JOC The Journal of Organic Chemistry

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Synthesis of Thiohydroxamic Acids and Thiohydroximic Acid Derivatives

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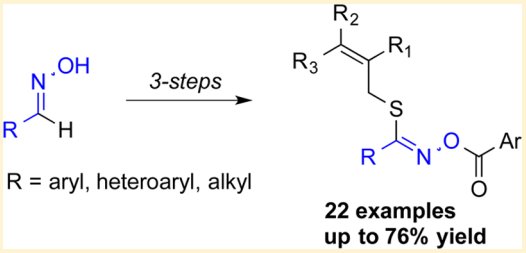
Supporting Information

ABSTRACT: An improved and expanded preparation of thiohydroxamic acids is reported along with a one-pot conversion of these compounds to novel thiohydroximic acid derivatives. A variety of aryl, heteroaryl, and alkyl substituents are well tolerated to provide a rapid approach to alkene-functionalized thiohydroximic acids that serve as potentially useful building blocks for organic synthesis.



Thiohydroxamic acids are unusual molecules with four different types of atoms in close proximity (C-sp^2, N, O, and S), which gives them a wide range of reactivity and makes them very *N*-acidic: the average pK_a of thiohydroxamic acids is 4.2−5.6.[1] Therefore they are excellent bidentate chelators, and this property has been exploited in the study of metal ions.[2] Thiohydroxamic acids exist in equilibrium between their thione and thiol forms (Figure 1a). The thiohydroxamic tautomers are

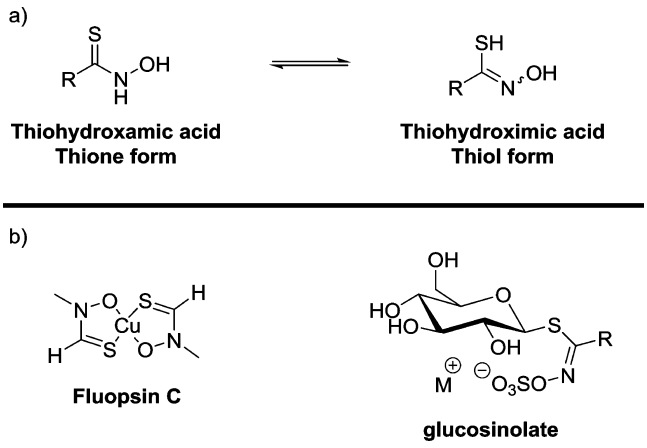


Figure 1. (a) Tautomers of thiohydroxamic acids. (b) Naturally occurring thiohydroxamic and thiohydroximic acids.

equally stable in the gas phase, and the thione form is more stable in the solution and solid phases.[3] Naturally occurring thiohydroxamic acids are rare, but some simple thiohydroxamate metal chelates have antibacterial properties (Figure 1b).[4] In contrast, naturally occurring thiohydroximic acid derivatives are frequently observed, exemplified by *O*-sulfonyl *S*-glucosyl thiohydroximates, known as glucosinolates, which are isocyanate precursors in plants.[5] The most common synthetic thiohydroxamic acids are the *O*-acyl thiohydroxamic acids known as Barton esters that are widely used as radical precursors.[6]

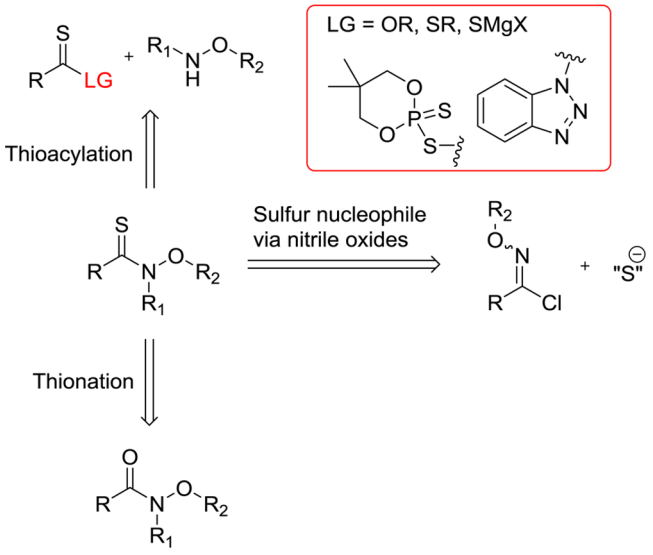


Figure 2. Synthesis of thiohydroxamic acids.

There are three main methods for the synthesis of thiohydroxamic acids in the literature (Figure 2).[7] Given the broad availability of hydroxamic acids,[8] thionation with Lawesson's reagent or P_2S_5 appears to be the most straightforward way of accessing thiohydroxamic acids; however, this method works well only with *O*-protected hydroxamic acids and yields complex mixtures with other hydroxamic acids.[9] Another method to prepare thiohydroxamic acids is thioacylation of hydroxylamine derivatives. Dithiocarboxylic esters,[10] their salts,[2b] and thionocarboxylic acid esters[1] have been used with variable success to make thiohydroxamic acids. These thioacylating agents are often made from dithiocarboxylic acids and thus are not

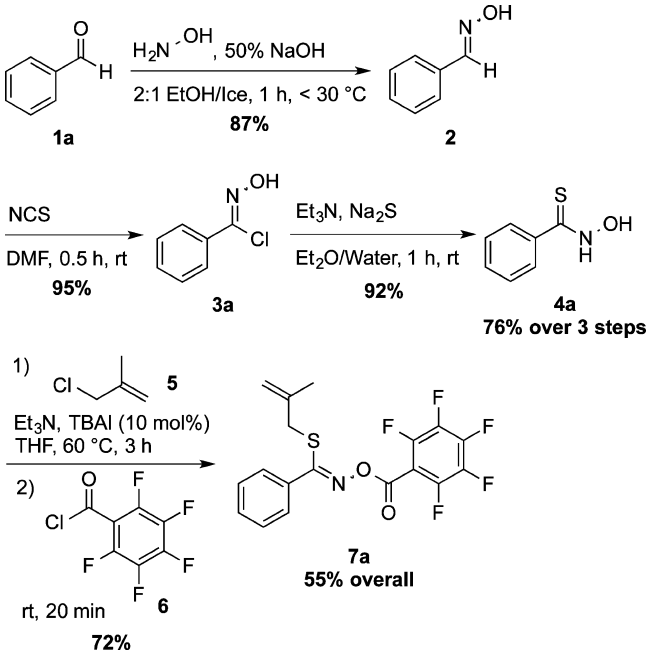
Received: January 13, 2014
Published: February 20, 2014

   dx.doi.org/10.1021/jo500080x | J. Org. Chem. 2014, 79, 2321−2330

broadly commercially available and are unstable to storage and handling. Modern thioacylating agents have been introduced that are easier to access, handle, and store;[11] unfortunately, these reagents are not easily employed for the preparation of unsubstituted thiohydroxamic acids because they create by-products that can be difficult to remove from the acidic thiohydroxamic acid products. The final method to synthesize thiohydroxamic acids is the addition of sulfur nucleophiles to *N*-hydroxyimidoyl chlorides or nitrile oxides.[12] This is also the method of choice to synthetically access thiohydroximic acids from the glucosinolate family and Barton esters.[13] Despite the availability of synthetic methods to access thiohydroxamic acids, their synthesis and use in synthetic chemistry is rare, with the exception of Barton's esters. Indeed, they are plagued with a bad reputation of decomposing and rearranging through Lossen or Beckmann rearrangements before any useful reaction can occur.

We chose to revisit and expand the previously described addition of sulfur nucleophiles to *N*-hydroxyimidoyl chlorides to access a variety of unknown *N*-unsubstituted thiohydroxamic acids and *S*-allyl thiohydroximic acid derivatives.[12] We targeted this subclass of thiohydroximic acid derivatives since they bear functional groups that can potentially be employed as reactive handles for their application in heterocycle synthesis. As a starting point to evaluate the potential of this approach we targeted benzothiohydroxamic acid (**4a**, Scheme 1). Freshly

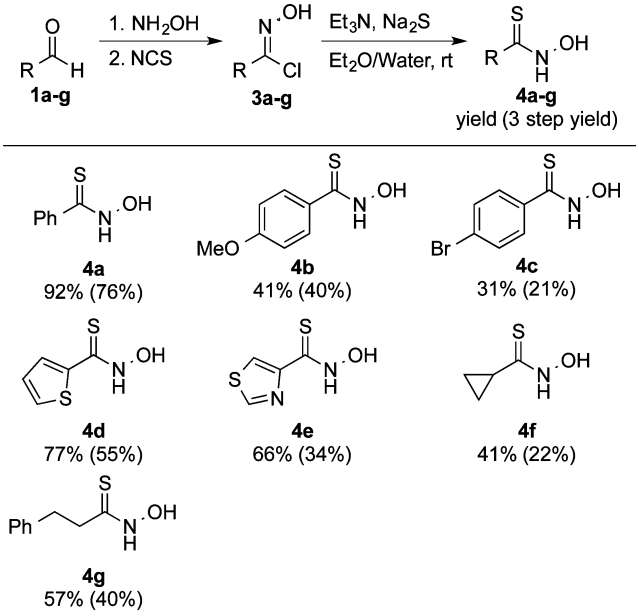
Scheme 1. Optimized Synthesis of Thiohydroxamic and Thiohydroximic Acids



distilled benzaldehyde (**1a**) was treated with hydroxylamine hydrochloride to provide oxime **2** in 87% yield. After aqueous workup, the pure oxime **2** was chlorinated with NCS in DMF to provide the *N*-hydroxyimidoyl chloride **3a** in 95% yield. With **3a** in hand we initially explored the addition of allylthiol reagents to the *N*-hydroxyimidoyl chlorides; however, in all cases cycloaddition between the alkene and the *in situ* generated nitrile oxide was the predominant reaction product.[14] To circumvent this issue we modified and expanded an isolated report for the addition of sodium sulfide to di-ortho-substituted arylimidoyl chlorides.[12a] Optimization of this method was achieved through a significant reduction in the equivalents of sodium sulfide, the addition of an amine base, and the use of hydrochloric acid for reaction quenching. Accordingly, under our optimized conditions, sodium sulfide (3 equiv) was added to *N*-hydroxyimidoyl chloride **3a** (1 equiv) in the presence of triethylamine (1 equiv) to generate thiohydroxamic acid **4a** in 92% yield after extraction of the acidified water layer. With a high yielding synthesis of thiohydroxamic acid **4a** in hand, we explored the one-pot conversion to activated thiohydroximic acid derivatives. Thiohydroxamic acid **4a** was *S*-alkylated with allyl chloride **5** in the presence of catalytic tetrabutylammonium iodide (TBAI) followed by treatment with pentafluorobenzoyl chloride (**6**) to obtain thiohydroximic acid **7a** in 72% yield (55% over 4 steps, 2 purifications) (Scheme 1).

