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Catalysis by Ionic Liquids: Significant Rate Acceleration with the Use of [pmIm]Br in the Three-Component Synthesis of Dithiocarbamates

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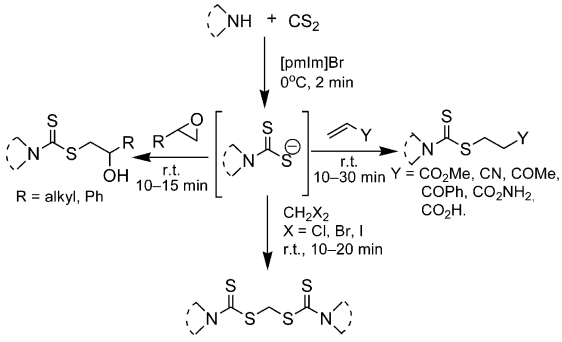
An easily accessible neutral ionic liquid, 1-methyl-3-pentylimidazolium bromide, promoted a one-pot three-component condensation of an amine, carbon disulfide, and an activated alkene/dichloromethane/epoxide to produce the corresponding dithiocarbamates in high yields at room temperature. The reactions are very fast in ionic liquids relative to those in other reaction media. These reactions do not require any additional catalyst or solvent. The ionic liquid can be recovered and recycled for subsequent reactions. A plausible mechanism is suggested.

Introduction

Room-temperature ionic liquids have been the subject of considerable interest since their introduction as "green" solvents for reactions.[1] Besides their usefulness as powerful reaction media, ionic liquids have been well recognized as efficient catalysts and successfully applied in many organic reactions.[2] They are also able to dictate the course of a reaction.[3] We encountered a remarkable acceleration in the rate of a reaction with the use of a simple ionic liquid, which will be reported here.

Dithiocarbamates have received considerable attention in recent times because of their occurrence in a variety of biologically active compounds.[4] They also play pivotal roles in agriculture,[5] and they act as linkers in solid-phase organic synthesis.[6] In addition, functionalized carbamates are an important class of compounds and their medicinal and biological properties warrant study.[4] Thus, the synthesis of dithiocarbamates with varied substitution at the thiol chain is receiving continued interest. A variety of reagents and catalysts including Mitsunobu's reagent,[7a] solid $LiClO_4$/DMF,[7b] DMSO,[7c] and Cs_2CO_3/tetrabutylammonium iodide[7d] have been used. Recently, a few catalyst- and organic-solvent-free procedures performed either in water[7b,7e] or neat[8a,8b] were reported. Although all of these procedures are quite satisfactory, several of them involve costly and toxic reagents and long reaction times. However, an alternative procedure that is simpler and faster is always appreciated. As a part of our continuing commitment[9] to explore ionic liquids in organic reactions, we observed a significant rate acceleration in the reaction between an amine and carbon disulfide by using 1-methyl-3-pentylimidazolium bromide {[pmIm]Br} at 0 °C to generate a dithiocarbamate anion, which subsequently underwent Michael-type addition to conjugated alkenes followed by condensation with methylene halides and reaction with epoxides to give a variety of functionalized dithiocarbamates (Scheme 1).



Scheme 1. Synthesis of dithiocarbamates.

Results and Discussion

The experimental procedure is very simple. To a cooled (0 °C) and stirred mixture of amine, carbon disulfide, and [pmIm]Br (20 mol-%) was added conjugated alkene/methylene halide/epoxide. The reaction mixture was stirred at room temperature for a certain period of time (TLC) and worked up as usual to provide the product.

Several structurally diverse amines underwent reactions with a variety of conjugated alkenes and carbon disulfide in the presence of the [pmIm]Br ionic liquid in one pot to provide the corresponding dithiocarbamates. The conjugated alkenes included a wide range of substrates such as

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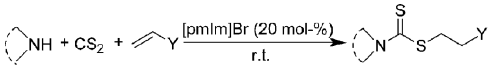
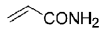
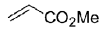
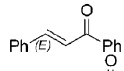
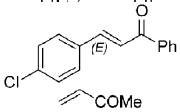
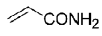
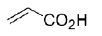
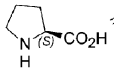
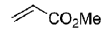
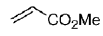
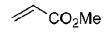
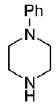
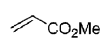
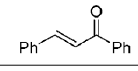
Table 1. Nucleophilic addition of dithiocarbamate anions to Michael acceptors.



