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Efficient and regioselective one-pot synthesis of *S*-vinyl dithiocarbamates from electron-deficient allenes, amines and CS_2

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ABSTRACT

A novel and efficient one-pot procedure for the synthesis of *S*-vinyl dithiocarbamates from electron-deficient allenes, amines and CS_2 was presented. The reactions proceed at room temperature for 10–30 min without any catalyst to afford the products in high yields, excellent regioselectivity and stereoselectivity.

1. Introduction

Dithiocarbamates have been widely used in organic and medicinal chemistry. For instance, they were used as useful synthetic intermediates,[1–3] protecting groups in peptide synthesis[4] and linker in solid phase organic synthesis.[5] Their extensive biological properties, including antiviral,[6] antihistaminic,[7] anticholinergic,[8] antibacterial,[9] and anticancer activities,[10] have been reported. Therefore, the synthesis of dithiocarbamates has received considerable attention recently. Many efficient methods have been developed for the synthesis of different kinds of dithiocarbamates.[11] However, the synthesis of vinyl dithiocarbamates still remains a challenge. The general procedures for the synthesis of vinyl dithiocarbamates involved the Wittig reaction of aldehydes with phosphorous ylides,[12] the reactions of hypervalent iodine compounds with sodium salt of dithiocarbamic acid,[13] or vinyl Grignard reagents with tetramethylthiuram disulfide.[14] All of them have certain disadvantages such as harsh reaction conditions, lack of stereoselectivity, difficultly accessible materials and limit scope. Recently, Bao's group reported the Ullmann-type coupling reaction of sodium dithiocarbamates with aryl iodides and vinyl bromides catalyzed by CuI/*N*,*N*-dimethylglycine (Fig. 1a).[15] Ranu and coworkers reported a method for the synthesis of aryl and vinyl dithiocarbamates by a one-pot three component condensation of an amine, CS_2 and aryl/styrenyl bromides catalyzed by copper nanoparticles in water (Fig. 1b).[16] However both of these methods suffer from several drawbacks, such as elevated temperatures, long reaction time, the use of metal catalyst and narrow substrate scope (the halide and amine substrates are restricted to only styrenyl bromide and secondary amines, respectively). More recently, Saidi et al. reported a protocol for the synthesis of *S*-vinyl dithiocarbamates by addition of dithiocarbamates to alkynes under

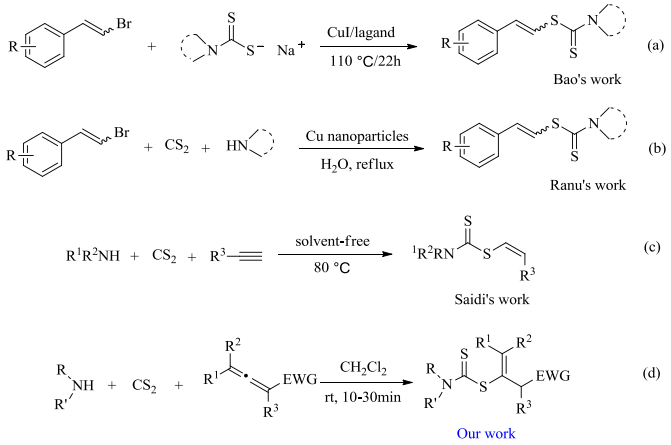

Fig. 1. Design of new approach for *S*-vinyl dithiocarbamates.

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0040-4020/

solvent-free condition (Fig. 1c).[17] Unfortunately, primary amines are also not suitable for this reaction. Therefore, a simple and convenient procedure for the synthesis of vinyl dithiocarbamates is still highly desirable.

Allenes, in particular electron-deficient allenes, as electrophiles have been widely used in organic synthesis.[18] Recently, the Michael β-addition of nucleophiles to electron-deficient allenes has attracted great attention. Huang et al. reported the nucleophilic addition of sodium azide to 1,2-allenyl esters affording functionalized vinyl azides.[19] In another group, Huang and co-workers demonstrated a phosphine-catalyzed aza-Michael addition reaction of hydrazones with allenoates.[20] In 2015, the first phosphine catalyzed Michael addition of arylcyanoacetates to allenoates was developed by Lu's group.[21] More recently, Kang and co-workers described a protocol for synthesis of vinylphosphonates from *N*-heterocyclic phosphine and allenes via phospha Michael/intramolecular nucleophilic substitution reaction.[22] Inspired by their work, we envisioned that electron-deficient allenes should be reacted with amines and CS_2 in situ to form the *S*-vinyl dithiocarbamates (Fig. 1d).