With this optimized route we were able to synthesize a series of thiohydroxamic acids (**4a**–**g**) in 21–76% yield over three steps and only one purification from the corresponding aldehyde (Table 1). Aryl (**4a**–**c**), heteroaryl (**4d**,**e**), and alkyl

Table 1. Substrate Scope of Thiohydroxamic Acid Formation

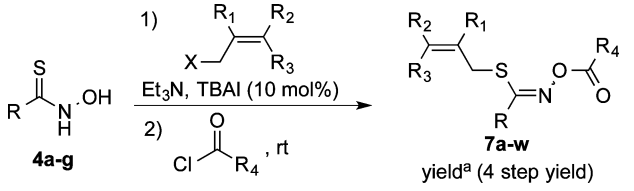


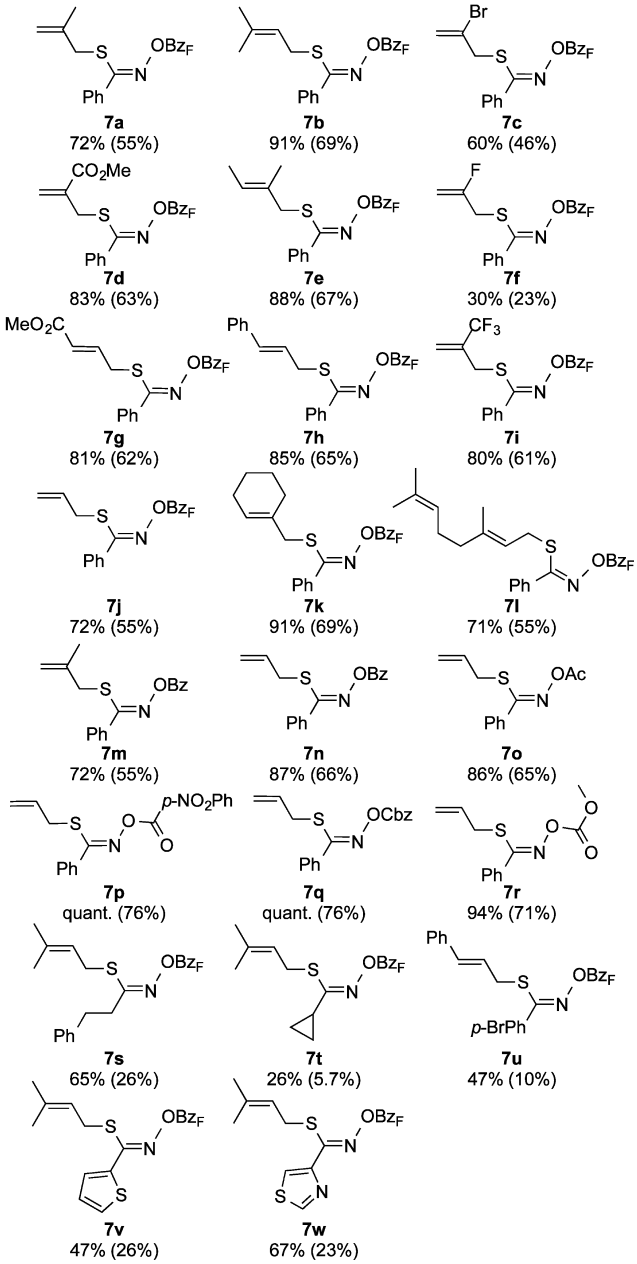
(**4f**,**g**) substituted oximes were well tolerated in the reaction, providing an expanded substrate scope for this transformation. The variance in yield for these reactions stems from the varying stability of the intermediate nitrile oxides (generated *in situ* from the *N*-hydroxyimidoyl chlorides) as these intermediates can readily undergo dimerization and other decomposition pathways.[12]

We next sought to convert the thiohydroxamic acids to a variety of *S*-alkyl-*O*-acyl derivatives via the one-pot alkylation/acylation approach. Acylation of the oxygen effectively weakens the N–O bond, allowing for the potential application of these derivatives in transition metal mediated and radical reactions.[15] Employing this method a series of thiohydroximic acid derivatives (**7a**–**w**) were prepared in 30% to quantitative yield (6–76% overall over four steps, Table 2). Electron-rich and electron-deficient alkenes performed well in the transformation as well as mono- and disubstituted alkenes. Additionally, the acylation could be accomplished with pentafluorobenzoyl

dx.doi.org/10.1021/jo500080x | J. Org. Chem. 2014, 79, 2321–2330

Table 2. Substrate Scope of Thiohydroximic Acid Derivative Formation





[a]Isolated yield. Bz_F = pentafluorobenzoyl; Bz = benzoyl; Ac = acetyl; Cbz = carboxybenzyl.

(**7a**–**l**, **7s**–**w**), benzoyl (**7m**,**n**), acetyl (**7o**), nitrobenzoyl (**7p**), carboxybenzyl (**7q**), and carboxymethyl (**7r**) groups in high yield. In all cases variation in yield is reflective of the thiohydroxamic acid formation (Table 1) as the alkylation/acylation steps proceed in moderate to high yield over two steps. It is important to note that the reaction products are readily purified via silica gel flash chromatography and have been stable to storage at room temperature for months without decomposition.

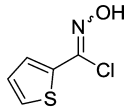
In conclusion, we have optimized a procedure for the preparation of *N*-unsubstituted thiohydroxamic acids and developed a one-pot preparation of thiohydroximic acid derivatives. A variety of functional groups are well tolerated, and products bearing alkene groups and activated *N*-*O* bonds are readily prepared. These thiohydroximic acid products are functionalized to undergo a variety of further organic transformations and serve as new heteroatom building blocks for synthesis.

EXPERIMENTAL SECTION

General Information. THF was purified using an alumina filtration system. Aldehydes were purchased from a commercial chemical company and used as received.

Reactions were monitored by TLC analysis (precoated silica gel 60 F_{254} plates, 250 mm layer thickness), and visualization was accomplished with a 254 nm UV light and by staining with a $KMnO_4$ solution (1.5 g of $KMnO_4$, 10 g of K_2CO_3, and 1.25 mL of a 10% NaOH solution in 200 mL of water). Reactions were also monitored by LC–MS (2.6 mm C18 50 × 2.10 mm column). Flash chromatography on SiO_2 was used to purify the crude reaction mixtures and performed on a flash system utilizing prepacked cartridges and linear gradients.

Melting points were determined using a capillary melting point apparatus. Infrared spectra were determined on a FT/IR spectrometer. ^1H, ^{13}C, and ^{19}F NMR spectra were obtained on a 400 MHz instrument in $CDCl_3$ unless otherwise noted. Chemical shifts were reported in parts per million with the residual solvent peak used as an internal standard ($CDCl_3$ = 7.26 ppm for ^1H and 77.16 ppm for ^{13}C). ^1H NMR spectra were run at 300 or 400 MHz and are tabulated as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, bs = broad singlet, dt = doublet of triplet, tt = triplet of triplet), number of protons, and coupling constant(s). ^{13}C NMR spectra were run at 100 MHz using a proton-decoupled pulse sequence with a d_1 of 0 s unless otherwise noted and are tabulated by observed peak. C═S and C═O peaks are reported only for selected products (due to tautomers). Extended delay times and multiday experiments were required to observe these peaks on 50+ mg quantities. ^{19}F NMR spectra were run at 376 MHz and are tabulated as follows: chemical shift, multiplicity (m = multiplet, tt = triplet of triplet), number of fluorines, and coupling constant(s). High-resolution mass spectra were obtained on an ion trap mass spectrometer using heated electrospray ionization (HESI).



