes-Integradas-Program. We thank Dipl.-Chem. Rainer Kneuer for helpful discussions.

---

[1] For recent applications of alkoxyl radicals in synthesis, see: [1a] J. Hartung, F. Gallou, *J. Org. Chem.* **1995**, *60*, 6706–6716. – [1b] A. Goosen, C. W. McCleland, F. C. Rinaldi, *J. Chem. Soc., Perkin Trans. 2* **1993**, 279–281. – [1c] D. H. R. Barton, J. Cs. Jaszberenyi, A. I. Morrell, *Tetrahedron Lett.* **1991**, *32*, 311–314. – [1d] M. Newcomb, M. U. Kumar, J. Boivin, E. Crépon, S. Z. Zard, *Tetrahedron Lett.* **1991**, *32*, 45–48. – [1e] A. L. J. Beckwith, I. G. E. Davison, *Tetrahedron Lett.* **1991**, *32*, 49–52. – [1f] G. Pattenden, C. W. Ellwood, *Tetrahedron Lett.* **1991**, *32*, 1591–1594. – [1g] C. G. Francisco, R. Freire, C. C. González, E. Súarez, *Tetrahedron: Asymmetry* **1997**, *8*, 1971–1974. – [1h] Y. Guindon, R. C. Denis, *Tetrahedron Lett.* **1998**, *39*, 339–342.

[2] [2a] B. Giese, *Radicals in Organic Synthesis: Formation of Carbon–Carbon Bonds*, Pergamon Press, Oxford, **1986**. – [2b] D. H. R. Barton, S. I. Parekh, *Half a Century of Free Radical Chemistry*, Cambridge University Press, Cambridge, **1993**.

[3] B. Giese, N. Porter, D. P. Curran, *Stereochemistry of Radical Reactions*, VCH, Weinheim, **1995**.

[4] B. Giese, B. Kopping, T. Göbel, J. Dickhaut, G. Thoma, K. J. Kulicke, F. Trach, *Org. React.* **1996**, *48*, 301–856.

[5] J. L. Esker, M. Newcomb, *Adv. Heterocycl. Chem.* **1993**, *58*, 1–45.

[6] J. Hartung, M. Hiller, P. Schmidt, *Chem. Eur. J.* **1996**, *2*, 1014–1023.

[7] J. Hartung, M. Hiller, P. Schmidt, *Liebigs Ann.* **1996**, 1425–1436.

[8] [8a] R. D. Rieke, N. A. Moore, *J. Org. Chem.* **1972**, *37*, 413–418. – [8b] G. A. Kraus, J. Thurston, *Tetrahedron Lett.* **1987**, *28*, 4011–4014. – [8c] J.-M. Surzur, M.-P. Bertrand, R. Nougier, *Tetrahedron Lett.* **1969**, 4197–4200. – [8d] A. Johns, J. A. Murphy, *Tetrahedron Lett.* **1988**, *29*, 837–840. – [8e] A. L. J. Beckwith, B. P. Hay, *J. Org. Chem.* **1988**, *53*, 4330–4334.

[9] G. Majetich, K. Wheless, *Tetrahedron* **1995**, *51*, 7095–7129.

[10] D. H. R. Barton, J. M. Beaton, L. W. Geller, M. M. Pechet, *J. Am. Chem. Soc.* **1961**, *83*, 4076–4083.

[11] [11a] P. de Armas, J. I. Concepcíon, C. G. Francisco, R. Hernández, J. A. Salazar, E. Suárez, *J. Chem. Soc., Perkin Trans. 1* **1989**, 405–411. – [11b] A. Boto, R. Hernández, E. Suárez, *Tetrahedron Lett.* **1994**, *35*, 2597–2600.

[12] [12a] H. Makabe, A. Tanaka, T. Oritani, *J. Chem. Soc., Perkin Trans. 1* **1994**, 1975–1981. – [12b] I. Fleming, S. K. Ghosh, *J. Chem. Soc., Chem. Commun.* **1994**, 2287–2288. – [12c] A. K. Saksena, V. M. Girijavallabhan, R. G. Lovey, R. E. Pike, H. Wang, A. K. Ganguly, B. Morgan, A. Zaks, M. S. Puar, *Tetrahedron Lett.* **1995**, *36*, 1787–1790. – [12d] F. Giordano, L. Mayol, G. Notaro, V. Piccialli, D. Sica, *J. Chem. Soc., Chem. Commun.* **1990**, 1559–1561. – [12e] D. A. Evans, A. M. Ratz, B. E. Huff, G. S. Sheppard, *J. Am. Chem. Soc.* **1995**, *117*, 3448–3467. – [12f] W. Francke, J. Bartels, S. Krohn, S. Schulz, E. Baader, J. Tengö, D. Schneider, *Pure Appl. Chem.* **1989**, *61*, 539–542. – [12g] R. Hoppe, H.-D. Scharf, *Synthesis* **1995**, 1447–1464. – [12h] P. Angeli, F. Cantalamessa, R. Cavagna, R. Conti, M. De Amici, C. De Micheli, A. Gamba, B. Marucci, *J. Med. Chem.* **1997**, *40*, 1099–1103.