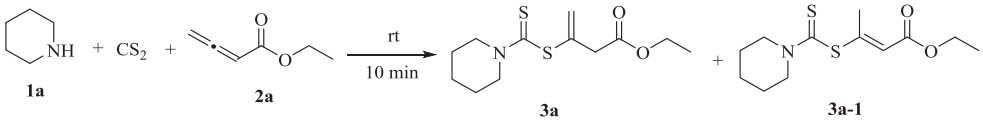
2. Results and discussion

To examine our hypothesis, the ethyl-2,3-butadienoate **2a** was selected to react with piperidine **1a** and CS_2 in the presence of anhydrous K_3PO_4 with CH_2Cl_2 as solvent at room temperature referring our previous works[23] (Table 1, entry 1). To our delight, the reaction proceeded smoothly to afford the desired β-addition adduct **3a** in 95% yield and no C=C bond migrated product **3a-1** was detected (Table 1, entry 1). This result encouraged us to further improve the reaction conditions. The different bases, including K_2CO_3, Cs_2CO_3 and Et_3N, were first screened. It is clear that anhydrous K_3PO_4 is still the best one among tested bases (Table 1, entries 1–4). Notably, the yield of product **3a** also achieved at 95% in the absence of base (Table 1, entry 5). However, when triphenylphosphine, which was widely used in the catalytic reactions of allenes,[21] was added to the reaction system, the yield did not increase (Table 1, entry 6). Then, the various solvents were examined in the absence of base and catalyst. However, replacing CH_2Cl_2 with other solvents led the yield decrease significantly (Table 1, entries 7–14). Thus, we defined the reaction of ethyl-2,3-butadienoate **2a** (1.0 equiv), piperidine **1a** (1.0 equiv) and CS_2 (1.5 equiv) in CH_2Cl_2 at room temperature as the standard conditions (Table 1, entry 5).

With the optimized reaction conditions in hand, we turned our attention to explore the scope and limitation of this novel method for the synthesis of *S*-vinyl dithiocarbamates. Different kind of amines were first allowed to react with CS_2 and ethyl 2,3-butadienoate **2a** under optimized reaction conditions. As shown in Table 2, all the tested amines, no matter the cyclic and acyclic secondary amines, aliphatic primary amines, or benzylamines, reacted smoothly to produce the corresponding *S*-vinyl dithiocarbamates in excellent yields (80%–95%) within a short time (10–30 min). Usually, the allyl amines and benzylamines with high activity gave the corresponding products in over 90% yields. Due to the mild reaction conditions, the heterocycles and the ester group in products showed good tolerance. However, the optimized reaction conditions are not suitable for the aromatic amines. Subsequently, we explored the reactions of different allenes with CS_2 and representative amines, including piperidine, benzylamine and propylamine, under optimized reaction conditions. As shown in Table 3, all the tested reactions proceed smoothly to afford the corresponding products in good yields. When the ethyl ester moiety in allene was replaced by benzyl ester, the reaction yields decreased slightly (compare the yields derived from **2a** and **2b**). Both α,γ-disubstituted allene (**2c**) and α,α-disubstituted allene (**2d**) as substrates also gave the corresponding β-addition products in high yields (Table 3, entries 4–8). More interesting, the products (**3r-3t**) from γ-methyl substituted ethyl 2,3-butadienoate (**2c**) exhibit excellent *E* stereoselectivity (Table 3, entries 4–6), which has been demonstrated through the $^1H-^1H$ NOESY spectra of **3r** (Fig. 2). Furthermore, it is noteworthy that all the reactions proceeded with complete regioselectivity to afford only the β-addition products.