3d

*N-Hydroxythiophene-2-carbimidoyl Chloride (**3d**). General Protocol A.* To thiophene-2-carbaldehyde oxime (0.50 g, 3.9 mmol) in DMF (3.9 mL) at 0 °C was added 1/5 portion of NCS (0.56 g, 4.1 mmol), and the reaction mixture was stirred at 0 °C for 1 h. The remaining of the NCS was added portion wise over 1 h while the temperature was slowly warmed to rt. The reaction mixture was stirred at rt for 2 h, poured into iced water (16 mL), and extracted with EtOAc, and the organic layer was separated, washed with water, dried ($MgSO_4$), and concentrated *in vacuo*. The residue was purified by flash chromatography on SiO_2 (hexanes/EtOAc, 0 to 12%) to yield 0.46 g (72%) of **3d** (mixture of two isomers) as a yellow solid: ^1H NMR (400 MHz) δ 7.82 (bs, 1 H), 7.58 (d, 0.1 H, J = 4.8 Hz, minor), 7.54 (dd, 1 H, J = 3.8, 1.2 Hz, major), 7.38 (dd, 1 H, J = 5.1, 1.3 Hz, major), 7.31 (d, 0.1 H, J = 4.0 Hz, minor), 7.06 (dd, 1 H, J = 5.1, 3.8 Hz, major), 6.88 (d, 0.1 H, J = 4.1 Hz, minor); ^{13}C NMR δ 135.3, 135.2, 130.0, 128.9, 127.3; IR (film) 3298, 3100, 1624, 1582, 1000, 838 cm^{-1}; HRMS m/z calcd for C_5H_5ClNOS $[M + H]^+$ 161.9775, found 161.9774.

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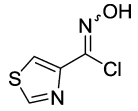
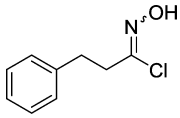


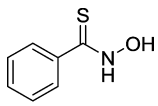
3e

*N-Hydroxythiazole-4-carbimidoyl Chloride (**3e**). General Protocol B.* To a stirred solution of thiazole-4-carbaldehyde (0.50 g, 4.5 mmol) in EtOH (8.7 mL) was added hydroxylamine hydrochloride (0.34 g, 4.8 mmol) followed by pyridine (0.39 mL, 4.8 mmol). The reaction mixture was stirred for 2 h at rt, quenched with satd aq NH_4Cl, and extracted with EtOAc. The organic layer was separated, dried ($MgSO_4$), and concentrated *in vacuo* to yield 0.53 g (95%) of thiazole-4-carbaldehyde oxime as a yellow solid (mixture of isomers) after extraction: ^{1}H NMR (400 MHz) δ 8.88 (d, 1 H, J = 1.8 Hz, major), 8.85 (d, 0.7 H, J = 2.0 Hz, minor), 8.36 (d, 0.7 H, J = 2.0 Hz, minor), 8.34 (s, 1 H, major), 7.86 (s, 0.7 H, minor), 7.63 (d, 1 H, J = 2.0 Hz, major); ^{13}C NMR (d_1 = 1 s) δ 153.9, 152.2, 149.6, 146.3, 144.5, 140.6, 124.9, 118.4; IR (film) 3208, 3076, 2920, 2854, 1636, 1510, 976, 820 cm^{-1}; ESIMS m/z 129 $[M + H]^+$; HRMS m/z calcd for $C_4H_5N_2OS$ $[M + H]^+$ 129.0117, found 129.0119; mp = 115−122 °C. According to general protocol A, thiazole-4-carbaldehyde oxime (0.52 g, 4.1 mmol) and NCS (0.58 g, 4.3 mmol) in DMF (4.1 mL) for 4 h afforded 0.36 g (54%) of **3e** as a white crystalline solid after filtration: ^{1}H NMR (DMSO-d_6, 400 MHz) δ 12.46 (s, 1 H), 9.18 (dd, 1 H, J = 2.0, 1.0 Hz), 8.15 (dd, 1 H, J = 2.0, 1.0 Hz); ^{13}C NMR (DMSO-d_6) δ 155.6, 148.4, 131.0, 121.1; IR (film) 3300, 3070, 1537, 997, 808 cm^{-1}; ESIMS m/z 163 $[M + H]^+$; HRMS m/z calcd for $C_4H_4ClN_2OS$ $[M + H]^+$ 162.9727, found 162.9727; mp > 175 °C.



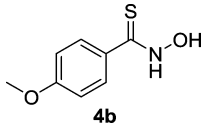
3g

*N-Hydroxy-3-phenylpropanimidoyl Chloride (**3g**).* According to general protocol B, 3-phenylpropanal oxime (0.40 g, 2.7 mmol) and NCS (0.38 g, 2.8 mmol) in DMF (2.7 mL) for 1 h afforded 0.42 g (86%) of **3g** (mixture of isomers) as a pale yellow oil after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 20%): ^{1}H NMR (400 MHz) δ 7.45 (s, 1 H), 7.34−7.27 (m, 2.4 H, major and minor), 7.25−7.19 (m, 3 H, major), 7.09−7.06 (m, 0.6 H, minor), 2.97 (dd, 2 H, J = 8.9, 6.3 Hz, major), 2.84−2.79 (m, 2 H, major), 2.61 (t, 0.4 H, J = 7.2 Hz, minor), 2.47−2.42 (m, 0.4 H, minor); ^{13}C NMR δ 141.3, 139.7, 128.7, 128.5, 126.6, 38.6, 32.6; IR (film) 3298, 3028, 2932, 1636, 1492, 1456, 952, 688 cm^{-1}; HRMS m/z calcd for $C_9H_{11}ClNO$ $[M + H]^+$ 184.0524, found 184.0524.



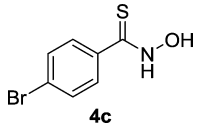
4a

*N-Hydroxybenzothioamide (**4a**). General Protocol C.* To a stirred solution of *N*-hydroxybenzimidoyl chloride **3a**[16] (2.00 g, 12.9 mmol) in Et_2O (172 mL) was added an aqueous solution of Na_2S (9.26 g, 38.6 mmol) followed by Et_3N (1.79 mL, 12.9 mmol). The reaction mixture was stirred for 1 h and poured into a separatory funnel. The Et_2O was separated from the aqueous, which was acidified to pH = 2 with 5 M HCl, extracted with dichloromethane, dried ($MgSO_4$), and concentrated *in vacuo* to yield 1.71 g (87%) of **4a** as a green solid: ^{1}H NMR (400 MHz) δ 8.17 (bs, 2 H), 7.69−7.64 (m, 2 H), 7.52−7.38 (m, 3 H); ^{13}C NMR δ 171.5, 135.3, 131.5, 129.1, 127.0; IR (film) 3177, 3061, 2572, 1556, 960, 691 cm^{-1}; ESIMS m/z 152 $[M - H]^-$; HRMS m/z calcd for C_7H_8NOS $[M + H]^+$ 154.0321, found 154.0321; mp = 39−40 °C.



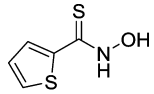
4b

*N-Hydroxy-4-methoxybenzothioamide (**4b**).* According to general protocol C, *N*-hydroxy-4-methoxybenzimidoyl chloride **3b**[17] (0.10 g, 0.54 mmol), Et_3N (0.075 mL, 0.54 mmol), and Na_2S (0.39 g, 1.6 mmol) afforded 0.40 g (41%) of **4b** as a yellow solid after extraction: ^{1}H NMR (400 MHz) δ 7.67 (d, 2 H, J = 8.8 Hz), 6.93 (d, 2 H, J = 8.8 Hz), 3.85 (s, 3 H); ^{13}C NMR δ 162.4, 128.5, 127.6, 114.2, 55.6 (C═S not visible under experimental conditions); IR (film) 3136, 3004, 2884, 1600, 1396, 1174, 964, 838 cm^{-1}; ESIMS m/z 182 $[M - H]^-$; HRMS m/z calcd for $C_8H_{10}NO_2S$ $[M + H]^+$ 184.0427, found 184.0425; mp = 96−98 °C.



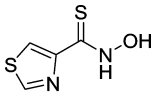
4c

*4-Bromo-N-hydroxybenzothioamide (**4c**).* According to general protocol C, 4-bromo-*N*-hydroxybenzimidoyl chloride **3c**[18] (0.43 g, 1.8 mmol), Et_3N (0.25 mL, 1.8 mmol), and Na_2S (1.3 g, 5.5 mmol) afforded 0.13 g (32%) of **4c** as a yellow solid after extraction: ^{1}H NMR (400 MHz) δ 7.57 (s, 4 H); ^{13}C NMR δ 133.9, 132.2, 128.3, 125.8 (C═S not visible under experimental conditions); IR (film) 3148, 3028, 1588, 826 cm^{-1}; ESIMS m/z 230, 232 $[M - H]^-$; HRMS m/z calcd for C_7H_5BrNOS $[M - H]^-$ 229.9273, found 229.9273; mp = 106−110 °C.



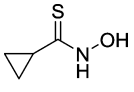
4d

*N-Hydroxythiophene-2-carbothioamide (**4d**).* According to general protocol C, *N*-hydroxythiophene-2-carbimidoyl chloride **3d**[19] (0.32 g, 2.0 mmol), Et_3N (0.27 mL, 2.0 mmol), and Na_2S (1.5 g, 5.9 mmol) afforded 0.24 g (77%) of **4d** as a brown oil (two tautomers) after extraction: ^{1}H NMR (400 MHz) δ 7.66−7.61 (m, 0.6 H, minor), 7.48−7.43 (m, 2 H, major), 7.14 (dd, 0.3 H, J = 5.0, 3.8 Hz, minor), 7.08−7.06 (m, 1 H, major); ^{13}C NMR δ 138.3, 129.8, 127.8, 126.9 (C═S not visible under experimental conditions); IR (film) 3454, 3328, 3094, 2220, 1648, 1588, 718 cm^{-1}; ESIMS m/z 158 $[M - H]^-$; HRMS m/z calcd for $C_5H_4NOS_2$ $[M - H]^-$ 157.9729, found 157.9729.



