

Efficient One-Pot Synthesis of 1,3-Disubstituted Pyridin-2(1*H*)-ones from α -Hydroxyketene *S,S*-Acetals under Vilsmeier Conditions

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Abstract: A facile and efficient one-pot synthesis of 1,3-disubstituted pyridin-2(1*H*)-ones is developed via a novel cascade reaction of readily available α -hydroxy- α -carbamoyl ketene *S,S*-acetals under Vilsmeier conditions (DMF/POCl₃), and a mechanism of this domino reaction is proposed.

Key words: pyridin-2(1*H*)-ones, Vilsmeier reagent, α -hydroxyketene *S,S*-acetals

Pyridin-2(1*H*)-ones are an important class of organic heterocycles due to their presence in numerous natural products and because of their use as synthetic organic compounds with diverse bio-, physio-, and pharmacological activities.^{1,2} A variety of synthetic approaches for accessing substituted pyridin-2(1*H*)-ones have been developed,³ including modification of the preconstructed heterocyclic ring by pyridinium salt chemistry^{4,5} and the construction of the nitrogen heterocyclic skeleton from appropriate acyclic precursors via Guareschi–Thorpe reaction,⁶ Dieckmann-type condensation,⁷ hetero-Diels–Alder reaction,⁸ or metal-mediated cycloaddition.⁹ However, these methods are generally limited in their use by the lack of substrate scope, the harsh reaction conditions, or the multistep procedure required. Recently, Dong et al. reported an alternative method for the facile synthesis of highly substituted pyridin-2(1*H*)-ones in one-pot from cyclopropyl amides,^{10a} cyclic enamines,^{10b} and β -oxo amides,^{10c} respectively, under Vilsmeier conditions. Lately, a novel synthesis of 3-thiocarbonothioyl-4-chloro/bromo pyridin-2(1*H*)-ones via a domino reaction of α -acetyl- α -carbamoyl ketene *S,S*-acetals with Vilsmeier reagents has also been developed in our group.¹¹ It is true that the development of simple and efficient synthetic approaches for the construction of pyridin-2(1*H*)-ones, especially from readily available starting materials under mild reaction conditions, are highly desired.

As a kind of important organic intermediates, α -hydroxyketene *S,S*-acetals have been proved to possess high reactivities toward nucleophiles under acidic conditions and have found their applications in the synthesis of substituted pyridines,^{12a} α,β -unsaturated dithioesters^{12b} and conjugated polyene esters.^{12c} During our ongoing research on the chemistry of functionalized ketene *S,S*-acetals, α -hy-

droxyketene *S,S*-acetals have been successfully applied in the synthesis of functionalized unsaturated δ -lactones,^{13a} substituted 3,4-dihydro-2-pyridones,^{13b} and 3,4-disubstituted dihydrocoumarins.^{13c} As a part of our continuing interest in further synthetic potential of α -hydroxyketene *S,S*-acetals and the Vilsmeier–Haack reaction for the synthesis of various heterocycles, in the present work, we examined the reactivity of α -hydroxyketene *S,S*-acetals toward Vilsmeier reagent (VR). As a result, a facile and alternative method for the one-pot synthesis of 1,3-disubstituted pyridin-2(1*H*)-ones of type **3** has been developed via a new cascade reaction of readily available α -hydroxy- α -carbamoyl ketene *S,S*-acetals **1** under Vilsmeier conditions (DMF/POCl₃). Herein, we wish to report our preliminary results and the proposed mechanism of the transformation from **1** into **3**.

The substrates, α -hydroxy- α -carbamoyl ketene *S,S*-acetals **1**, were prepared by the reduction of the corresponding α -acetyl- α -carbamoyl ketene *S,S*-acetals using NaBH₄ as reductive in excellent yields according to the procedure described in our previous work.^{13b} Initially, the reaction of 2-[bis(ethylthio)methylene]-3-hydroxy-*N*-phenylbutanamide (**1a**) with POCl₃ (2.0 equiv) in DMF (10 mL) was tried at room temperature for 4 hours, but no reaction occurred. When the reaction was performed at 60 °C for 20 minutes, the reaction furnished a white solid after workup and purification by column chromatography of the resulting reaction mixture. The product was characterized as 2-[bis(ethylthio)methylene]-*N*-phenylbut-3-enamide (**2a**) in 90% yield based on their spectroscopic and analytical data (Table 1, entry 1). Interestingly, on increasing the reaction temperature to 90 °C for 60 minutes, **2a** (50% yield) along with a new cyclic product (25% yield), *S*-ethyl 2-oxo-1-phenyl-1,2-dihydropyridine-3-carbothioate (**3a**), were obtained (Table 1, entry 2) with the recovery of **1a** in 10% yield. Obviously, **2a** is the precursor of **3a** in this process. Thus a transformation of **2a** into **3a** was tried by treatment of **2a** with POCl₃ (5.0 equiv) in DMF at 90 °C for 30 minutes. As expected, the reaction afforded the desired product **3a** in 75% yield (Table 1). It is noteworthy that the one-pot construction of **3a** under such mild conditions represents a novel and alternative route to substituted pyridin-2(1*H*)-ones from readily available starting materials. Aiming to optimize this new cyclization, compound **1a** was chosen as model substrate toward Vilsmeier reagent. From the results summarized in Table 1, it is clear that the 1:4 ratio of **1a** to POCl₃ is enough to lead to a complete conversion of **1a** into **3a** at 90 °C (entry 4) and high-