Based on relevant reports in the literatures[24] and our results, a possible mechanism for this Micheal β-addition of electron-deficient allenes with amines and CS_2 is proposed (Scheme 1). Initially, intermediate **A** was formed in situ quickly via the reaction of amines (**1**) with CS_2. Then nucleophilic attack of intermediate **A** on the β carbon of electron-deficient allenes (**2**) led to the formation of products (**3**). When using α,γ-disubstituted allenes as substrates, intermediate **A** tend to occur nucleophilic addition on the

Table 1
Optimization of reaction conditions[a]

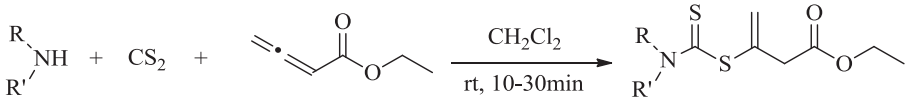


1a 2a 3a 3a-1

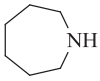
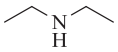
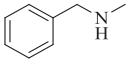
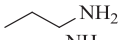
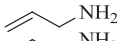
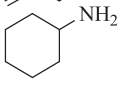
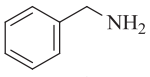
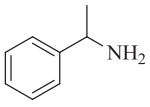
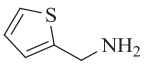
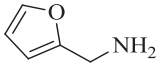
Entry	Solvent	Base[b]	Yield [%][c]
1	CH_2Cl_2	K_3PO_4	95
2	CH_2Cl_2	K_2CO_3	90
3	CH_2Cl_2	Cs_2CO_3	83
4	CH_2Cl_2	Et_3N	90
5	CH_2Cl_2	—	95
6[d]	CH_2Cl_2	—	94
7	Acetone	—	87
8	MeOH	—	55
9	CH_3CN	—	78
10	THF	—	71
11	DMF	—	30
12	Toluene	—	85
13	Dioxane	—	70
14	H_2O	—	20

[a] All the reaction conditions were performed with piperidine (**1a**, 2 mmol), CS_2 (3 mmol) and ethyl-2,3-butadienoate (**2a**, 2 mmol) in 5 mL of solvent at rt.
[b] 2 mmol base was added.
[c] Isolated yields.
[d] Reaction in the presence of 5 mol % of triphenylphosphine.

Table 2
Substrate scope of the three-component reaction with respect to amines, CS_2 and ethyl-2,3-butadienoate[a]



1 **2a** **3a-3n**

Entry	RR'NH	Product	Yield [%][b]
1		**3a**	95
2		**3b**	89
3		**3c**	87
4		**3d**	80
5		**3e**	84
6		**3f**	80
7		**3g**	85
8		**3h**	88
9		**3i**	91
10		**3j**	88
11		**3k**	95
12		**3l**	81
13		**3m**	90
14		**3n**	92

[a] Reactions were performed using **1** (2 mmol), CS_2 (3 mmol) and **2a** (2 mmol) in CH_2Cl_2 (5 mL) at rt for 10–30 min.
[b] Isolated yield.

side of less steric hindrance in allenes, accounting for the formation of *E*-olefin products.

3. Conclusion

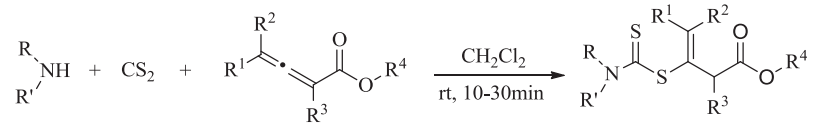
In conclusion, we have developed the first one-pot protocol for the synthesis of *S*-vinyl dithiocarbamates from electron-deficient allenes, amines and CS_2. The reactions proceed at room temperature for 10–30 min without any catalyst to afford the products in high yields, excellent regioselectivity and stereoselectivity. We hope that this efficient protocol could be widely used in the organic synthesis and the medicinal chemistry.