4e

*N-Hydroxythiazole-4-carbothioamide (**4e**).* According to general protocol C, *N*-hydroxythiazole-4-carbimidoyl chloride **3e** (0.33 g, 2.0 mmol), Et_3N (0.28 mL, 2.0 mmol), and Na_2S (1.5 g, 6.1 mmol) afforded 0.21 g (66%) of **4e** as an off white crystalline solid after extraction: ^{1}H NMR (400 MHz) δ 8.90 (d, 1 H, J = 2.1 Hz), 8.34 (d, 1 H, J = 2.1 Hz); ^{13}C NMR δ 154.1, 150.3, 125.2 (C═S not visible under experimental conditions); IR (film) 3173, 3093, 1566, 682 cm^{-1}; ESIMS m/z 159 $[M - H]^-$; HRMS m/z calcd for $C_4H_5N_2OS_2$ $[M + H]^+$ 160.9838, found 160.9835; mp = 102−104 °C.

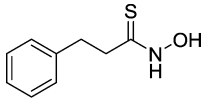


4f

*N-Hydroxycyclopropanecarbothioamide (**4f**).* According to general protocol C, *N*-hydroxycyclopropanecarbimidoyl chloride **3f** (0.16 g, 1.3 mmol), Et_3N (0.18 mL, 1.3 mmol), and Na_2S (0.95 g, 4.0 mmol) afforded 0.071 g (46%) of **4f** as a yellow solid (two tautomers) after extraction: ^{1}H NMR (400 MHz) δ 1.80−1.72

dx.doi.org/10.1021/jo500080x | J. Org. Chem. 2014, 79, 2321−2330

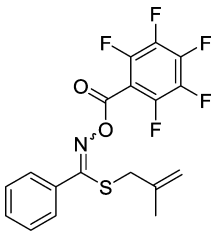
(m, 1 H, major), 1.37−1.30 (m, 0.6 H, minor), 1.39−1.24 (m, 2 H, major), 1.11−1.06 (m, 1.4 H, minor), 1.06−0.96 (m, 3.7 H, major and minor); ^{13}C NMR δ 18.8, 10.4, 7.3 (C═S not visible under experimental conditions); IR (film) 3508, 3190, 2920, 1378 cm^{-1}; ESIMS m/z 116 [M − H]$^-$; HRMS m/z calcd for C_4H_6NOS [M − H]$^-$ 116.0165, found 116.0161; mp = 111−112 °C.



4g

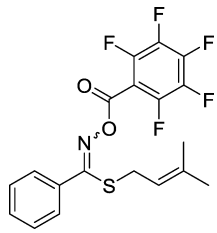
*N-Hydroxy-3-phenylpropanethioamide (**4g**).* According to general protocol C, *N*-hydroxy-3-phenylpropanimidoyl chloride **3g** (0.40 g, 2.2 mmol), Et_3N (0.31 mL, 2.2 mmol), and Na_2S (1.6 g, 6.6 mmol) afforded 0.15 g (37%) of **4g** as a yellow solid (4:1 mixture of tautomers) after extraction: ^{1}H NMR (400 MHz) δ 7.36−7.28 (m, 2.5 H, major and minor), 7.25−7.18 (m, 4 H, major and minor), 3.06 (t, 2 H, J = 7.5 Hz, major), 2.97 (t, 0.5 H, J = 7.5 Hz, minor), 2.84−2.81 (m, 2 H, major), 2.63 (t, 0.5 H, J = 7.4 Hz, minor); ^{13}C NMR (d_1 = 1 s) δ 139.8, 128.8, 128.5, 126.8, 41.1, 34.2, C═S not visible under experimental conditions; IR (film) 3316, 3190, 3064, 2920, 2566, 1450, 1366, 700 cm^{-1}; ESIMS m/z 180 [M − H]$^-$; HRMS m/z calcd for $C_9H_{10}NOS$ [M − H]$^-$ 180.0489, found 180.0480; mp = 45−48 °C.

General Protocol D: One-Pot Allylation and Acylation of Thiohydroxamic Acids. To a stirred solution of thiohydroxamic acid (1 equiv) in Et_2O or THF (0.1 M) was added allyl bromide or chloride derivative (1 equiv), tetrabutylammonium iodide (TBAI) (0.1 equiv), and Et_3N (1 equiv). The reaction mixture was stirred at rt or 60 °C for 1.5−3 h, then Et_3N (1.2 equiv) and acylating agent (1.2 equiv) were added at rt, and the reaction mixture was stirred for 30 min. After completion the reaction was quenched with 10% aqueous solution of $Na_2S_2O_3$, stirred for 15 min, and extracted with EtOAc, and the organic layer was separated, washed with $NaHCO_3$, water and brine, dried ($MgSO_4$), and concentrated *in vacuo*. The residue was purified by chromatography on SiO_2 to yield the pure product.



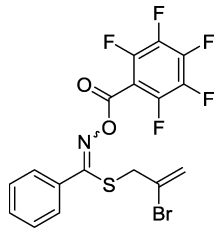
7a

*2-Methylallyl N-(Perfluorobenzoyl)oxybenzimidothioate (**7a**).* According to general protocol D, *N*-hydroxybenzothioamide **4a** (0.751 g, 4.90 mmol), 3-chloro-2-methyl-1-propene (505 μL, 4.90 mmol), Et_3N (684 μL, 4.90 mmol), TBAI (183 mg, 0.490 mmol), Et_3N (820 μL, 5.88 mmol), and pentafluorobenzoyl chloride (864 μL, 5.88 mmol) in THF (49.0 mL) at 60 °C afforded 1.41 g (72%) of **7a** as a yellow solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 7%): ^{1}H NMR (400 MHz) δ 7.51−7.46 (m, 5 H), 4.76 (s, 1 H), 4.55 (s, 1 H), 3.20 (s, 2 H), 1.68 (s, 3 H); ^{13}C NMR δ 168.7, 156.2, 139.5, 131.0, 130.9, 129.2, 128.9, 115.4, 39.8, 21.2; ^{19}F NMR δ −136.8−136.9 (m, 2 F), −147.8−147.9 (m, 1 F), −160.1−160.3 (m, 2 F); IR (film) 3052, 2920, 1762, 1648, 1522, 1492, 1414, 1330, 1198, 1000, 916, 874 cm^{-1}; ESIMS m/z 402 [M + H]$^+$; HRMS m/z calcd for $C_{18}H_{12}F_5NO_2SNa$ [M + Na]$^+$ 424.0401, found 424.0399; mp = 60−61 °C.



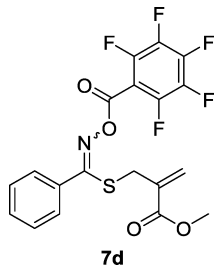
7b

*3-Methylbut-2-en-1-yl N-((Perfluorobenzoyl)oxy)benzimidothioate (**7b**).* According to general protocol D, *N*-hydroxybenzothioamide **4a** (0.200 g, 1.31 mmol), 1-bromo-3-methyl-2-butene (0.160 g, 1.31 mmol), Et_3N (0.182 mL, 1.31 mmol), TBAI (49.0 mg, 0.131 mmol), Et_3N (0.219 mL, 1.57 mmol), and pentafluorobenzoyl chloride (0.228 mL, 1.57 mmol) in Et_2O (13.1 mL) at rt afforded 0.493 g 91%) of **7b** as a off-white solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 10%): ^{1}H NMR (300 MHz) δ 7.53−7.45 (m, 5 H), 5.05−4.99 (m, 1 H), 3.21 (d, 2 H, J = 7.8 Hz), 1.65 (s, 3 H), 1.41 (s, 3 H); ^{13}C NMR δ 169.1, 138.7, 131.6, 130.8, 129.0, 117.6, 31.3, 25.7, 17.7 (C═O not visible under experimental conditions); ^{19}F NMR δ −136.8−136.9 (m, 2 F), −147.9−148.0 (m, 1 F), −160.2−160.4 (m, 2 F); IR (film) 3058, 3034, 1768, 1654, 1546, 1504, 1426, 1324, 1186, 1000, 910, 862 cm^{-1}; ESIMS m/z 416 [M + H]$^+$; HRMS m/z calcd for $C_{19}H_{14}F_5NO_2SNa$ [M + Na]$^+$ 438.0558, found 438.0552; mp = 71−73 °C.



7c

*2-Bromoallyl N-(Perfluorobenzoyl)oxybenzimidothioate (**7c**).* According to general protocol D, *N*-hydroxybenzothioamide **4a** (0.200 g, 1.31 mmol), 2,3-dibromopropene (0.153 g, 1.31 mmol), Et_3N (182 μL, 1.31 mmol), TBAI (48.7 mg, 0.131 mmol), Et_3N (219 μL, 1.57 mmol), and pentafluorobenzoyl chloride (230 μL, 1.57 mmol) in Et_2O (13.0 mL) at rt afforded 0.362 g (60%) of **7c** as a white solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 15%): ^{1}H NMR (400 MHz) δ 7.54−7.46 (m, 5 H), 5.47 (s, 1 H), 5.43 (d, 1 H, J = 2.3 Hz), 3.57−3.56 (m, 2 H); ^{13}C NMR δ 166.9, 131.2, 130.4, 129.3, 129.1, 127.2, 120.5, 42.0 (C═O not visible under the experimental conditions); ^{19}F NMR δ −136.7−136.6 (m, 2 F), −147.4−145.5 (m, 1 F), −160.0−160.1 (m, 2 F); IR (film) 3060, 2919, 1766, 1652, 1625, 1504, 1420, 1326, 1189, 1004, 914, 864 cm^{-1}; ESIMS m/z 466, 468 [M + H]$^+$; HRMS m/z calcd for $C_{17}H_9BrF_5NO_2SNa$ [M + Na]$^+$ 487.9350, found 487.9348; mp = 45−46 °C.