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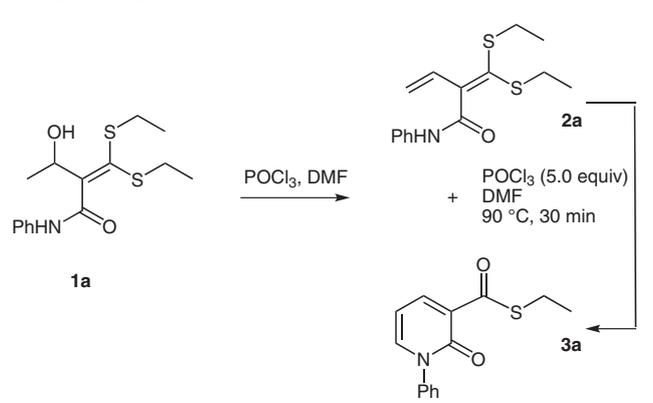
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er temperature did not show obvious improvement for this cyclization (entries 7 and 8). By comparison, the reaction performed at 90 °C with the 1:5 ratio of **1a** to POCl₃ was superior, regarding both the yield and reaction time (entry 5). Thus, these conditions were chosen for the following investigations.

Table 1 Optimization of Conditions for the Cyclization of **1a** under Vilsmeier Conditions^a



Entry	1a :POCl ₃	Temp (°C)	Time (min)	Yield of 2a ^b	Yield of 3a ^b
1	1: 2	60	20	90	0
2 ^c	1: 2	90	60	50	25
3	1: 3	90	60	10	67
4	1: 4	90	50	0	78
5	1: 5	90	45	0	80
6	1: 6	90	42	0	81
7	1: 4	100	40	0	80
8	1: 4	120	38	0	78

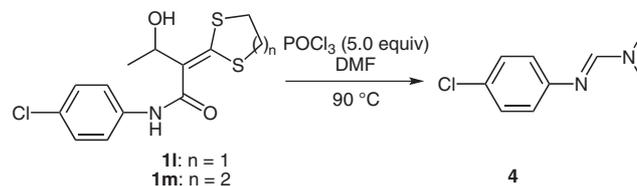
^a Reaction conditions: **1a** (1.0 mmol), DMF (10 mL).

^b Isolated yields after silica gel chromatography.

^c Compound **1a** was recovered in 10%.

Next, under the optimized conditions (Table 1, entry 5), the scope of this Vilsmeier cyclization was studied by treating various **1** with Vilsmeier reagent. As described in Table 2, a wide scope of **1** bearing variable *N*-aryl- and *N*-alkylamide groups can give the corresponding 1,3-disubstituted pyridin-2(1*H*)-ones **3** in good to high yields (Table 2, entries 1–9). Especially, those substrates having sterically hindered aryl amide also showed high reactivities in the cyclization (entries 5–8). The impact of variation at ketene *S,S*-acetal moieties of **1** on this procedure was also investigated. Clearly, the reactions of **1j** and **1k** with Vilsmeier reagent can yield the corresponding products **3j** and **3k** in good yields (entries 10 and 11). Differently, under the same conditions as above, the reactions of α -hydroxy- α -carbamoyl cyclic ketene dithioacetals **1l** and **1m** with Vilsmeier reagent (DMF/POCl₃) did not afford the corresponding 1,3-disubstituted pyridin-2(1*H*)-ones in shorter reaction time, while (*E*)-*N'*-(4-chlorophenyl)-*N,N*-

dimethylformimidamide (**4**)¹⁴ was obtained as the major product in 45 and 50% yield, respectively, when prolonging the reaction time to 5 hours (Scheme 1). All the 1,3-disubstituted pyridin-2(1*H*)-ones **3** were well characterized by the analytical and spectral data and the structure of them was further established by X-ray diffraction studies of **3a** (Figure 1).¹⁵