4. Experimental section

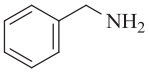
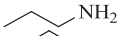
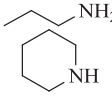
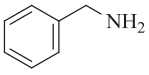
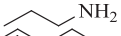
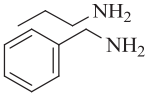
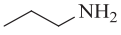
4.1. General information

All melting points (mp) were measured on a melting point apparatus with a microscope and a hot stage and were uncorrected. ^{1}H NMR spectra were determined in $CDCl_3$ on a Bruke 400 MHz spectrometer and chemical shifts were reported in parts per million from internal TMS (δ). Data for ^{1}H NMR are recorded as follows: chemical shift (δ, ppm), multiplicity (integration, s=singlet, d=doublet, dd=doublets, t=triplet, q=quintet, m=multiplet or unresolved, coupling constant(s) in Hertz). ^{13}C NMR spectra were obtained by

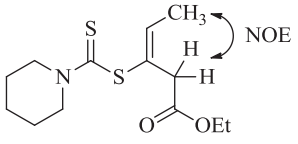
Table 3
Substrate scope of different electron-deficient allenes[a]



1 2 3

Entry	RR'NH	Allene	$R^1/R^2/R^3$	R^4	Product	Yield [%][b]
1		**2b**	H/H/H	Bn	**3o**	82
2		**2b**	H/H/H	Bn	**3p**	82
3		**2b**	H/H/H	Bn	**3q**	81
4		**2c**	H/Me/H	Et	**3r**[c]	77
5		**2c**	H/Me/H	Et	**3s**	80
6		**2c**	H/Me/H	Et	**3t**	76
7		**2d**	H/H/Me	Et	**3u**	82
8		**2d**	H/H/Me	Et	**3v**	78

[a] Reactions were performed using **1** (2 mmol), CS_2 (3 mmol) and **2** (2 mmol) in CH_2Cl_2 (5 mL) at rt for 10–30 min.
[b] Isolated yield.
[c] Determined by ^1H–^1H NOESY spectrum.



***E*-3r**

Fig. 2. ^1H–^1H NOESY of *E*-**3r**.

using the same NMR spectrometers. High-resolution mass spectra (HRMS) was recorded using a Bruker Apex IV FTMS instrument. Column chromatography was performed with 200–300 mesh silica gel using flash column techniques. All of the reagents obtained commercially were used directly unless otherwise noted.

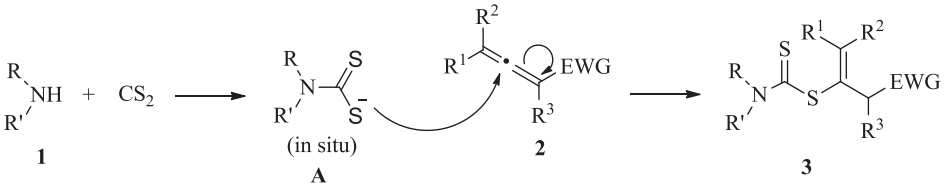
4.2. General procedure for the synthesis of compounds 3

The mixture of amine (2 mmol) and carbon disulfide (3 mmol) was stirred at room temperature in dichloromethane for 5 min. After the electron-deficient allenes (2 mmol) was added, the mixture was stirred vigorously for 5–25 min (monitored by TLC).

The solvent was removed under reduced pressure and the residue was purified by flash column chromatography (ethyl acetate: petroleum ether=1: 6–12) to afford the desired products.

*4.2.1. Ethyl 3-[(piperidine-1-carbonothioyl)thio]but-3-enoate (**3a**).* 95% yield, yellow solid, mp=51–53 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 5.92 (s, 1H), 5.75 (s, 1H), 4.24 (s, 2H), 4.16 (q, *J*=7.2 Hz, 2H), 3.84 (s, 2H), 3.64 (s, 2H), 1.71 (s, 6H), 1.26 (t, *J*=7.2 Hz, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 195.06, 170.33, 142.91, 125.46, 60.53, 52.25, 51.70, 38.24, 25.96, 25.20, 23.97, 15.69, 14.07. HRMS: $C_{12}H_{20}NO_2S_2$ Calcd for $[M+H]^+$ 274.0935, Found 274.0933.

*4.2.2. Ethyl 3-[(morpholine-4-carbonothioyl)thio]but-3-enoate (**3b**).* 89% yield, yellow solid, mp=69–70 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 5.95 (s, 1H), 5.77 (s, 1H), 4.32 (s, 2H), 4.16 (q, *J*=7.2 Hz, 2H), 3.90 (s, 2H), 3.77 (s, 4H), 3.63 (s, 2H), 1.27 (t, *J*=7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 195.68, 170.51, 134.16, 132.49, 66.29, 61.07, 51.04,



1 A 2 3

Scheme 1. Proposed mechanism for the formation of compounds **3**.