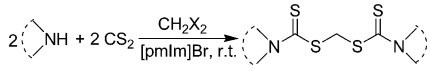
Entry	Amine	Michael acceptor	Time [min]	Yield [%][a]	Ref.
1			10	97	[7e]
2			10	98	[7e]
3			15	96	[7e]
4			10	95	[7e]
5			30	80	[7e]
6			10	98	[7e]
7			10	98	[7e]
8			15	97	[7e]
9			30	82	[7e]
10			30	78	
11			10	97	[7e]
12			30	85	[7e]
13			20	77	[7e]
14			30	75	
15	Et_2NH		15	90	[7e]
16			15	92	[7e]
17			10	95	[7e]
18			15	96	[7e]
19			20	78	[7e]
20			15	80	[7e]
21			25	75	
22			25	80	
23			20	82	
24			30	76	

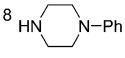
[a] The yields refer to those of pure isolated products characterized by spectroscopic (IR, ^1H NMR and ^{13}C NMR) data.

α,β-unsaturated esters, nitriles, ketones, amides, and carboxylic acids, whereas the amines involved in this reaction were piperidine, pyrrolidine, proline, morpholine, piperazine benzylamine, and diethylamine. The results are summarized in Table 1. As is evident from the results, proline participated in this addition reaction, as did the other amines, without any difficulty, and the chiral dithiocarbamate obtained (Table 1, Entry 14) may be of interest as a catalyst. Benzylamine provided the corresponding dithiocarbamates (Table 1, Entries 17 and 18) in high yields without any side product formation by a direct aza-Michael reaction. The involvement of *N*-phenylpiperazine in this reaction (Table 1, Entries 22–24) is addressed for the first time and the corresponding dithiocarbamates may be of importance for biological activity.

To exploit this in situ generated dithiocarbamate anion for other useful reactions, we next explored its addition to a methylene halide to achieve a symmetrical dithiocarbamate. Thus, several cyclic and open-chain amines were subjected to reactions with carbon disulfide and methylene halides in the presence of [pmIm]Br at room temperature to produce the corresponding dithiocarbamates. Although the reaction proceeded equally well with CH_2Cl_2, CH_2Br_2, and CH_2I_2, CH_2Cl_2 was chosen in consideration of its widespread availability and low cost. The results are summarized in Table 2.

Table 2. Synthesis of symmetrical dithiocarbamates.



Entry	Amine	X	Time [min]	Yield [%][a]	Ref.
1		Cl	10	85	[12]
2		Br	10	82	[12]
3		I	10	83	[12]
4		Cl	10	88	[12]
5		Cl	20	82	
6	Et_2NH	Cl	15	80	[12]
7		Cl	20	83	[12]
8		Cl	20	80	
9	iPr_2NH	Cl	20	82	

[a] The yields refer to those of pure isolated products characterized by spectroscopic (IR, ^1H NMR and ^{13}C NMR) data.

These symmetrical dithiocarbamates bis(*N*,*N*-dialkylthiocarbamoylthio) methane were used as valuable intermediates in the synthesis of several biologically active mole-

cules.[10] The preparation of this type of dithiocarbamate was reported earlier; the procedure involved the reaction of dithiocarbamate anions generated from the sodium salt of either the corresponding dithiocarbamic acid or the thiols with dichloromethane by using a catalyst such as $RhCl(PPh_3)_3$[11] and polyethylene glycol (PEG).[12] However, these reactions required long times of 24 and 12 h, respectively, and the yields were also not always satisfactory.