7d

*Methyl 2-(((((Perfluorobenzoyl)oxy)imino)(phenyl)methyl)thio)methyl)acrylate (**7d**).* According to general protocol D, *N*-hydroxybenzothioamide **4a** (0.10 g, 0.65 mmol), methyl 2-(bromomethyl)acrylate (82 μL, 0.65 mmol), Et_3N (91 μL, 0.65 mmol), TBAI (24 mg, 0.065 mmol), Et_3N (0.11 mL, 0.78 mmol), and pentafluorobenzoyl chloride (0.11 mL, 0.78 mmol) in Et_2O (6.5 mL) at rt afforded 0.24 g (83%) of **7d** as a white solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 25%): ^{1}H NMR (400 MHz)

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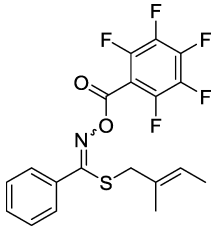
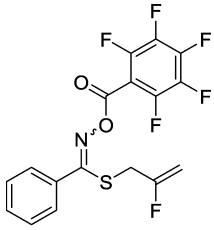
δ 7.52−7.46 (m, 5 H), 6.14 (s, 1 H), 5.26 (d, 1 H, J = 0.7 Hz), 3.74 (s, 3 H), 3.51 (d, 2 H, J = 0.9 Hz); ^{13}C NMR δ 168.0, 165.7, 135.5, 131.1, 130.8, 129.3, 129.0, 128.6, 52.4, 33.4 (C═O not visible under the experimental conditions); ^{19}F NMR δ −136.7−136.8 (m, 2 F), −147.7 (tt, 1 F, J = 21.0, 4.9 Hz), −160.1−160.3 (m, 2 F); IR (film) 3064, 3004, 2962, 1768, 1726, 1648, 1522, 1498, 1420, 1198, 1006, 916, 868, 742 cm^{-1}; ESIMS m/z 446 [M + H]$^+$; HRMS m/z calcd for $C_{19}H_{12}F_5NO_4SNa$ [M + Na]$^+$ 468.0299, found 468.0299; mp = 49−50 °C.



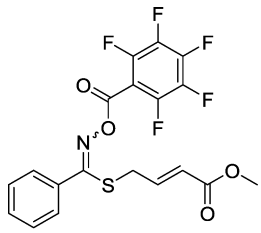
7e

*(E)-2-Methylbut-2-en-1-yl N-(Perfluorobenzoyl)oxybenzimidothioate (**7e**).* According to general protocol D, *N*-hydroxybenzothioamide **4a** (0.10 g, 0.65 mmol), (*E*)-1-bromo-2-methylbut-2-ene[20] (0.20 g, 0.65 mmol), Et_3N (91 μL, 0.65 mmol), TBAI (65 mg, 0.065 mmol), Et_3N (0.11 mL, 0.78 mmol), and pentafluorobenzoyl chloride (0.11 mL, 0.78 mmol) in Et_2O (6.5 mL) at rt afforded 0.24 g (88%) of **7e** as a white solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 10%): ^{1}H NMR (300 MHz) δ 7.50−7.46 (m, 5 H), 4.99−4.92 (m, 1 H), 3.20 (s, 2 H), 1.59−1.58 (m, 3 H), 1.49−1.46 (m, 3 H); ^{13}C NMR (d_1 = 5 s) δ 169.0, 156.3, 131.4, 130.8, 129.6, 129.2, 128.8, 124.9, 42.3, 14.8, 13.7; ^{19}F NMR δ −136.9−136.9 (m, 2 F), −148.0 (tt, 1 F, J = 21.2, 5.1 Hz), −160.2−160.4 (m, 2 F); IR (film) 3058, 3022, 2926, 1762, 1648, 1504, 1426, 1324, 1000, 910, 862 cm^{-1}; ESIMS m/z 416 [M + H]$^+$; HRMS m/z calcd for $C_{19}H_{14}F_5NO_2SNa$ [M + Na]$^+$ 438.0558, found 438.0558; mp = 66−67 °C.



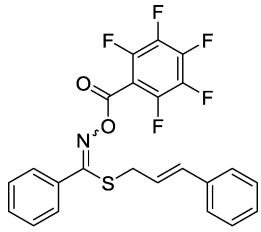
7f

*2-Fluoroallyl N-(Perfluorobenzoyl)oxybenzimidothioate (**7f**).* According to general protocol D, *N*-hydroxybenzothioamide **4a** (0.300 g, 1.96 mmol), 2-fluoro-3-(methylsulfonyl)prop-1-ene[21] (0.302 g, 1.96 mmol), Et_3N (273 μL, 1.96 mmol), TBAI (73.1 mg, 0.196 mmol), Et_3N (328 μL, 2.35 mmol), and pentafluorobenzoyl chloride (342 μL, 2.45 mmol) in Et_2O (6.50 mL) at rt afforded 0.230 g (29%) of **7f** as a yellow solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 15%): ^{1}H NMR (400 MHz) δ 7.55−7.47 (m, 5 H), 4.57 (dd, 1 H, J = 15.5, 3.4 Hz), 4.11 (dd, 1 H, J = 47.2, 3.4 Hz), 3.34 (d, 2 H, J = 15.5 Hz); ^{13}C NMR δ 167.0, 160.1 (d, $^1J_{C-F}$ = 257.1 Hz), 131.2, 130.4, 129.3, 129.1, 93.9 (d, $^2J_{C-F}$ = 18.6 Hz), 33.2 (d, $^2J_{C-F}$ = 31.3 Hz) (C═O not visible under the experimental conditions); ^{19}F NMR δ −98.9−99.2 (m, 1 F), −136.6−139.9 (m, 2 F), −147.4−147.5 (m, 1 F), −160.0−160.2 (m, 2 F); IR (film) 3064, 3016, 2932, 1768, 1678, 1654, 1498, 1444, 1330, 1186, 1000, 916, 868 cm^{-1}; ESIMS m/z 406 [M + H]$^+$; HRMS m/z calcd for $C_{17}H_9F_6NO_2SNa$ [M + Na]$^+$ 428.0150, found 428.0151; mp = 45−49 °C.



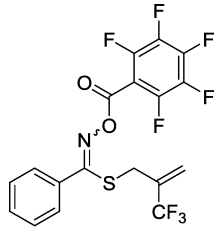
7g

*(2E)-Methyl 4-(((((Perfluorobenzoyl)oxy)imino)(phenyl)methyl)thio)but-2-enoate (**7g**).* According to general protocol D, *N*-hydroxybenzothioamide **4a** (0.10 g, 0.65 mmol), methyl 4-bromocrotonate (90 μL, 0.65 mmol), Et_3N (91 μL, 0.65 mmol), TBAI (24 mg, 0.065 mmol), Et_3N (0.11 mL, 0.78 mmol), and pentafluorobenzoyl chloride (0.11 mL, 0.78 mmol) in Et_2O (6.5 mL) at rt afforded 0.24 g (81%) of **7g** as a off-white solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 30%): ^{1}H NMR (300 MHz) δ 7.53−7.48 (m, 5 H), 6.63 (dt, 1 H, J = 15.6, 7.2 Hz), 5.47 (d, 1 H, J = 15.5 Hz), 3.71 (s, 3 H), 3.37 (dd, 2 H, J = 7.1, 1.3 Hz); ^{13}C NMR δ 167.0, 165.9, 141.2, 131.3, 130.6, 129.1, 124.1, 51.9, 33.5 (C═O not visible under the experimental conditions); ^{19}F NMR δ −136.6−136.7 (m, 2 F), −147.5 (tt, 1 F, J = 21.2, 5.4 Hz), −160.0−160.2 (m, 2 F); IR (film) 3064, 2998, 2956, 1762, 1648, 1504, 1438, 1324, 1192, 1000, 910, 862 cm^{-1}; ESIMS m/z 446 [M + H]$^+$; HRMS m/z calcd for $C_{19}H_{12}F_5NO_4SNa$ [M + Na]$^+$ 468.0299, found 468.0301; mp = 67−68 °C.



7h

*Cinnamyl N-(Perfluorobenzoyl)oxybenzimidothioate (**7h**).* According to general protocol D, *N*-hydroxybenzothioamide **4a** (0.10 g, 0.65 mmol), cinnamyl bromide (0.10 mL, 0.65 mmol), Et_3N (91 μL, 0.65 mmol), TBAI (24 mg, 0.065 mmol), Et_3N (0.11 mL, 0.78 mmol), and pentafluorobenzoyl chloride (0.11 mL, 0.78 mmol) in Et_2O (6.5 mL) at rt afforded 0.26 g (85%) of **7g** as a white solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 7%): ^{1}H NMR (300 MHz) δ 7.54−7.48 (m, 5 H), 7.29−7.19 (m, 5 H), 5.96−5.93 (m, 2 H), 3.44−3.42 (m, 2 H); ^{13}C NMR δ 168.2, 136.0, 134.2, 131.2, 131.0, 129.2, 129.0, 128.7, 128.2, 126.5, 123.0, 35.6 (C═O not visible under the experimental conditions); ^{19}F NMR δ −136.8−136.7 (m, 2 F), −147.7−147.8 (m, 1 F), −160.3−160.1 (m, 2 F); IR (film) 3056, 3028, 2920, 1768, 1654, 1498, 1414, 1318, 1084, 1000, 916, 862 cm^{-1}; ESIMS m/z 464 [M + H]$^+$; HRMS m/z calcd for $C_{23}H_{14}F_5NO_2SNa$ [M + Na]$^+$ 486.0558, found 486.0560; mp = 124−125 °C.