Scheme 1 Reaction of **1l,m** with Vilsmeier reagent

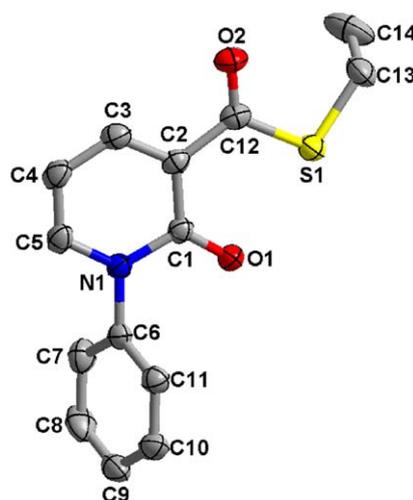
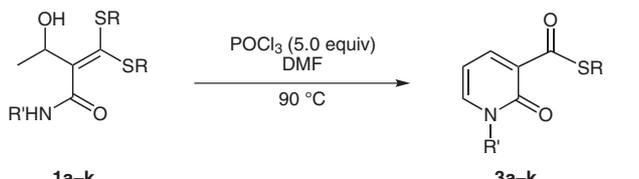


Figure 1 ORTEP drawing of **3a**

The mechanism of the Vilsmeier cyclization, on the basis of all the obtained results combined with our previous studies,¹¹ most likely begins with dehydration of **1** to afford **2**, which can be converted into intermediate **A** upon treatment with Vilsmeier reagent. Then, a nucleophilic attack of the amide nitrogen at the positive carbon of the methylene moiety leads to a cyclization of **A** into **B** with elimination of HCl. The sequential removal of dimethylamine from **B** results in the formation of intermediate **C**, the hydrolysis of which produces 3-thiocarbonyl pyridin-2(1*H*)-ones **3** during the workup. Different from our previous work¹¹ on the study of the Vilsmeier cyclization of α -acetyl- α -carbamoyl ketene *S,S*-acetals, the domino process reported here was observed to be accompanied with hydrolysis of ketene *S,S*-acetal moiety in all cases (Scheme 2).

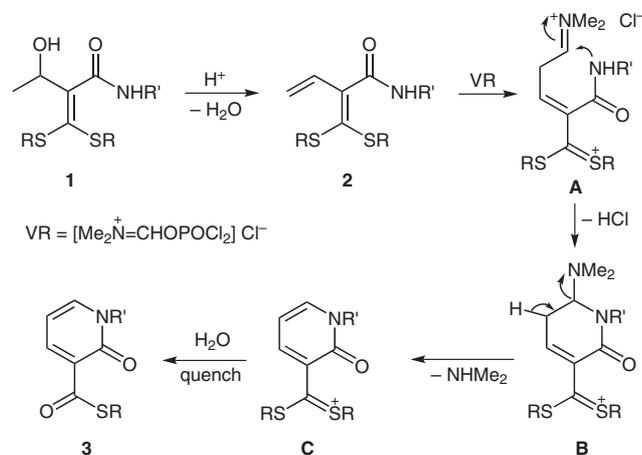
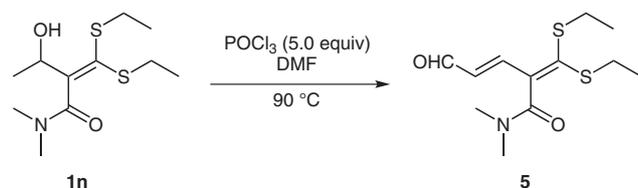
To gain insight into the mechanism of the cyclization, the reaction of **1n** bearing *N,N*-disubstituents with 5.0 equivalents of Vilsmeier reagent was performed under the identical conditions described above for 40 minutes, and then quenched with aqueous NaOH. This led to the formation of the acyclic dehydration–formylation product **5**, (*E*)-2-