43.03, 14.32; HRMS: $C_{11}H_{18}NO_3S_2$ Calcd for $[M+H]^+$ 276.0728, Found 276.0727.

*4.2.3. Ethyl 3-[(pyrrolidine-1-carbonothioyl)thio]but-3-enoate (**3c**).* 87% yield, brown oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.93 (s, 1H), 5.76 (s, 1H), 4.16 (q, J=7.2 Hz, 2H), 3.89 (t, J=6.8 Hz, 2H), 3.67 (s, 2H), 3.64 (t, J=6.8 Hz, 2H), 2.14–2.05 (m, 2H), 2.02–1.95 (m, 2H), 1.26 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.97, 170.56, 134.42, 132.02, 60.96, 54.89, 51.26, 43.02, 26.43, 24.52, 14.29; HRMS: $C_{11}H_{18}NO_2S_2$ Calcd for $[M+H]^+$ 260.0779, Found 260.0774.

*4.2.4. Ethyl 3-[(azepane-1-carbonothioyl)thio]but-3-enoate (**3d**).* 80% yield, yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.92 (s, 1H), 5.75 (s, 1H), 4.23–4.06 (m, 4H), 3.86 (t, J=6.0 Hz, 2H), 3.65 (s, 2H), 1.86 (d, J=3.6 Hz, 4H), 1.65–1.56 (m, 4H), 1.26 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 194.34, 170.63, 134.77, 131.75, 60.96, 55.44, 53.66, 43.11, 27.64, 26.81, 26.68, 26.31, 14.31; HRMS: $C_{13}H_{22}NO_2S_2$ Calcd for $[M+H]^+$ 288.1092, Found 288.1090.

*4.2.5. Ethyl 3-[(diethylcarbamothioyl)thio]but-3-enoate (**3e**).* 84% yield, yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.92 (s, 1H), 5.75 (s, 1H), 4.16 (q, J=7.2 Hz, 2H), 4.00 (q, J=7.2 Hz, 2H), 3.72 (q, J=7.2 Hz, 2H), 3.64 (s, 2H), 1.36–1.19 (m, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.59, 170.61, 134.67, 131.84, 60.95, 49.31, 47.61, 43.08, 14.28, 12.73, 11.69; HRMS: $C_{11}H_{20}NO_2S_2$ Calcd for $[M+H]^+$ 262.0935, Found 262.0926.

*4.2.6. Ethyl 3-[(benzyl(methyl)carbamothioyl)thio]but-3-enoate (**3f**).* 80% yield, brown oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48–7.15 (m, 5H), 5.95 (d, J=5.2 Hz, 1H), 5.78 (d, J=8.8 Hz, 1H), 5.32 (s, 1H), 4.96 (s, 1H), 4.24–4.06 (m, 2H), 3.68 (d, J=12.0 Hz, 2H), 3.55–3.11 (m, 3H), 1.27 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.93, 170.56, 135.49, 134.70, 132.14, 128.88, 127.95, 127.25, 61.00, 59.12, 42.91, 39.45, 14.29; HRMS: $C_{15}H_{20}NO_2S_2$ Calcd for $[M+H]^+$ 310.0935, Found 310.0924.

*4.2.7. Ethyl 3-[(propylcarbamothioyl)thio]but-3-enoate (**3g**).* 85% yield, yellow solid, mp=64–66 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.29 (s, 1H), 6.02 (s, 1H), 5.94 (s, 1H), 4.20 (q, J=7.2 Hz, 2H), 3.66 (dd, J=12.4, 7.2 Hz, 2H), 3.43 (s, 2H), 1.71 (dd, J=14.6, 7.2 Hz, 3H), 1.29 (t, J=7.2 Hz, 3H), 0.98 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.27, 171.57, 134.62, 133.57, 61.90, 48.67, 43.75, 21.43, 14.22, 11.52; HRMS: $C_{10}H_{18}NO_2S_2$ Calcd for $[M+H]^+$ 248.0779, Found 248.0777.