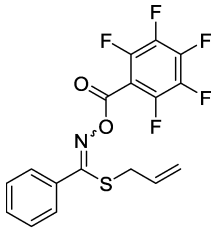


7i

*2-(Trifluoromethyl)allyl N-(Perfluorobenzoyl)oxybenzimidothioate (**7i**).* According to general protocol D, *N*-hydroxybenzothioamide **4a** (0.150 g, 0.979 mmol), 2-bromomethyl-3,3,3-trifluoropropene (0.185 g, 0.979 mmol), Et_3N (135 μL, 0.979 mmol), TBAI (36.7 mg, 0.0979 mmol), Et_3N (164 μL, 1.17 mmol), and pentafluorobenzoyl chloride (171 μL, 1.17 mmol) in Et_2O (9.80 mL) at

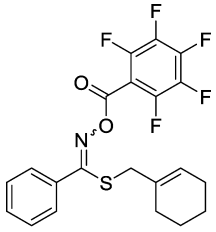
dx.doi.org/10.1021/jo500080x | J. Org. Chem. 2014, 79, 2321−2330

rt afforded 0.358 g (80%) of **7i** as a yellow oil after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 10%): ^{1}H NMR (400 MHz) δ 7.53−7.47 (m, 5 H), 5.77 (s, 1 H), 5.41−5.40 (m, 1 H), 3.39 (s, 2 H); ^{13}C NMR δ 166.9, 133.9, 133.6, 131.3, 130.3, 129.1, 124.0, 122.5, 121.3, 30.9 (C═O not visible under the experimental conditions); ^{19}F NMR δ −68.3 (s, 3 F), −136.7−136.8 (m, 2 F), −147.3−147.5 (m, 1 F), −160.0−160.2 (m, 2 F); IR (film) 3064, 2926, 1768, 1702, 1648, 1504, 1420, 1270, 1192, 1126, 1006, 916, 868 cm^{-1}; HRMS m/z calcd for $C_{18}H_9F_8NO_2SNa$ $[M + Na]^+$ 478.0119, found 478.0115.



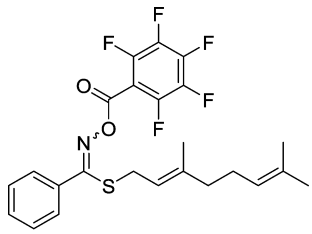
7j

*Allyl N-(Perfluorobenzoyl)oxybenzimidothioate (**7j**).* According to general protocol D, *N*-hydroxybenzothioamide **4a** (0.200 g, 1.31 mmol), allyl bromide (116 μL, 1.31 mmol), Et_3N (182 μL, 1.31 mmol), TBAI (48.7 mg, 0.130 mmol), Et_3N (219 μL, 1.57 mmol), and pentafluorobenzoyl chloride (230 μL, 1.57 mmol) in Et_2O (13.0 mL) at rt afforded 0.391 g (77%) of **7j** as a white solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 10%): ^{1}H NMR (400 MHz) δ 7.52−7.45 (m, 5 H), 5.67−5.57 (m, 1 H), 5.03−5.00 (m, 1 H), 4.89−4.84 (m, 1 H), 3.26−3.23 (m, 2 H); ^{13}C NMR δ 168.3, 132.0, 131.1, 131.0, 129.2, 128.9, 119.3, 35.7 (C═O not visible under the experimental conditions); ^{19}F NMR δ −136.8−136.7 (m, 2 F), −147.8−147.7 (m, 1 F), −160.3−160.1 (m, 2 F); IR (film) 3082, 3064, 2932, 1762, 1654, 1510, 1426, 1324, 1192, 1006, 916, 862 cm^{-1}; ESIMS m/z 388 $[M + H]^+$; HRMS m/z calcd for $C_{17}H_{10}F_5NO_2SNa$ $[M + Na]^+$ 410.0245, found 410.0243; mp = 65−66 °C.



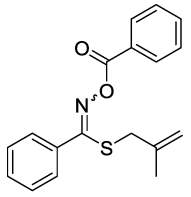
7k

*Cyclohex-1-en-1-ylmethyl N-((Perfluorobenzoyl)oxy)benzimidothioate (**7k**).* According to general protocol D, *N*-hydroxybenzothioamide **4a** (0.200 g, 1.31 mmol), 1-(bromomethyl)cyclohex-1-ene[22] (116 μL, 1.31 mmol), Et_3N (183 μL, 1.31 mmol), TBAI (48.7 mg, 0.130 mmol), Et_3N (219 μL, 1.57 mmol), and pentafluorobenzoyl chloride (228 μL, 1.57 mmol) in Et_2O (13.0 mL) at rt afforded 0.523 g (91%) of **7k** as a white solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 10%): ^{1}H NMR (400 MHz) δ 7.50−7.43 (m, 5 H), 5.19 (s, 1 H), 3.15 (s, 1 H), 1.87 (s, 4 H), 1.59−1.55 (m, 2 H), 1.50−1.46 (m, 2 H); ^{13}C NMR δ 169.1, 131.8, 131.3, 130.7, 129.2, 128.8, 127.2, 40.5, 27.1, 25.3, 22.6, 22.0 (C═O not visible under the experiment conditions); ^{19}F NMR δ −136.8−136.9 (m, 2 F), −147.9−148.1 (m, 1 F), −160.2−160.3 (m, 2 F); IR (film) 3058, 2932, 1762, 1648, 1540, 1522, 1504, 1420, 1324, 1192, 1000, 916, 856 cm^{-1}; ESIMS m/z 442 $[M + H]^+$; HRMS m/z calcd for $C_{21}H_{17}F_5NO_2S$ $[M + H]^+$ 442.0895, found 442.0886; mp = 52−56 °C.



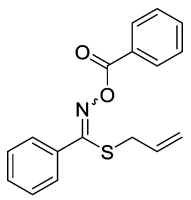
7l

*(E)-7-Methylocta-2,6-dien-1-yl N-((Perfluorobenzoyl)oxy)-benzimidothioate (**7l**).* According to general protocol D, *N*-hydroxybenzothioamide **4a** (0.200 g, 1.31 mmol), geranyl bromide (270 μL, 1.31 mmol), Et_3N (182 μL, 1.31 mmol), TBAI (48.7 mg, 0.130 mmol), Et_3N (219 μL, 1.57 mmol), and pentafluorobenzoyl chloride (228 μL, 1.57 mmol) in Et_2O (13.1 mL) at rt afforded 0.450 g (71%) of **7l** as a white solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 7%): ^{1}H NMR (400 MHz) δ 7.52−7.46 (m, 5 H), 5.04−4.99 (m, 2 H), 3.22 (d, 2 H, J = 7.8 Hz), 2.02−1.92 (m, 4 H), 1.66 (s, 3 H), 1.57 (s, 3 H), 1.41 (s, 3 H); ^{13}C NMR δ 169.1, 142.2, 132.1, 131.6, 130.8, 129.0, 123.6, 117.4, 39.5, 31.2, 26.3, 25.8, 17.8, 16.1 (C═O not visible under the experimental conditions); ^{19}F NMR δ −136.8−136.9 (m, 2 F), −147.9−148.1 (m, 1 F), −160.2−160.4 (m, 2 F); IR (film) 3064, 3028, 2920, 1768, 1648, 1540, 1504, 1420, 1324, 1186, 1000, 916, 856 cm^{-1}; ESIMS m/z 484 $[M + H]^+$; HRMS m/z calcd for $C_{24}H_{23}F_5NO_2S$ $[M + H]^+$ 484.1364, found 484.1358; mp = 42−44 °C.



7m

*2-Methylallyl N-Benzoyloxybenzimidothioate (**7m**).* According to general protocol D, *N*-hydroxybenzothioamide **4a** (0.619 g, 4.04 mmol), 3-chloro-2-methyl-1-propene (416 μL, 4.04 mmol), Et_3N (564 μL, 4.04 mmol), TBAI (0.151 g, 0.400 mmol), Et_3N (676 μL, 4.85 mmol), and benzoyl chloride (569 μL, 4.85 mmol) in THF (40.4 mL) at 60 °C afforded 0.455 g (36%) of **7m** as a white solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 15%): ^{1}H NMR (400 MHz) δ 8.20−8.17 (m, 2 H), 7.64−7.60 (m, 1 H), 7.54−7.51 (m, 4 H), 1.71 (s, 3 H), 7.49−7.47 (m, 3 H), 4.77−4.76 (m, 1 H), 4.60 (s, 1 H), 3.23 (s, 2 H); ^{13}C NMR δ 166.4, 163.5, 139.9, 133.6, 131.7, 130.5, 130.0, 129.4, 128.9, 128.7, 115.2, 39.6, 21.3; IR (film) 3058, 2932, 1732, 1534, 1438, 1228, 964, 850, 760 cm^{-1}; ESIMS m/z 312 $[M + H]^+$; HRMS m/z calcd for $C_{18}H_{17}NO_2SNa$ $[M + Na]^+$ 334.0872, found 334.0872; mp = 80−81 °C.