Table 2 Synthesis of Pyridin-2(1*H*)-ones **3**^a


Entry	1	R	R'	3	Time (min)	Yield (%) ^b
1	1a	Et	Ph	3a	45	80
2	1b	Et	4-ClC ₆ H ₄	3b	40	76
3	1c	Et	4-MeC ₆ H ₄	3c	45	69
4	1d	Et	4-MeOC ₆ H ₄	3d	40	73
5	1e	Et	2-ClC ₆ H ₄	3e	60	70
6	1f	Et	2-MeC ₆ H ₄	3f	50	64
7	1g	Et	2-MeOC ₆ H ₄	3g	45	87
8	1h	Et	2,4-Me ₂ C ₆ H ₃	3h	60	65
9	1i	Et	Me	3i	35	70
10	1j	Me	4-ClC ₆ H ₄	3j	40	75
11	1k	Bn	4-ClC ₆ H ₄	3k	50	70

^a Reaction conditions: **1** (1.0 mmol), POCl₃ (5.0 mmol), DMF (10 mL), 90 °C.

^b Isolated yields after silica gel chromatography.

**Scheme 2** Proposed mechanism for the formation of **3****Scheme 3** Reaction of **1n** with Vilsmeier reagent

[bis(ethylthio)methylene]-*N,N*-dimethyl-5-oxopent-3-enamide, in 79% yield (Scheme 3).

In conclusion, we have developed a facile and efficient method for the preparation of 1,3-disubstituted pyridin-2(1*H*)-ones via the Vilsmeier cyclization of α -hydroxy- α -carbamoyl ketene *S,S*-acetals **1**. The simple execution, readily available substrates, mild conditions, and high yields make this protocol very attractive. Further studies on the details and potential of this new strategy and the synthetic applications of 1,3-disubstituted pyridin-2(1*H*)-ones are in progress.

All reagents were purchased from commercial sources and used as such, unless otherwise indicated. The products were purified by column chromatography over silica gel (300–400 mesh). All reactions were monitored by TLC, which was performed on precoated aluminum sheets of silica gel 60 (F₂₅₄). Melting points were uncorrected. ¹H and ¹³C NMR spectra were determined at r.t. on a Varian spectrometer at 500 and 125 MHz, respectively, using TMS as internal standard. All shifts were given in ppm. IR spectra (KBr) were recorded on a Magna-560 FTIR spectrophotometer in the range of 400–4000 cm⁻¹. Mass spectra were measured on an Agilent 1100 LCMsD spectrometer. Elemental analyses were obtained on a VarioEL analyzer. X-ray diffraction was measured on a Siemens P4 diffractometer. Compounds **1** were prepared according to our previous report.^{13b} Petroleum ether used refers to the fraction boiling at 60–90 °C.

2-[Bis(ethylthio)methylene]-*N*-phenylbut-3-enamide (**2a**)

To a stirred solution of **1a** (1.0 mmol, 311 mg) in DMF (10 mL) was added POCl₃ (2.0 mmol, 0.18 mL) in one portion at r.t. Then, the mixture was heated to 60 °C for 20 min. After the consumption of **1a** (monitored by TLC), the mixture was poured into H₂O (50 mL), neutralized with sat. aq NaHCO₃ to pH 7, and extracted with CH₂Cl₂ (2 × 10 mL). The combined organic extracts were dried (MgSO₄), filtered, and concentrated in vacuo to yield the crude product, which was purified by silica gel chromatography (eluent: petroleum ether–Et₂O, 8:1) to give **2a** (264 mg, 90%) as colorless crystals; mp 132–134 °C.

IR (KBr): 1975, 1715, 1625, 1597, 1520, 967, 938 cm⁻¹.

¹H NMR (500 MHz, CDCl₃): δ = 1.25–1.30 (m, 6 H), 2.82–2.89 (m, 4 H), 5.33 (d, *J* = 11.0 Hz, 1 H), 5.44 (d, *J* = 17.5 Hz, 1 H), 7.13 (dd, *J* = 11.0, 17.5 Hz, 1 H), 7.16 (t, *J* = 7.5 Hz, 1 H), 7.19 (s, 1 H), 7.36 (t, *J* = 7.5 Hz, 2 H), 7.59 (d, *J* = 8.0 Hz, 2 H).

¹³C NMR (125 MHz, CDCl₃): δ = 166.1, 145.2, 138.0, 135.5, 132.4, 129.4 (2 C), 124.8, 120.1 (2 C), 118.5, 28.4, 28.2, 15.3, 15.3.

ES-MS: *m/z* = 294 [(*M* + 1)]⁺.

Anal. Calcd for C₁₅H₁₉NOS₂: C, 61.39; H, 6.53; N, 4.77. Found: C, 61.50; H, 6.66; N, 4.67.