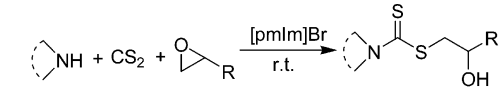
The dithiocarbamate anions also participated in ring cleavage of epoxides to produce the corresponding hydroxy dithiocarbamates. The results are presented in Table 3. The reactions of a variety of epoxides with different cyclic and open-chain amines proceeded smoothly at room temperature. The cleavages were highly regio- and stereoselective. In alkyl-substituted epoxides, nucleophilic attack took place at the less-substituted carbon atom to produce the secondary alcohols (Markovnikov product) exclusively. The cyclohexene oxides furnished the *trans* hydroxy derivatives as the sole product. However, the reactions of styrene oxides were quite different. The dithiocarbamate anions generated from the reactions of piperidine, pyrrolidine, and morpholine with CS_2 were treated with styrene oxides to afford a mixture of products. The major isomer in all of these reactions was the secondary alcohol, which resulted from the usual Markovnikov addition. The minor isomer was the anti-Markovnikov product, which was formed by cleavage at the benzylic position. Although the styrene epoxide was usually cleaved by nucleophiles at the benzylic carbon atom exclusively or selectively, in this case, because the dithiocarbamate anion is bulky and stable, it preferred to attack at the less-substituted carbon atom.

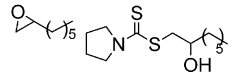
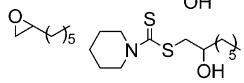
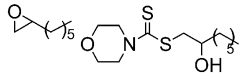
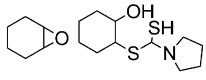
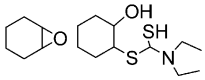
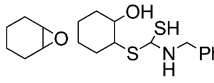
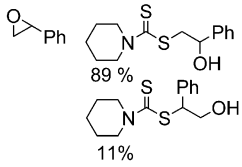
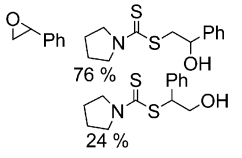
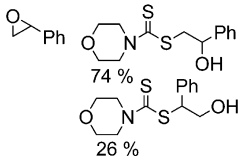
All the reactions included in Tables 1–3 were very fast (10–30 min), clean, and high yielding. Significant rate acceleration in an ionic liquid was observed as exemplified by comparison of the results of a few representative reactions in different media as shown in Table 4. The use of organic solvents such as THF, acetonitrile, and toluene in place of the ionic liquid did not produce very good results (much longer reaction times and relatively low yield). The catalytic activity of the [pmIm]Br ionic liquid was established by the fact that without it the neat reactions took much longer (Table 4) and provided lower yields of products. Although the reactions can be carried out with amounts as low as 10 mol-% of the ionic liquid, it was found that 20 mol-% provided the best results in terms of reaction time and yield. The ionic liquid was recycled in subsequent reactions without any loss of efficiency.

Although we do not have any experimental evidence to support a reaction path, we speculate that the imidazolium cation of [pmIm]Br activates CS_2 towards nucleophilic attack by amine to generate a dithiocarbamate anion, which can then undergo Michael-type addition to conjugated alkenes to afford the substituted dithiocarbamate, as outlined in Scheme 2.

The key role of the imidazolium cation in this reaction is also supported by the fact that other imidazolium ionic liquids such as $[pmIm]BF_4$ also produced comparable results.

Table 3. Regio- and stereoselective reaction of epoxides with dithiocarbamate anions.

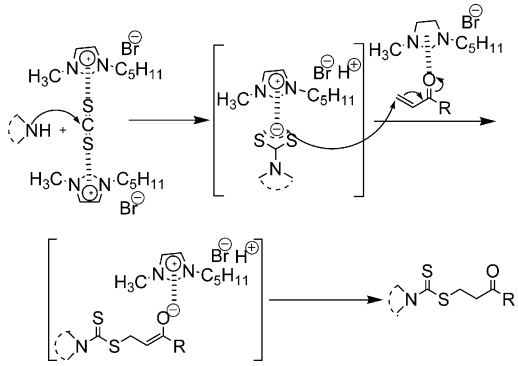


Entry	Amine	Epoxide	Product	Time [min]	Yield [%][a]	Ref.
1				15	88	
2				10	90	
3				15	85	
4				10	93	[8a]
5	Et_2NH			10	92	[8a]
6	Ph NH2			15	86	[7b]
7			89 % 11%	10	90	[8a]
8			76 % 24 %	10	93	[8a]
9			74 % 26 %	15	87	

[a] The yields refer to those of pure isolated products characterized by spectroscopic (IR, ^1H NMR and ^{13}C NMR) data.