*4.2.8. Ethyl 3-[(isopropylcarbamothioyl)thio]but-3-enoate (**3h**).* 88% yield, yellow solid, mp=60–61 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.09 (s, 1H), 6.01 (s, 1H), 5.92 (s, 1H), 4.78–4.50 (m, 1H), 4.20 (q, J=7.2 Hz, 2H), 3.41 (d, J=0.8 Hz, 2H), 1.40–1.14 (m, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.84, 171.54, 134.65, 133.49, 61.88, 48.71, 43.72, 21.27, 14.25; HRMS: $C_{10}H_{18}NO_2S_2$ Calcd for $[M+H]^+$ 248.0779, Found 248.0772.

*4.2.9. Ethyl 3-[(allylcarbamothioyl)thio]but-3-enoate (**3i**).* 91% yield, brown oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.25 (s, 1H), 6.03 (s, 1H), 5.99–5.85 (m, 2H), 5.32–5.23 (m, 2H), 4.34 (t, J=5.6 Hz, 2H), 4.19 (q, J=7.2 Hz, 2H), 3.43 (s, 2H), 1.29 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.76, 171.38, 134.72, 133.46, 131.77, 118.41, 61.92, 49.10, 43.77, 14.24; HRMS: $C_{10}H_{16}NO_2S_2$ Calcd for $[M+H]^+$ 246.0622, Found 246.0621.

*4.2.10. Ethyl 3-[(cyclohexylcarbamothioyl)thio]but-3-enoate (**3j**).* 88% yield, pale yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.11 (s, 1H), 6.01 (s, 1H), 5.91 (s, 1H), 4.37–4.34 (m, 1H), 4.20 (q, J=7.2 Hz, 2H), 3.40 (d, J=0.8 Hz, 2H), 2.04 (dd, J=12.0, 3.2 Hz, 2H), 1.78–1.72 (m, 2H), 1.62–1.66 (m, 2H), 1.36–1.43 (m, 2H), 1.32–1.27 (m, 5H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.68, 171.38, 134.39, 133.65, 61.85, 55.42, 43.68, 31.39, 25.50, 24.74, 14.24; HRMS: $C_{13}H_{22}NO_2S_2$ Calcd for $[M+H]^+$ 288.1092, Found 288.1086.

*4.2.11. Ethyl 3-[(benzylcarbamothioyl)thio]but-3-enoate (**3k**).* 95% yield, white solid, mp=56–58 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.37 (s, 1H), 7.38–7.31 (m, 5H), 5.93 (d, J=28.4 Hz, 2H), 4.90 (d, J=5.6 Hz, 2H), 4.10 (q, J=7.2 Hz, 2H), 3.40 (s, 2H), 1.23 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.83, 171.19, 136.16, 134.53, 133.52, 128.93, 128.32, 128.11, 61.84, 50.71, 43.75, 14.21; HRMS: $C_{14}H_{18}NO_2S_2$ Calcd for $[M+H]^+$ 296.0779, Found 296.0776.

*4.2.12. Ethyl 3-[[(1-phenylethyl)carbamothioyl]thio]but-3-enoate (**3l**).* 81% yield, brown oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.54 (d, J=7.6 Hz, 1H), 7.36–7.28 (m, 5H), 5.99 (s, 1H), 5.89 (s, 1H), 5.76–5.69 (m, 1H), 4.19 (qd, J=7.2, 1.6 Hz, 2H), 3.40 (s, 2H), 1.61 (d, J=6.8 Hz, 3H), 1.27 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.35, 171.54, 141.50, 134.72, 133.49, 128.78, 127.75, 126.61, 61.90, 55.68, 43.73, 20.69, 14.23; HRMS: $C_{15}H_{20}NO_2S_2$ Calcd for $[M+H]^+$ 310.0935, Found 310.0930.