Compounds **3**; *S*-Ethyl 2-Oxo-1-phenyl-1,2-dihydropyridine-3-carbothioate (**3a**); Typical Procedure

To a stirred solution of **1a** (1.0 mmol, 311 mg) in DMF (10 mL) was added POCl₃ (5.0 mmol, 0.45 mL) in one portion at r.t. Then, the reaction mixture was heated to 90 °C for 45 min. After the consumption of **1a** (monitored by TLC), the mixture was poured into H₂O (50 mL), neutralized with sat. aq NaHCO₃ to pH 7, and extracted with CH₂Cl₂ (2 × 10 mL). The combined organic extracts were dried (MgSO₄), filtered, and concentrated in vacuo to yield the crude product, which was purified by silica gel chromatography (eluent: petroleum ether–Et₂O, 5:1) to give **3a** (207 mg, 80%) as colorless crystals; mp 146–148 °C.

IR (KBr): 2960, 1662, 1528, 1492, 1358, 1273, 1048, 937, 767 cm^{-1} .

^1H NMR (500 MHz, CDCl_3): δ = 1.31 (t, J = 7.5 Hz, 3 H), 2.98 (q, J = 7.5 Hz, 2 H), 6.45 (t, J = 7.0 Hz, 1 H), 7.39 (d, J = 7.5 Hz, 2 H), 7.47 (t, J = 7.5 Hz, 1 H), 7.52 (t, J = 7.5 Hz, 2 H), 7.59 (dd, J = 2.0, 7.0 Hz, 1 H), 8.33 (dd, J = 2.0, 7.0 Hz, 1 H).

^{13}C NMR (125 MHz, CDCl_3): δ = 189.7, 160.4, 142.7, 142.7, 140.0, 129.4 (2 C), 129.1, 126.6 (2 C), 126.4, 105.7, 23.7, 13.9.

ES-MS: m/z = 260 [(M + 1)]⁺.

Anal. Calcd for $\text{C}_{14}\text{H}_{13}\text{NO}_2\text{S}$: C, 64.84; H, 5.05; N, 5.40. Found: C, 64.94; H, 4.75; N, 5.27.

S-Ethyl 1-(4-Chlorophenyl)-2-oxo-1,2-dihydropyridine-3-carbothioate (3b)

Colorless crystals; mp 101–103 °C.

IR (KBr): 2925, 1659, 1530, 1439, 1250, 1217, 1037, 938, 920, 775 cm^{-1} .

^1H NMR (500 MHz, CDCl_3): δ = 1.29 (t, J = 7.5 Hz, 3 H), 2.97 (q, J = 7.5 Hz, 2 H), 6.43 (t, J = 7.0 Hz, 1 H), 7.33 (d, J = 8.5 Hz, 2 H), 7.46 (d, J = 8.5 Hz, 2 H), 7.58 (dd, J = 2.0, 7.0 Hz, 1 H), 8.29 (dd, J = 2.0, 7.0 Hz, 1 H).

^{13}C NMR (125 MHz, CDCl_3): δ = 189.8, 159.0, 142.6, 140.5, 138.8, 134.9, 129.6 (2 C), 128.0 (2 C), 126.5, 106.1, 32.3, 11.6.

ES-MS: m/z = 294 [(M + 1)]⁺.

Anal. Calcd for $\text{C}_{14}\text{H}_{12}\text{ClNO}_2\text{S}$: C, 57.24; H, 4.12; N, 4.77. Found: C, 57.20; H, 4.17; N, 4.85.

S-Ethyl 2-Oxo-1-*p*-tolyl-1,2-dihydropyridine-3-carbothioate (3c)

Colorless crystals; mp 150–152 °C.

IR (KBr): 2924, 1663, 1536, 1509, 1273, 1220, 1019, 938, 762 cm^{-1} .

^1H NMR (500 MHz, CDCl_3): δ = 1.30 (t, J = 7.0 Hz, 3 H), 2.42 (s, 3 H), 2.98 (q, J = 7.0 Hz, 2 H), 6.42 (t, J = 7.0 Hz, 1 H), 7.25 (d, J = 8.5 Hz, 2 H), 7.29 (d, J = 8.5 Hz, 2 H), 7.62 (dd, J = 2.0, 7.0 Hz, 1 H), 8.31 (dd, J = 2.0, 7.0 Hz, 1 H).

^{13}C NMR (125 MHz, CDCl_3): δ = 189.7, 160.5, 142.8, 142.5, 139.1, 137.5, 130.0 (2 C), 126.3, 126.3 (2 C), 105.5, 23.6, 21.2, 13.9.