7n

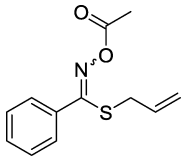
*Allyl N-Benzoyloxybenzimidothioate (**7n**).* According to general protocol D, *N*-hydroxybenzothioamide **4a** (0.200 g, 1.31 mmol), allyl bromide (116 μL, 1.31 mmol), Et_3N (182 μL, 1.31 mmol), TBAI (48.7 mg, 0.0131 mmol), Et_3N (219 μL, 1.57 mmol), and benzoyl chloride (184 μL, 1.57 mmol) in Et_2O (13.0 mL) at rt afforded 0.336 g (87%) of **7n** as a white solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 15%): ^{1}H NMR (400 MHz) δ 8.19−8.17 (m, 2 H), 7.64−7.60 (m, 1 H), 7.54−7.47 (m, 7 H), 5.70−5.61 (m, 1 H), 5.04−5.01 (m, 1 H), 4.92−4.87 (m, 1 H), 3.29−3.26 (m, 2 H); ^{13}C NMR δ 166.0, 163.4, 133.6, 132.4, 131.7, 130.6, 130.0, 129.3, 128.9, 128.8, 128.7, 119.0, 35.5; IR (film) 3064, 3010, 2920, 1738, 1600, 1576, 1534, 1444, 1234, 970, 850, 712 cm^{-1}; ESIMS m/z 298

dx.doi.org/10.1021/jo500080x | J. Org. Chem. 2014, 79, 2321−2330

$[M + H]^+$; HRMS m/z calcd for $C_{17}H_{15}NO_2SNa$ $[M + Na]^+$ 320.0716, found 320.0717; mp = 88−89 °C.

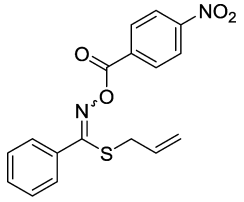
General Protocol E: Acylation of Thiohydroximic Acids. To a stirred solution of *N*-hydroxybenzothioamide **4a** (0.708 g, 4.62 mmol) in Et_2O (46.2 mL) were added allyl bromide (412 μL, 4.62 mmol), tetrabutylammonium iodide (TBAI) (0.172 g, 0.462 mmol), and Et_3N (645 μL, 4.62 mmol). The reaction mixture was stirred at rt for 1.5 h, quenched with water, and extracted with EtOAc, and the organic layer was separated, washed with a 10% aqueous solution of $Na_2S_2O_3$ until the yellow color disappeared, then washed with brine, dried ($MgSO_4$), and concentrated *in vacuo*. The residue was purified by chromatography on SiO_2 (hexanes/EtOAc, 0 to 20%) to yield 0.770 g (86%) of allyl *N*-hydroxybenzimidothioate as a colorless oil: ^1H NMR (400 MHz) δ 9.46 (bs, 1 H), 7.52−7.49 (m, 2 H), 7.43−7.40 (m, 3 H), 5.73−5.63 (m, 1 H), 4.98−4.96 (m, 1 H), 4.89−4.84 (m, 1 H), 3.30−3.28 (m, 2 H); ^{13}C NMR δ 155.4, 133.4, 133.1, 129.9, 128.8, 128.7, 128.7, 118.3, 34.9; IR (film) 3220, 3082, 2980, 1636, 1588, 1492, 1444, 928, 760, 694 cm^{-1}; ESIMS m/z 194 $[M + H]^+$; HRMS m/z calcd for $C_{10}H_{12}NOS$ $[M + H]^+$ 194.06341, found 194.06359.

To a solution of thiohydroximic acid (1 equiv) in DCM (0.1 M) at 0 °C were added Et_3N (1.2 equiv) or pyridine (1.1 equiv) and acylating agent (1.2 eq or 1.1 equiv), and the reaction mixture was stirred for 30 min to 1.5 h. After completion the reaction was quenched with water and extracted with DCM; the organic layer was separated, washed with brine, and dried ($MgSO_4$); and the solvent was removed *in vacuo* to yield the pure product or the residue was purified by chromatography on SiO_2.



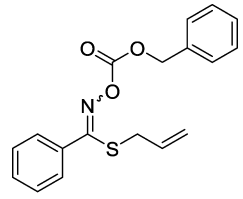
7o

*Allyl N-Acetoxybenzimidothioate (**7o**).* According to general protocol E, allyl *N*-hydroxybenzimidothioate (0.10 g, 0.52 mmol), Et_3N (87 μL, 0.62 mmol), and acetic anhydride (59 μL, 0.62 mmol) in DCM (5.2 mL) afforded 0.13 g (quant) of **7o** as a yellow oil: ^1H NMR (400 MHz) δ 7.46−7.44 (m, 5 H), 5.69−5.59 (m, 1 H), 5.02−4.99 (m, 1 H), 4.90−4.85 (m, 1 H), 3.25−3.23 (m, 2 H), 2.25 (s, 3 H); ^{13}C NMR δ 168.8, 164.8, 132.4, 131.8, 130.6, 129.2, 128.8, 119.0, 35.5, 19.6; IR (film) 3076, 3058, 2926, 1768, 1636, 1552, 1198, 1000, 904, 862, 706 cm^{-1}; ESIMS m/z 236 $[M + H]^+$; HRMS m/z calcd for $C_{12}H_{13}NO_2SNa$ $[M + Na]^+$ 258.0559, found 258.0558.



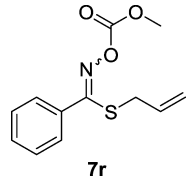
7p

*Allyl N-(4-Nitrobenzoyl)oxybenzimidothioate (**7p**).* According to general protocol E, allyl *N*-hydroxybenzimidothioate (0.10 g, 0.52 mmol), Et_3N (87 μL, 0.62 mmol), and 4-nitrobenzoyl chloride (0.12 g, 0.62 mmol) in DCM (5.2 mL) afforded 0.18 g (quant) of **7p** as a white solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 20%): ^1H NMR (400 MHz) δ 8.35 (s, 4 H), 7.51−7.49 (m, 5 H), 5.71−5.61 (m, 1 H), 5.06−5.03 (m, 1 H), 4.92−4.87 (m, 1 H), 3.30−3.28 (m, 2 H); ^{13}C NMR δ 167.6, 161.6, 150.9, 134.4, 131.3, 131.1, 130.9, 129.2, 128.9, 123.9, 119.3, 35.6; IR (film) 3082, 3058, 2980, 1756, 1606, 1522, 1486, 1402, 1348, 1252, 976, 928, 862 cm^{-1}; ESIMS m/z 343 $[M + H]^+$; HRMS m/z calcd for $C_{17}H_{14}N_2O_4SNa$ $[M + Na]^+$ 365.0567, found 365.0568; mp = 96−97 °C.



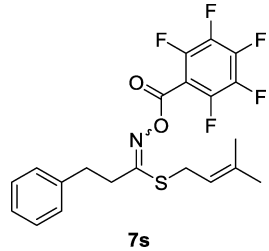
7q

*Allyl N-((Benzyloxy)carbonyl)oxybenzimidothioate (**7q**).* According to general protocol E, allyl *N*-hydroxybenzimidothioate (0.10 g, 0.52 mmol), pyridine (46 μL, 0.57 mmol), and benzyl chloroformate (83 μL, 0.57 mmol) in DCM (5.2 mL) afforded 0.18 g (quant) of **7q** as a white solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 20%): ^1H NMR (400 MHz) δ 7.49−7.36 (m, 10 H), 5.67−5.57 (m, 1 H), 5.30 (s, 2 H), 5.00−4.97 (m, 1 H), 4.88−4.82 (m, 1 H), 3.26−3.24 (m, 2 H); ^{13}C NMR δ 164.7, 153.6, 134.9, 132.3, 131.6, 130.7, 129.2, 128.9, 128.8, 125.7, 119.0, 70.5, 35.6; IR (film) 3064, 3034, 2933, 1780, 1636, 1378, 1240, 1222, 946, 868, 844 cm^{-1}; ESIMS m/z 328 $[M + H]^+$; HRMS m/z calcd for $C_{18}H_{17}NO_3SNa$ $[M + Na]^+$ 350.0821, found 350.0822; mp = 76−78 °C.



7r

*Allyl N-(Methoxycarbonyl)oxybenzimidothioate (**7r**).* According to general protocol E, allyl *N*-hydroxybenzimidothioate (0.11 g, 0.54 mmol), pyridine (48 μL, 0.60 mmol), and methyl chloroformate (47 μL, 0.60 mmol) in DCM (5.2 mL) afforded 0.13 g (94%) of **7r** as a colorless oil: ^1H NMR (400 MHz) δ 7.47−7.44 (m, 5 H), 5.69−5.58 (m, 1 H), 5.01−4.98 (m, 1 H), 4.89−4.84 (m, 1 H), 3.86 (s, 3 H), 3.27−3.24 (m, 2 H); ^{13}C NMR δ 164.7, 154.1, 132.3, 131.5, 130.7, 129.2, 128.8, 119.0, 55.6, 35.5; IR (film) 3076, 3056, 2950, 1780, 1635, 1558, 1492, 1438, 1234, 916, 880, 772 cm^{-1}; ESIMS m/z 252 $[M + H]^+$; HRMS m/z calcd for $C_{12}H_{13}NO_3SNa$ $[M + Na]^+$ 274.0508, found 274.0508.