*4.2.13. Ethyl 3-[[(thiophen-2-ylmethyl)carbamothioyl]thio]but-3-enoate (**3m**).* 90% yield, yellow solid, mp=64–65 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.41 (s, 1H), 7.28–7.24 (m, 1H), 7.08 (dd, J=3.6, 0.8 Hz, 1H), 6.98 (dd, J=5.2, 3.6 Hz, 1H), 5.99 (s, 1H), 5.90 (s, 1H), 5.06 (d, J=5.2 Hz, 2H), 4.12 (q, J=7.2 Hz, 2H), 3.40 (s, 2H), 1.25 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.68, 171.24, 138.12, 134.72, 133.35, 127.35, 127.06, 125.94, 61.87, 45.15, 43.67, 14.21; HRMS: $C_{12}H_{16}NO_2S_3$ Calcd for $[M+H]^+$ 302.0343, Found 302.0342.

*4.2.14. Ethyl 3-[[(furan-2-ylmethyl)carbamothioyl]thio]but-3-enoate (**3n**).* 92% yield, yellow solid, mp=60–62 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.35 (s, 1H), 7.39 (s, 1H), 6.35 (s, 2H), 6.00 (s, 1H), 5.91 (s, 1H), 4.88 (d, J=5.2 Hz, 2H), 4.14 (q, J=7.2 Hz, 2H), 3.42 (s, 2H), 1.26 (t, J=7.1 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.91, 171.15, 149.11, 142.74, 134.59, 133.35, 110.69, 109.03, 61.83, 43.60, 43.46, 14.20; HRMS: $C_{12}H_{16}NO_3S_2$ Calcd for $[M+H]^+$ 286.0572, Found 286.0569.

*4.2.15. Benzyl 3-[(piperidine-1-carbonothioyl)thio]but-3-enoate (**3o**).* 82% yield, yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35–7.31 (m, 5H), 5.92 (s, 1H), 5.75 (s, 1H), 5.14 (s, 2H), 4.21 (s, 2H), 3.79 (s, 2H), 3.71 (s, 2H), 1.67 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.24, 170.29, 135.77, 134.32, 131.92, 128.50, 128.20, 128.16, 66.59, 52.34, 50.04, 43.00, 26.01, 25.33, 24.07; HRMS: $C_{17}H_{22}NO_2S_2$ Calcd for $[M+H]^+$ 336.1092, Found 336.1088.

*4.2.16. Benzyl 3-[(benzylcarbamothioyl)thio]but-3-enoate (**3p**).* 82% yield, yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.29 (s, 1H), 7.37–7.34 (m, 5H), 7.33–7.29 (m, 5H), 5.96 (s, 1H), 5.88 (s, 1H), 5.07 (s, 2H), 4.85 (d, J=5.6 Hz, 2H), 3.46 (s, 2H).; ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.64, 170.95, 136.07, 135.18, 134.63, 133.24, 128.90, 128.78, 128.68, 128.49, 128.30, 128.08, 67.54, 50.65, 43.63; HRMS: $C_{19}H_{20}NO_2S_2$ Calcd for $[M+H]^+$ 358.0935, Found 358.0920.

*4.2.17. Benzyl 3-[(propylcarbamothioyl)thio]but-3-enoate (**3q**).* 81% yield, yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.15 (s, 1H), 7.39–7.34 (m, 5H), 6.01 (s, 1H), 5.92 (s, 1H), 5.16 (s, 2H), 3.60 (dd, J=14.4, 5.6 Hz, 2H), 3.48 (s, 2H), 1.66 (dd, J=14.8, 7.2 Hz, 2H), 0.95 (t, J=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.06, 171.20, 135.10, 134.57, 133.36, 128.76, 128.67, 128.43, 67.42, 48.60, 43.64, 21.37, 11.48; HRMS: $C_{15}H_{20}NO_2S_2$ Calcd for $[M+H]^+$ 310.0935 Found 310.0934.

*4.2.18. (E)-Ethyl 3-[(piperidine-1-carbonothioyl)thio]pent-3-enoate (**3r**).* 77% yield, yellow solid, mp=56–57 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.16 (q, J=6.8 Hz, 1H), 4.15 (s, 2H), 4.05 (dd, J=14.0, 6.8 Hz,

2H), 3.75 (s, 2H), 3.51 (s, 2H), 1.79 (d, *J*=7.2 Hz, 3H), 1.61 (s, 6H), 1.17 (t, *J*=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 195.06, 170.33, 142.91, 125.46, 60.53, 52.25, 51.70, 38.24, 25.96, 25.20, 23.97, 15.69, 14.07; HRMS: $C_{13}H_{22}NO_2S_2$ Calcd for $[M+H]^+$ 288.1092, Found 288.1090.