ES-MS: m/z = 274 [(M + 1)]⁺.

Anal. Calcd for $\text{C}_{15}\text{H}_{15}\text{NO}_2\text{S}$: C, 65.91; H, 5.53; N, 5.12. Found: C, 66.09; H, 5.49; N, 5.21.

S-Ethyl 1-(4-Methoxyphenyl)-2-oxo-1,2-dihydropyridine-3-carbothioate (3d)

Colorless crystals; mp 143–145 °C.

IR (KBr): 2978, 1672, 1528, 1509, 1258, 1174, 1023, 943, 758 cm^{-1} .

^1H NMR (500 MHz, CDCl_3): δ = 1.30 (t, J = 7.0 Hz, 3 H), 2.98 (q, J = 7.0 Hz, 2 H), 3.85 (s, 3 H), 6.41 (t, J = 7.0 Hz, 1 H), 7.00 (d, J = 9.0 Hz, 2 H), 7.30 (d, J = 9.0 Hz, 2 H), 7.62 (dd, J = 2.0, 7.0 Hz, 1 H), 8.31 (d, J = 7.0 Hz, 1 H).

^{13}C NMR (125 MHz, CDCl_3): δ = 189.7, 160.6, 159.8, 142.9, 142.4, 132.8, 127.6 (2 C), 126.3, 114.5 (2 C), 105.4, 55.6, 23.6, 13.9.

ES-MS: m/z = 290 [(M + 1)]⁺.

Anal. Calcd for $\text{C}_{15}\text{H}_{15}\text{NO}_3\text{S}$: C, 62.26; H, 5.23; N, 4.84. Found: C, 62.11; H, 5.20; N, 4.93.

S-Ethyl 1-(2-Chlorophenyl)-2-oxo-1,2-dihydropyridine-3-carbothioate (3e)

Colorless crystals; mp 146–148 °C.

IR (KBr): 2931, 1662, 1536, 1444, 1255, 1221, 1028, 938, 768 cm^{-1} .

^1H NMR (500 MHz, CDCl_3): δ = 1.30 (t, J = 7.5 Hz, 3 H), 2.98 (q, J = 7.5 Hz, 2 H), 6.46 (t, J = 7.0 Hz, 1 H), 7.39–7.49 (m, 4 H), 7.57 (d, J = 7.0 Hz, 1 H), 8.35 (d, J = 7.0 Hz, 1 H).

^{13}C NMR (125 MHz, CDCl_3): δ = 189.4, 159.8, 143.0, 142.6, 137.4, 131.5, 130.7, 130.6, 129.1, 127.9, 126.7, 105.6, 23.6, 13.8.

ES-MS: m/z = 294 [(M + 1)]⁺.

Anal. Calcd for $\text{C}_{14}\text{H}_{12}\text{ClNO}_2\text{S}$: C, 57.24; H, 4.12; N, 4.77. Found: C, 57.06; H, 4.04; N, 4.81.

S-Ethyl 2-Oxo-1-*o*-tolyl-1,2-dihydropyridine-3-carbothioate (3f)

Colorless crystals; mp 99–101 °C.

IR (KBr): 2924, 1662, 1532, 1441, 1268, 1220, 1032, 934, 773 cm^{-1} .

^1H NMR (500 MHz, CDCl_3): δ = 1.31 (t, J = 7.5 Hz, 3 H), 2.16 (s, 3 H), 2.98 (q, J = 7.5 Hz, 2 H), 6.44 (t, J = 7.0 Hz, 1 H), 7.20 (d, J = 7.5 Hz, 1 H), 7.33–7.38 (m, 3 H), 7.51 (dd, J = 2.5, 7.0 Hz, 1 H), 8.35 (dd, J = 2.5, 7.0 Hz, 1 H).

^{13}C NMR (125 MHz, CDCl_3): δ = 190.0, 160.2, 143.0, 142.8, 139.5, 135.1, 131.4, 129.8, 127.4, 127.3, 126.8, 105.7, 23.8, 17.8, 14.1.

ES-MS: m/z = 274 [(M + 1)]⁺.

Anal. Calcd for $\text{C}_{15}\text{H}_{15}\text{NO}_2\text{S}$: C, 65.91; H, 5.53; N, 5.12. Found: C, 65.83; H, 5.45; N, 5.16.

S-Ethyl 1-(2-Methoxyphenyl)-2-oxo-1,2-dihydropyridine-3-carbothioate (3g)

Colorless crystals; mp 138–140 °C.