Table 4. Comparison of the results of reactions of the dithiocarbamate anion in H_2O, neat, and [pmIm]Br.

Amine	Electrophile	Medium	Time [h]	Yield [%]
Ph NH2	CO_2Me	H_2O[7e]	5–18	80
		neat	15	68
		[pmIm]Br (20 mol-%)	0.17	95
	CH_2Cl_2	H_2O	15	64
		neat	15	70
		[pmIm]Br (20 mol-%)	0.17	85
		H_2O[7b]	18	89
		neat[8a]	2–8	95
		[pmIm]Br (20 mol-%)	0.17	93



Scheme 2. Plausible Mechanism.

Conclusions

The present procedure that involves the use of a simple and inexpensive ionic liquid, [pmIm]Br, provides a novel protocol for the generation of dithiocarbamate anions and their reaction with conjugated alkenes, methylene halides, and epoxides to furnish a library of diversely substituted dithiocarbamates. The dithiocarbamates are of high importance in academia as well as in industry.[4–7] It is also noteworthy that the [pmIm]Br ionic liquid works here as a catalyst as well as the reaction medium and accelerates the rate of the reaction. Thus, the significant advantages of this procedure include remarkably fast reactions relative to those in other procedures, high yields, excellent regio- and stereoselectivity, and the reusability of the ionic liquids.

Experimental Section

Representative Procedure for the Reaction of a Dithiocarbamate Anion with a Conjugated Alkene. Preparation of 2-Cyanoethyl Pyrrolidine-1-carbodithioate (Table 1, Entry 7): Carbon disulfide (304 mg, 4 mmol) was added drop by drop to a stirred mixture of pyrrolidine (142 mg, 2 mmol) in [pmIm]Br[13] (94 mg, 0.4 mmol) at 0 °C. This mixture was stirred for 2 min and acrylonitrile (133 mg, 2.5 mmol) was added. The reaction mixture was then stirred at room temperature (28–30 °C) for 10 min (TLC) until completion of the reaction. The whole mixture was extracted with Et_2O (3×10 mL), and the upper organic layer was washed with H_2O, dried (Na_2SO_4), and evaporated to leave the crude product, which was purified by column chromatography over silica gel (hexane/ether, 80:20) to provide the pure product as a pale-yellow solid. Yield: 392 mg (98%), m.p. 72–74 °C. The spectroscopic data (IR, ^{1}H NMR and ^{13}C NMR) are in good agreement with the reported values.[7e] The remaining ionic liquid was rinsed with ether, dried under vacuum, and reused for four runs after which fresh ionic liquid was added to compensate for the loss during washing with ether.

This procedure was followed for all the reactions listed in Tables 1, 2, and 3. Although this procedure was described on the mmol scale, gram-scale reactions also provided uniform results.

Many of these products are known compounds and were easily identified by comparison of their spectroscopic data and melting points with those reported (references in Tables 1–3). Unknown compounds were properly characterized by spectroscopy (IR, ^{1}H NMR, ^{13}C NMR, HRMS) and elemental analysis, and the data are provided below.