[13] D. Crich, L. Quintero, *Chem. Rev.* **1989**, *89*, 1413–1432.

[14] π-bond strengths: C=S: 218 kJ mol^{-1}, C=O: 323 kJ mol^{-1}; see: M. W. Schmidt, P. N. Truong, M. S. Gordon, *J. Am. Chem. Soc.* **1987**, *109*, 5217–5227.

[15] D. H. R. Barton, D. Crich, G. Kretzschmar, *J. Chem. Soc., Perkin Trans. 1* **1986**, 39–53.

[16] [16a] J. Hartung, M. Schwarz, *Synlett* **1997**, 848–850. – [16b] J. Hartung, M. Schwarz, *Synlett* **1997**, 1116.

[17] [17a] L.Tietze, T. Eicher, *Reaktionen und Synthesen im organisch-chemischen Praktikum und Forschungslaboratorium,* 2nd ed., Georg Thieme, Stuttgart, **1991**, p. B51. – [17b] J. W. Baker, *J. Chem. Soc. II* **1931**, 2416–2426. – [17c] M. C. Rebstock, E. L. Pfeiffer, *J. Am. Chem. Soc.* **1952**, *74*, 3207–3210. – [17d] U. Amschler, O.-E. Schultz, *Arzneim.-Forsch.* **1972**, *22*, 2095–2096. – [17e] F. Kunckell, *Ber. Dtsch. Chem. Ges.* **1901**, *34*, 1901–1914. – [17f] M. Masaki, K. Fukui, M. Ohta, *J. Org. Chem.* **1967**, *32*, 3564.

[18] J. Hartung, R. Kneuer, M. Schwarz, I. Svoboda, H. Fueß, *Eur. J. Org. Chem.* **1999**, 97–106.

[19] For a further example of an intermolecular hydrogen bond in thiohydroxamate chemistry, see: J. Hartung, I. Svoboda, M. T. Duarte, *Acta Crystallogr.* **1997**, *C53*, 1631–1634.

[20] For example, 3.4 Å for DNA (D. B. Hall, J. K. Barton, *J. Am Chem. Soc.* **1997**, *119*, 5045–5046), 3.6–3.8 Å in poly(3-alkylthiophenes) (T. Yamamoto, D. Komarudin, M. Arai, B.-L. Lee, H. Suganuma, Y. Inoue, K. Kubota, S. Sasaki, T. Fukuda, H. H. Matsuda, *J. Am. Chem. Soc.* **1998**, *120*, 2047–2058).

[21] A. Bondi, *J. Phys. Chem.* **1964**, *68*, 441–451.

[22] J. Hartung, M. Hiller, M. Schwarz, I. Svoboda, H. Fueß, *Liebigs Ann.* **1996**, 2091–2097.

[23] F. G. Riddell, *Tetrahedron* **1981**, *37*, 849–858.

[24] M. Raban, D. Kost, *J. Org. Chem.* **1972**, *37*, 499–501.

[25] Thiazolethiones **19c**, **19f**, and **19k** were prepared as racemates and unit cells were found to contain 1:1 mixtures of rotamers having (M) and (P) configuration at the N–O axis. Thus, (M) rotamers were arbitrarily chosen for the ellipsoid graphics in Figure 2. For 1-phenylpentenyl ester **19c**, only (M/R) and (P/S) diastereomers were observed in the solid state. For stereochemical assignments along stereogenic axes, see: V. Prelog, G. Helmchen, *Angew. Chem.* **1982**, *94*, 614–631; *Angew. Chem. Int. Ed. Engl.* **1982**, *21*, 567–620.

[26] F. Runge, *J. Prakt. Chem.* **1963**, *21*, 39–49.

[27] P. A. Bartlett, in *Asymmetric Synthesis* (Ed.: J. D. Morrison), Academic Press, New York, **1984**, vol. 3, pp. 411−453.

[28] D. D. Perrin, W. L. F. Armarego, D. R. Perrin, *Purification of Laboratory Chemicals*, 2nd ed., Pergamon Press, Oxford, **1980**.

[29] G. M. Sheldrick, *SHELXS-86, Program for the Solution of Crystal Structures*, Universität Göttingen, **1986**.

[30] G. M. Sheldrick, *SHELXL-93, Program for the Refinement of Crystal Structures*, Universität Göttingen, **1993**.

[31] S. R. Hall, H. D. Flack, J. M. Stewart, *Xtal 3.2*, Universities of Western Australia, Geneva, and Maryland, **1992**.

[32] Crystallographic data (excluding structure factors) for the structures reported in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publications nos. CCDC-109506 (**9**), -109507 (**19c**), -109509 (**19f**), and -109508 (**19k**). Copies of the data can be obtained free of charge on application to CCDC, 12 Union Road, Cambridge CB2 1EZ, U.K. [Fax: (internat.) + 44-1223/336-033; E-mail: deposit@ccdc.cam.ac.uk].

[O98512]