IR (KBr): 2926, 1660, 1533, 1499, 1257, 1220, 1019, 936, 754 cm^{-1} .

^1H NMR (500 MHz, CDCl_3): δ = 1.29 (t, J = 7.5 Hz, 3 H), 2.97 (q, J = 7.5 Hz, 2 H), 3.80 (s, 3 H), 6.39 (t, J = 7.0 Hz, 1 H), 7.05 (t, J = 8.0 Hz, 2 H), 7.27 (t, J = 8.0 Hz, 1 H), 7.43 (t, J = 8.5 Hz, 1 H), 7.50 (dd, J = 1.5, 7.0 Hz, 1 H), 8.31 (dd, J = 1.5, 7.0 Hz, 1 H).

^{13}C NMR (125 MHz, CDCl_3): δ = 189.8, 160.3, 154.0, 144.0, 142.7, 130.7, 128.6, 128.5, 126.3, 120.8, 112.2, 105.1, 55.8, 23.6, 13.9.

ES-MS: m/z = 290 [(M + 1)]⁺.

Anal. Calcd for $\text{C}_{15}\text{H}_{15}\text{NO}_3\text{S}$: C, 62.26; H, 5.23; N, 4.84. Found: C, 62.45; H, 5.38; N, 4.90.

S-Ethyl 1-(2,4-Dimethylphenyl)-2-oxo-1,2-dihydropyridine-3-carbothioate (3h)

Colorless crystals; mp 101–103 °C.

IR (KBr): 2924, 1660, 1530, 1499, 1251, 1217, 1037, 939, 775 cm^{-1} .

^1H NMR (500 MHz, CDCl_3): δ = 1.29 (t, J = 7.5 Hz, 3 H), 2.09 (s, 3 H), 2.36 (s, 3 H), 2.96 (q, J = 7.5 Hz, 2 H), 6.41 (t, J = 7.0 Hz, 1 H), 7.05 (d, J = 8.0 Hz, 1 H), 7.11 (d, J = 8.0 Hz, 1 H), 7.14 (s, 1 H), 7.49 (dd, J = 1.5, 7.0 Hz, 1 H), 8.32 (dd, J = 1.5, 7.0 Hz, 1 H).

^{13}C NMR (125 MHz, CDCl_3): δ = 190.1, 160.4, 143.3, 142.8, 139.8, 137.0, 134.6, 132.1, 128.0, 127.0, 126.6, 105.7, 23.9, 21.4, 17.8, 14.2.

ES-MS: m/z = 288 [(M + 1)]⁺.

Anal. Calcd for $\text{C}_{16}\text{H}_{17}\text{NO}_2\text{S}$: C, 66.87; H, 5.96; N, 4.87. Found: C, 67.05; H, 6.14; N, 4.97.

S-Ethyl 1-Methyl-2-oxo-1,2-dihydropyridine-3-carbothioate (3i)

Colorless oil.

IR (KBr): 3024, 1674, 1540, 1516, 1465, 1295, 962, 848, 763 cm^{-1} .

^1H NMR (500 MHz, CDCl_3): δ = 1.31 (t, J = 7.5 Hz, 3 H), 2.99 (q, J = 7.5 Hz, 2 H), 3.64 (s, 3 H), 6.33 (t, J = 7.0 Hz, 1 H), 7.59 (d, J = 7.0 Hz, 1 H), 8.22 (d, J = 7.0 Hz, 1 H).

^{13}C NMR (125 MHz, CDCl_3): δ = 189.6, 160.8, 143.0, 142.0, 125.5, 105.5, 38.2, 23.6, 14.0.

ES-MS: m/z = 198 [(M + 1)]⁺.

Anal. Calcd for $\text{C}_9\text{H}_{11}\text{NO}_2\text{S}$: C, 54.80; H, 5.62; N, 7.10. Found: C, 54.99; H, 5.77; N, 7.16.

S-Methyl 1-(4-Chlorophenyl)-2-oxo-1,2-dihydropyridine-3-carbothioate (3j)

Colorless crystals; mp 185–187 °C.

IR (KBr): 3091, 1654, 1621, 1580, 1533, 1250, 1222, 1016, 934, 767 cm^{-1} .

^1H NMR (500 MHz, CDCl_3): δ = 2.38 (s, 3 H), 6.45 (t, J = 7.0 Hz, 1 H), 7.34 (d, J = 8.0 Hz, 2 H), 7.48 (d, J = 8.0 Hz, 2 H), 7.59 (dd, J = 2.0, 7.0 Hz, 1 H), 8.32 (dd, J = 2.0, 7.0 Hz, 1 H).