1-(4-Chlorophenyl)-3-oxo-3-phenylpropyl Pyrrolidine-1-carbodithioate (Table 1, Entry 10): Colorless viscous liquid. IR (neat): $\tilde{\nu}$ = 1683, 1490, 1334, 1222, 1180, 1008, 954 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.87–2.06 (m, 4 H), 3.54–3.61 (m, 2 H), 3.70 (dd, J = 9, 16 Hz, 1 H), 3.88 (t, J = 6 Hz, 2 H), 4.07 (dd, J = 6, 18 Hz, 1 H), 5.75 (dd, J = 6, 9 Hz, 1 H), 7.23 (d, J = 9 Hz, 2 H), 7.36–7.55 (m, 5 H), 7.94 (d, J = 6 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 24.0, 25.9, 44.8, 49.6, 50.4, 54.7, 127.9 (2 C), 128.4 (2 C), 128.5 (2 C), 129.6 (2 C), 133.1 (2 C), 136.2, 138.3, 190.4, 196.5 ppm. $C_{20}H_{20}ClNOS_2$ (389.96): calcd. C 61.60, H 5.17, N 3.59; found C 61.48, H 5.10, N 3.46.

1-(2-Cyanoethylsulfanylthiocarbonyl)-2-pyrrolidinoic Acid (Table 1, Entry 14): White crystalline solid, m.p. 125–126 °C. IR (KBr): $\tilde{\nu}$ = 2968, 2922, 2873, 2746, 2252, 1716, 1421, 1346, 1325, 1294, 1228, 1180, 1157, 1043, 1010, 952 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.91–2.10 (m, 4 H), 2.60–2.65 (m, 2 H), 3.23–3.32 (m, 2 H), 3.52–3.62 (m, 2 H), 4.81–4.84 (m, 1 H), 10.20 (br., 1 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 18.0, 24.5, 29.1, 31.7, 51.0, 66.2, 118.3, 175.9, 193.2 ppm. $[\alpha]_D$ = –10.6522 (c = 1.38, $CHCl_3$). $C_9H_{12}N_2O_2S_2$ (244.34): calcd. C 44.24, H 4.95, N 11.47; found C 44.10, H 4.83, N 11.38.

3-Oxocyclohexyl Morpholine-4-carbodithioate (Table 1, Entry 21): Yellowish solid, m.p. 82–84 °C. IR (KBr): $\tilde{\nu}$ = 2960, 2923, 2866, 1697, 1454, 1419, 1303, 1271, 1220, 1207, 1116, 1028, 1001, 962, 869 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.81–1.92 (m, 2 H), 2.04–2.07 (m, 1 H), 2.31–2.41 (m, 3 H), 2.48–2.57 (m, 1 H), 2.87–2.93 (m, 1 H), 3.73–3.76 (m, 4 H), 3.94 (br., 2 H), 4.28–4.42 (m, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 24.2, 30.9, 40.9, 46.9, 49.0, 50.7 (2 C), 66.1 (2 C), 195.1, 208.1 ppm. $C_{11}H_{17}NO_2S_2$ (259.39): calcd. C 50.93, H 6.61, N 5.40; found C 50.77, H 6.58, N 5.21.

Methyl 3-(4-Phenylpiperazine-1-carbothioylsulfanyl)propionoate (Table 1, Entry 22): Pale-yellow viscous liquid. IR (neat): $\tilde{\nu}$ = 2993, 2949, 2918, 2823, 1735, 1598, 1579, 1494, 1469, 1423, 1386, 1357, 1274, 1224, 1174, 1153, 1022, 1002, 941 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.81 (t, J = 6 Hz, 2 H), 3.22–3.25 (m, 4 H), 3.59 (t, J = 6 Hz, 2 H), 3.68 (s, 3 H), 4.06 (br., 2 H), 4.40 (br., 2 H), 6.86–6.90 (m, 3 H), 7.24–7.29 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 32.0, 34.1, 48.9 (2 C), 50.2, 51.8, 52.2, 116.6 (2 C), 120.8, 129.5 (2 C), 150.6, 172.7, 196.6 ppm. $C_{15}H_{20}N_2O_2S_2$ (324.46): calcd. C 55.53, H 6.21, N 8.63; found C 55.35, H 6.15, N 8.43.