7s

*3-Methylbut-2-en-1-yl N-((Perfluorobenzoyl)oxy)-3-phenylpropanimidothioate (**7s**).* According to general protocol D, *N*-hydroxy-3-phenylpropanethioamide **4g** (0.14 g, 0.77 mmol), 1-bromo-3-methyl-2-butene (94 μL, 0.77 mmol), Et_3N (0.11 mL, 0.77 mmol), TBAI (29 mg, 0.077 mmol), Et_3N (0.13 mL, 0.93 mmol), and pentafluorobenzoyl chloride (0.14 mL, 0.93 mmol) in Et_2O (7.7 mL) at rt afforded 0.22 g (65%) of **7s** as a white solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 12%): ^1H NMR (400 MHz) δ 7.35−7.31 (m, 2 H), 7.26−7.23 (m, 3 H), 5.22−5.18 (m, 1 H), 3.53 (d, 2 H, J = 7.7 Hz), 3.09−3.05 (m, 2 H), 2.93−2.89 (m, 2 H), 1.74 (s, 3 H), 1.65 (s, 3 H); ^{13}C NMR δ 168.5, 140.2, 139.4, 128.8, 128.5, 126.8, 117.0, 35.2, 33.7, 29.0, 25.8, 18.1 (C=O not visible under the experimental conditions); ^{19}F NMR δ −136.9−137.0 (m, 2 F), −148.1−148.2 (m, 1 F), −160.3−160.4 (m, 2 F); IR (film) 3058, 3028, 2932, 1756, 1654, 1606, 1504, 1420, 1198, 1144, 1006, 886, 838 cm^{-1}; ESIMS m/z 444 $[M + H]^+$; HRMS m/z calcd for $C_{21}H_{19}F_5NO_2S$ $[M + H]^+$ 444.1051, found 444.1047; mp = 90−91 °C.

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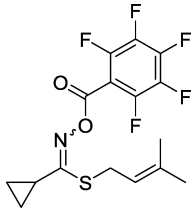
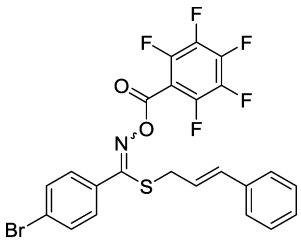


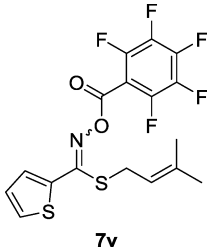
7t

*3-Methylbut-2-en-1-yl N-((Perfluorobenzoyl)oxy)cyclopropanecarbimidothioate (**7t**).* According to general protocol D, *N*-hydroxycyclopropanecarbothioamide **4f** (65 mg, 0.55 mmol), 1-bromo-3-methyl-2-butene (68 μL, 0.55 mmol), Et_3N (77 μL, 0.55 mmol), TBAI (21 mg, 0.055 mmol), Et_3N (93 μL, 0.67 mmol), and pentafluorobenzoyl chloride (97 μL, 0.67 mmol) in Et_2O (5.5 mL) at rt afforded 55 mg (26%) of **7t** as an orange oil after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 10%): ^{1}H NMR (400 MHz) δ 5.29−5.24 (m, 1 H), 3.73 (d, 2 H, *J* = 7.7 Hz), 1.80−1.73 (m, 1 H), 1.77 (s, 3 H), 1.71 (s, 3 H), 1.20−1.16 (m, 2 H), 1.02−1.00 (m, 2 H); ^{13}C NMR δ 170.5, 138.9, 117.5, 28.9, 25.9, 18.0, 13.9, 7.6 (C═O not visible under the experimental conditions); ^{19}F NMR δ −137.0−137.1 (m, 2 F), −148.3−148.4 (m, 1 F), −160.3−160.5 (m, 2 F); IR (film) 2974, 2920, 1768, 1654, 1558, 1510, 1426, 1324, 1192, 934, 874 cm^{-1}; ESIMS *m*/*z* 380 [M + H]$^+$; HRMS *m*/*z* calcd for $C_{16}H_{14}F_5NO_2SNa$ [M + Na]$^+$ 402.0558, found 402.0557.



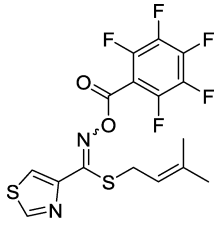
7u

*Cinnamyl 4-Bromo-N-((perfluorobenzoyl)oxy)benzimidothioate (**7u**).* According to general protocol D, 4-bromo-*N*-hydroxybenzothioamide **4c** (0.250 g, 1.08 mmol), cinnamyl bromide (0.164 mL, 1.08 mmol), Et_3N (0.150 mL, 1.08 mmol), TBAI (40.2 mg, 0.108 mmol), Et_3N (0.180 mL, 1.29 mmol), and pentafluorobenzoyl chloride (0.188 mL, 1.29 mmol) in Et_2O (10.8 mL) at rt afforded 0.275 g (47%) of **7u** as a off-white solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 10%): ^{1}H NMR (400 MHz) δ 7.62 (d, 2 H, *J* = 8.4 Hz), 7.40 (d, 2 H, *J* = 8.4 Hz), 7.32−7.29 (m, 2 H), 7.23−7.21 (m, 3 H), 6.01−5.91 (m, 2 H), 3.45 (d, 2 H, *J* = 6.1 Hz); ^{13}C NMR δ 167.1, 135.8, 134.4, 132.3, 130.7, 130.2, 128.8, 128.3, 126.5, 125.6, 122.7, 35.7 (C═O not visible under the experimental conditions); IR (film) 3088, 3064, 2926, 1762, 1654, 1588, 1498, 1414, 1318, 1192, 1000, 916, 862 cm^{-1}; HRMS *m*/*z* calcd for $C_{23}H_{14}BrF_5NO_2S$ [M + H]$^+$ 541.9843, found 541.9847; mp = 122−124 °C.



7v

*3-Methylbut-2-en-1-yl N-((Perfluorobenzoyl)oxy)thiophene-2-carbimidothioate (**7v**).* According to general protocol D, *N*-hydroxythiophene-2-carbothioamide **4d** (0.240 g, 1.51 mmol), 1-bromo-3-methyl-2-butene (0.184 mL, 1.51 mmol), Et_3N (0.210 mL, 1.51 mmol), TBAI (56.2 mg, 0.151 mmol), Et_3N (0.252 mL, 1.81 mmol), and pentafluorobenzoyl chloride (0.263 mL, 1.81 mmol) in Et_2O (15.0 mL) at rt afforded 0.297 g (47%) of **7v** as an orange oil after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 10%): ^{1}H NMR (400 MHz) δ 7.52 (dd, 1 H, *J* = 5.1, 1.2 Hz), 7.50 (dd, 1 H, *J* = 3.7, 1.2 Hz), 7.13 (dd, 1 H, *J* = 5.1, 3.7 Hz), 5.16−5.11 (m, 1 H), 3.56 (d, 2 H, *J* = 7.8 Hz), 1.69 (s, 3 H), 1.54 (s, 3 H); ^{13}C NMR δ 161.1, 139.2, 133.3, 131.2, 130.2, 127.8, 117.6, 32.4, 25.8, 17.8 (C═O not visible under the experimental conditions); IR (film) 3112, 2968, 2914, 1768, 1648, 1522, 1504, 1420, 1330, 1180, 1000, 838, 784 cm^{-1}; ESIMS *m*/*z* 422 [M + H]$^+$; HRMS *m*/*z* calcd for $C_{17}H_{12}F_5NO_2S_2Na$ [M + Na]$^+$ 444.0122, found 444.0114.



7w

*3-Methylbut-2-en-1-yl N-((Perfluorobenzoyl)oxy)thiazole-4-carbimidothioate (**7w**).* According to general protocol D, *N*-hydroxythiazole-4-carbothioamide **4e** (0.106 g, 0.662 mmol), 1-bromo-3-methyl-2-butene (81.0 μL, 0.662 mmol), Et_3N (92.0 μL, 0.662 mmol), TBAI (24.6 mg, 66.1 μmol), Et_3N (0.111 mL, 0.794 mmol), and pentafluorobenzoyl chloride (0.115 mL, 0.794 mmol) in Et_2O (6.60 mL) at rt afforded 0.187 g (67%) of **7w** as a pink crystalline solid after purification by chromatography on SiO_2 (hexanes/EtOAc, 0 to 15%): ^{1}H NMR (400 MHz) δ 8.93 (dd, 1 H, *J* = 2.1, 1.0 Hz), 7.88 (dd, 1 H, *J* = 2.1, 1.0 Hz), 5.06−5.02 (m, 1 H), 3.54 (d, 2 H, *J* = 7.8 Hz), 1.66 (s, 3 H), 1.54 (s, 3 H); ^{13}C NMR δ 163.3, 153.9, 147.4, 139.1, 122.1, 117.5, 30.6, 25.8, 25.7 (C═O not visible under the experimental conditions); ^{19}F NMR δ −136.6−136.6 (m, 2 F), −147.5−147.7 (m, 1 F), −160.0−160.2 (m, 2 F); IR (film) 3104, 2978, 2921, 1761, 1652, 1497, 1193, 1094, 934, 900, 859 cm^{-1}; ESIMS *m*/*z* 423 [M + H]$^+$; HRMS *m*/*z* calcd for $C_{16}H_{12}F_5N_2O_2S_2$ [M + H]$^+$ 423.0255, found 423.0243; mp = 69−71 °C.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

^{1}H NMR and ^{13}C NMR spectra. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We gratefully acknowledge North Carolina State University for generous start-up support, and acknowledgement is made to the Donors of the American Chemical Society Petroleum Research Fund for partial support of this research. Mass spectra were obtained at the Mass Spectrometry Laboratory at North Carolina State University.

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