^{13}C NMR (125 MHz, CDCl_3): δ = 189.9, 160.2, 142.7, 142.2, 138.3, 135.1, 129.6 (2 C), 127.9 (2 C), 126.3, 105.9, 12.7.

ES-MS: m/z = 280 [(M + 1)]⁺.

Anal. Calcd for $\text{C}_{13}\text{H}_{10}\text{ClNO}_2\text{S}$: C, 55.82; H, 3.60; N, 5.01. Found: C, 55.62; H, 3.72; N, 5.11.

S-Benzyl 1-(4-Chlorophenyl)-2-oxo-1,2-dihydropyridine-3-carbothioate (3k)

Colorless crystals; mp 101–103 °C.

IR (KBr): 3061, 1619, 1535, 1515, 1449, 1238, 1210, 1024, 920, 759 cm^{-1} .

^1H NMR (500 MHz, CDCl_3): δ = 4.22 (s, 2 H), 6.45 (t, J = 6.5 Hz, 1 H), 7.21 (t, J = 7.5 Hz, 1 H), 7.27–7.37 (m, 6 H), 7.47 (d, J = 8.0 Hz, 2 H), 7.59 (d, J = 6.5 Hz, 1 H), 8.33 (d, J = 6.5 Hz, 1 H).

^{13}C NMR (125 MHz, CDCl_3): δ = 188.7, 160.2, 143.0, 142.4, 138.2, 137.5, 135.1, 129.6 (2C), 129.1 (2C), 128.4 (2 C), 127.9 (2 C), 127.0, 126.2, 106.0, 34.0.

ES-MS: m/z = 356 [(M + 1)]⁺.

Anal. Calcd for $\text{C}_{19}\text{H}_{14}\text{ClNO}_2\text{S}$: C, 64.13; H, 3.97; N, 3.94. Found: C, 64.30; H, 4.10; N, 3.98.

(E)-N'-(4-Chlorophenyl)-N,N-dimethylformimidamide (4)

Colorless oil.

^1H NMR (500 MHz, CDCl_3): δ = 3.01 (s, 6 H), 6.88 (d, J = 8.5 Hz, 2 H), 7.20 (d, J = 8.5 Hz, 2 H), 7.48 (s, 1 H).

^{13}C NMR (125 MHz, CDCl_3): δ = 153.7, 150.9, 129.2 (2 C), 127.7, 122.6 (2 C), 30.0 (2 C).

ES-MS: m/z = 183 [(M + 1)]⁺.

Anal. Calcd for $\text{C}_9\text{H}_{11}\text{ClN}_2$: C, 59.18; H, 6.07; N, 15.34. Found: C, 59.33; H, 6.22; N, 15.40.

(E)-2-[Bis(ethylthio)methylene]-N,N-dimethyl-5-oxopent-3-enamide (5)

Yellow oil.

IR (KBr): 2973, 1740, 1678, 1587, 1515, 1397, 1255, 1125, 969 cm^{-1} .

^1H NMR (500 MHz, CDCl_3): δ = 1.25–1.35 (m, 6 H), 2.86–3.09 (m, 4 H), 2.89 (s, 3 H), 3.08 (s, 3 H), 6.04 (dd, J = 8.0, 15.5 Hz, 1 H), 7.91 (d, J = 15.5 Hz, 1 H), 9.66 (d, J = 8.0 Hz, 1 H).

^{13}C NMR (125 MHz, CDCl_3): δ = 193.7, 167.3, 146.5, 144.8, 140.5, 129.8, 37.5, 34.4, 29.1, 28.8, 15.4, 15.2.

ES-MS: m/z = 274 [(M + 1)]⁺.

Anal. Calcd for $\text{C}_{12}\text{H}_{19}\text{NO}_2\text{S}_2$: C, 52.71; H, 7.00; N, 5.12. Found: C, 52.63; H, 6.98; N, 5.16.

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References and Notes

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- (15) Crystal data for **3a**: C₁₄H₁₃NO₂S, colorless crystal, *M* = 259.31, monoclinic, space group *P*2₁, *a* = 5.6429(13), *b* = 12.163(3), *c* = 9.504(2), Å, *V* = 652.3(3) Å³, *α* = 90.00, *β* = 90.00, *γ* = 90.00, *Z* = 2, *T* = 293 (2) K, *F*₀₀₀ = 272,

*R*1 = 0.0428, *wR*2 = 0.1077. CCDC 690433 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.