2-Cyanoethyl 4-Phenylpiperazine-1-carbodithioate (Table 1, Entry 23): Yellowish solid, m.p. 76–77 °C. IR (KBr): $\tilde{\nu}$ = 2914, 2819, 2241, 1600, 1579, 1504, 1492, 1471, 1433, 1417, 1388, 1328, 1269, 1149, 1028 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 2.58 (t, J = 6 Hz, 2 H), 3.26 (t, J = 3 Hz, 4 H), 3.53 (t, J = 6 Hz, 2 H), 4.04 (br., 2 H), 4.42 (br., 2 H), 6.82–6.91 (m, 3 H), 7.24–7.29 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 17.9, 31.5, 48.4 (2 C), 50.3, 51.7, 116.0 (2 C), 118.1, 120.4, 129.1 (2 C), 149.9, 194.1 ppm. $C_{14}H_{17}N_3S_2$ (299.44): calcd. C 57.70, H 5.88, N 14.42; found C 57.43, H 5.78, N 14.22.

3-Oxo-1,3-diphenylpropyl 4-Phenylpiperazine-1-carbodithioate (Table 1, Entry 24): Yellowish viscous liquid. IR (neat): $\tilde{\nu}$ = 3058, 3012, 2989, 2923, 2819, 1664, 1598, 1577, 1494, 1448, 1415, 1334, 1213, 1016, 999, 923, 756 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.29 (br., 4 H), 3.78 (dd, J = 9, 15 Hz, 1 H), 4.09–4.16 (m, 3 H), 4.45 (br., 2 H), 5.77 (dd, J = 3, 10 Hz, 1 H), 6.89–6.91 (m, 4 H), 7.23–7.46 (m, 9 H), 7.95–7.98 (m, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 45.1, 48.6 (2 C), 50.3 (2 C), 51.4, 116.2 (2 C), 120.5, 127.7, 128.0

(2 C), 128.4 (4 C), 128.5 (2 C), 129.2 (2 C), 133.1, 136.5, 139.1, 150.2, 195.5, 196.8 ppm. $C_{26}H_{26}N_2OS_2$ (446.63): calcd. C 69.92, H 5.87, N 6.27; found C 69.67, H 5.48, N 6.21.

Benzylthiocarbamolylsylfanylmethyl Benzyldithiocarbamate (Table 2, Entry 5): White solid, m.p. 106–107 °C. IR (KBr): $\tilde{\nu}$ = 3282, 1504, 1452, 1375, 1317, 1247, 1091, 1060, 927, 729 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 4.85 (d, J = 6 Hz, 4 H), 5.21 (s, 2 H), 7.26–7.42 (m, 10 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 42.5, 51.5 (2 C), 128.1 (2 C), 128.4 (4 C), 129.0 (4 C), 135.8 (2 C), 196.3 (2 C) ppm. $C_{17}H_{18}N_2S_4$ (378.60): calcd. C 53.93, H 4.79, N 7.40; found C 53.71, H 4.53, N 7.22.

(4-Phenylpiperazinethiocarbamoylsulfanyl)methyl 4-Phenylpiperazinedithiocarboamate (Table 2, Entry 8): White solid, m.p. 196–198 °C. IR (KBr): $\tilde{\nu}$ = 2918, 2839, 1600, 1471, 1440, 1421, 1384, 1325, 1232, 1220, 1016, 993 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 3.30–3.31 (m, 8 H), 4.07 (br., 4 H), 4.48 (br., 4 H), 5.48 (s, 2 H), 6.90–6.97 (m, 6 H), 7.27–7.32 (m, 4 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 45.7, 48.8 (4 C), 50.0 (2 C), 50.8 (2 C), 116.4 (4 C), 120.7 (2 C), 129.4 (4 C), 150.2 (2 C), 196.0 (2 C) ppm. $C_{23}H_{28}N_4S_4$ (488.76): calcd. C 56.52, H 5.77, N 11.46; found C 56.32, H 5.71, N 11.23.

(Diisopropylthiocarbamoylsulfanyl)methyl Diisopropyldithiocarbamate (Table 2, Entry 9): White solid, m.p. 137–139 °C. IR (KBr): $\tilde{\nu}$ = 2968, 2927, 2869, 2736, 1473, 1440, 1365, 1311, 1220, 1190, 1139, 1112, 1028, 956 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 1.34 (br., 24 H), 4.12 (br., 2 H), 4.75 (br., 2 H), 5.40 (s, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 19.8 (8 C), 44.0, 52.6 (2 C), 54.9 (2 C), 193.5 (2 C) ppm. $C_{15}H_{30}N_2S_4$ (366.68): calcd. C 49.13, H 8.25, N 7.64; found C 48.95, H 8.11, N 7.62.