*4.2.19. (E)-Ethyl 3-[(benzylcarbamothioyl)thio]pent-3-enoate (**3s**).* 80% yield, yellow solid, mp=56–58 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.81 (s, 1H), 7.34–7.28 (m, 5H), 6.53 (q, *J*=7.2 Hz, 1H), 4.91 (d, *J*=5.6 Hz, 2H), 4.07–4.02 (m, 2H), 3.43 (s, 2H), 1.73 (d, *J*=6.8 Hz, 3H), 1.22 (t, *J*=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 195.47, 171.75, 147.51, 136.47, 128.72, 128.22, 127.82, 123.72, 61.89, 50.22, 39.41, 16.13, 14.15; HRMS: $C_{15}H_{20}NO_2S_2$ Calcd for $[M+H]^+$ 310.0935, Found 310.0936.

*4.2.20. (E)-Ethyl 3-[(propylcarbamothioyl)thio]pent-3-enoate (**3t**).* 76% yield, yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.63 (s, 1H), 6.57 (q, *J*=7.2 Hz, 1H), 4.21 (q, *J*=7.2 Hz, 2H), 3.64 (dd, *J*=12.4, 7.2 Hz, 2H), 3.46 (s, 2H), 1.79 (d, *J*=7.2 Hz, 3H), 1.70 (dd, *J*=14.4, 7.2 Hz, 2H), 1.30 (t, *J*=7.2 Hz, 3H), 0.96 (t, *J*=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 194.80, 172.04, 147.57, 123.72, 61.95, 48.53, 39.49, 21.31, 16.15, 14.18, 11.46; HRMS: $C_{11}H_{20}NO_2S_2$ Calcd for $[M+H]^+$ 262.0935, Found 262.0932.

*4.2.21. Ethyl 3-[(benzylcarbamothioyl)thio]-2-methylbut-3-enoate (**3u**).* 82% yield, brown oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.25 (s, 1H), 7.36–7.32 (m 5H), 5.95 (s, 1H), 5.85 (s, 1H), 4.90 (d, *J*=5.2 Hz, 2H), 4.04 (qd, *J*=7.2, 2.0 Hz, 2H), 3.42 (q, *J*=6.8 Hz, 1H), 1.37 (d, *J*=6.8 Hz, 3H), 1.18 (t, *J*=7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.77, 173.38, 140.35, 136.06, 131.52, 128.94, 128.25, 128.13, 61.72, 50.66, 48.12, 16.78, 14.16; HRMS: $C_{15}H_{20}NO_2S_2$ Calcd for $[M+H]^+$ 310.0935, Found 310.0934.

*4.2.22. Ethyl 2-methyl-3-[(propylcarbamothioyl)thio]but-3-enoate (**3v**).* 78% yield, yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13 (s, 1H), 6.02 (s, 1H), 5.87 (s, 1H), 4.19 (q, *J*=7.2 Hz, 2H), 3.68–3.65 (m, 2H), 3.46 (q, *J*=7.2 Hz, 1H), 1.70 (dd, *J*=14.4, 7.2 Hz, 2H), 1.41 (d, *J*=7.2 Hz, 3H), 1.29 (t, *J*=7.2 Hz, 3H), 0.98 (t, *J*=7.2 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 193.15, 173.64, 140.43, 131.39, 61.75, 48.49, 48.07, 21.41, 16.73, 14.15, 11.45; HRMS: $C_{11}H_{19}NO_2S_2$. Calcd for $[M+H]^+$ 262.0935, Found 262.0931.

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Supplementary data

Supplementary data (The original data of ^{1}H NMR and ^{13}C NMR of all products are supplied. The supplementary data files are to be used as an aid for the refereeing of the paper only.) associated with this article can be found in the online version, at http://dx.doi.org/10.1016/j.tet.2016.07.075. These data include MOL files and InChiKeys of the most important compounds described in this article.

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