2-Hydroxyoctyl Pyrrolidine-1-carbodithioate (Table 3, Entry 1): Yellowish viscous liquid. IR (neat): $\tilde{\nu}$ = 3408, 2925, 2856, 1461, 1434, 1330, 1249, 1220, 1184, 1161, 1006, 954 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 0.81–0.86 (m, 3 H), 1.21–1.53 (m, 10 H), 1.91–2.09 (m, 4 H), 2.79 (br., 1 H), 3.31 (dd, J = 9, 15 Hz, 1 H), 3.62–3.68 (m, 3 H), 3.86–3.90 (m, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.0, 22.6, 24.3, 25.5, 26.0, 29.2, 31.7, 36.6, 43.0, 50.8, 55.3, 71.0, 193.2 ppm. HRMS: calcd. for $C_{13}H_{25}NOS_2$ $[M + Na]^+$ 298.1275; found 298.1250.

2-Hydroxyoctyl Piperidine-1-carbodithioate (Table 3, Entry 2): White viscous liquid. IR (neat): $\tilde{\nu}$ = 3398, 2927, 2856, 1473, 1454, 1427, 1280, 1228, 1132, 1114, 1004, 977 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 0.79–0.81 (m, 3 H), 1.18–1.53 (m, 10 H), 1.64 (br., 6 H), 2.58 (br., 1 H), 3.30 (dd, J = 9, 15 Hz, 1 H), 3.64 (dd, J = 3, 12 Hz, 1 H), 3.85 (br., 3 H), 4.22 (br., 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.4, 23.0, 24.6, 25.9, 26.4 (2 C), 29.6, 32.1, 37.1, 44.1, 51.9, 53.8, 71.4, 196.4 ppm. HRMS: calcd. for $C_{14}H_{27}NOS_2$ $[M + Na]^+$ 312.1432; found 312.1406.

2-Hydroxyoctyl Morpholine-4-carbodithioate (Table 3, Entry 3): Yellowish viscous liquid. IR (neat): $\tilde{\nu}$ = 3396, 2956, 2925, 2856, 1512, 1463, 1417, 1269, 1228, 1114, 1028, 995 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 0.75–0.81 (m, 3 H), 1.18–1.54 (m, 10 H), 2.65 (br., 1 H), 3.31 (dd, J = 9, 13 Hz, 1 H), 3.63–3.71 (m, 5 H), 3.80–3.88 (m, 1 H), 3.95 (br., 2 H), 4.23 (br., 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.1, 22.7, 25.5, 29.3, 31.8, 36.8, 43.7, 51.7 (2 C), 66.2 (2 C), 71.0, 198.1 ppm. HRMS: calcd. for $C_{13}H_{25}NO_2S_2$ $[M + Na]^+$ 314.1224; found 314.1250.

2-Hydroxy-2-phenylethyl Morpholine-4-carbodithioate (Table 3, Entry 9): White solid, m.p. 146–147 °C. IR (KBr): $\tilde{\nu}$ = 3398, 2910, 2856, 1463, 1427, 1384, 1271, 1232, 1188, 1114, 995 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 3.0 (d, J = 3 Hz, 1 H), 3.62 (dd, J = 9, 12 Hz, 1 H), 3.79–3.81 (m, 4 H), 3.93 (dd, J = 3, 15 Hz, 1 H), 4.03 (br., 2 H), 4.37 (br., 2 H), 5.04–5.09 (m, 1 H), 7.28–7.51 (m, 5 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 45.2, 51.3 (2 C), 66.4 (2 C), 73.1, 125.9 (2 C), 128.0, 128.7 (2 C), 142.9, 197.9 ppm. HRMS: calcd. for $C_{13}H_{17}NO_2S_2$ $[M + Na]^+$ 306.0598; found 306.0625.

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