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Metal-Free Aminothiation of Alkynes: Three-Component Tandem Annulation toward Indolizine Thiones from 2-Alkylpyridines, Ynals, and Elemental Sulfur

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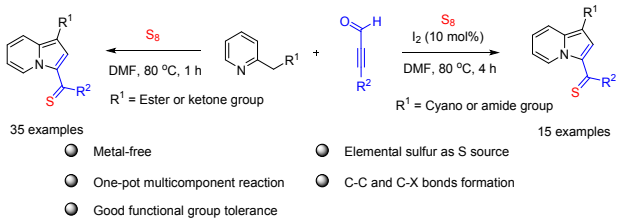


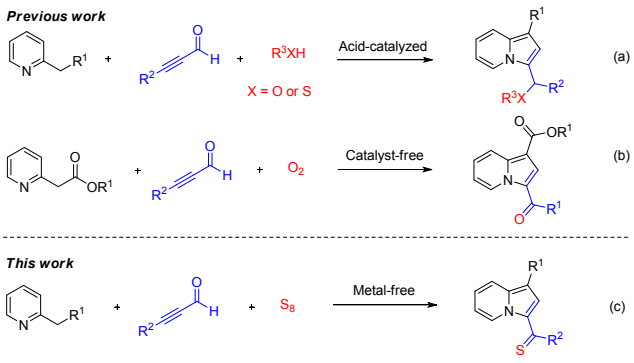
Abstract: A metal-free three-component annulation reaction for the synthesis of indolizine thiones via tandem C-C/C-N/C-S bonds formation was developed. Various 2-alkylpyridines with aromatic ynals and elemental sulfur proceeded smoothly under catalyst-free conditions, and the desired products were obtained in moderate to excellent yields.

Indolizines are privileged structural motif occurring frequently in natural products, synthetic pharmaceuticals, and materials chemistry.[1] Many substituted indolizines exhibit remarkable bioactivity, such as antibacterial, antifungal, antioxidant, anticancer, and antitumor activity.[2] As a result, much research has focused on access to indolizine skeletons based on pyridine[3] or pyrrole derivatives.[4] Among these approaches, transition metal catalysts, including copper,[5] rhodium,[6] palladium,[7] gold,[8]

platinum,[9] cobalt,[10] and iron,[11] have been widely utilized for the synthesis of indolizine derivatives through intramolecular or intermolecular annulation. However, in view of environmental and economical viewpoints, the development of efficient and complementary approaches to synthesize indolizine frameworks under metal-free conditions is highly desirable.

Elemental sulfur is a nontoxic and inexpensive agent, which has been widely used for the preparation of sulfur-containing molecules over the past decades.[12] Multicomponent reaction (MCR) was a powerful tool to generate relatively complex heterocyclic scaffolds in a straightforward and atom-economical manners by forming multiple bonds in a single step procedure. Very recently, Cao group[13] and our group[14] have reported three-component tandem reactions for the formation of functionalized indolizines from 2-pyridylacetates, ynals and coupling partners (Schemes 1a and 1b). Herein we report three-component annulation for the construction of indolizine thiones from 2-alkylpyridines, ynals, and elemental sulfur via a Knoevenagel condensation and aminothiation tandem process under metal-free conditions by forming the C-C, C-N and C-S bonds in one pot (Scheme 1c).

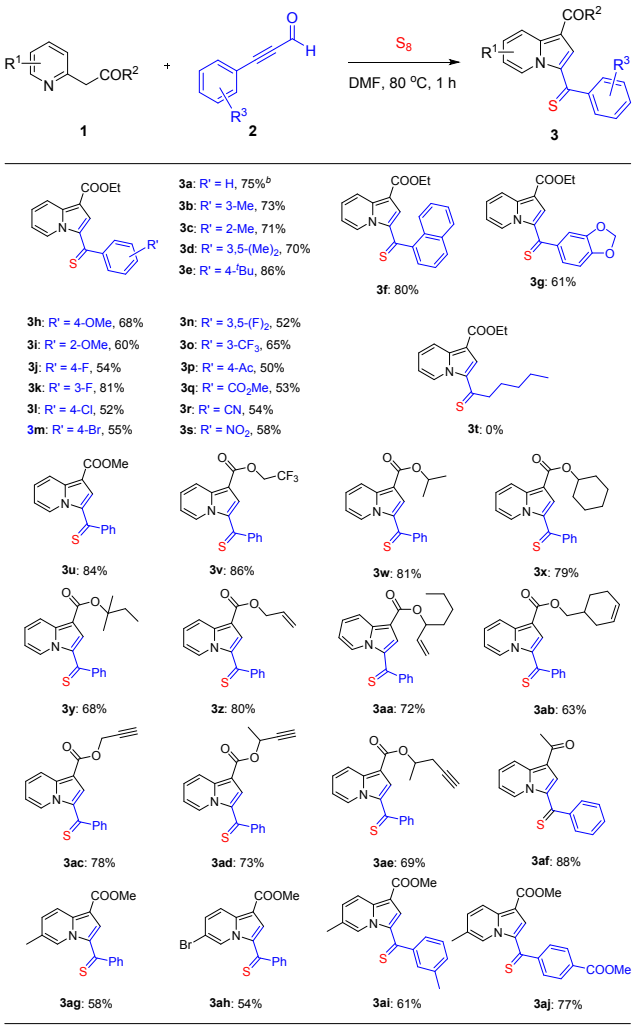
Scheme 1. Synthesis of Indolizines from 2-Alkylpyridines, Ynals and Coupling Partners



After obtaining the optimal reaction conditions (details in the Supporting Information), we subsequently investigated the substrate scope of this three-component annulation reaction. As illustrated in Scheme 2, various ynals were firstly explored, and indolizine thiones were achieved in moderate to good yields (**3b-s**). In general, both the electron-donating and electron-withdrawing groups substituted ynals worked well to furnish the desired products in 50%-86% yields. The reactants with a methyl or methoxy at the *ortho*-position of benzene ring had very little impact on the efficiency of this reaction (**3c** and **3i**). The disubstituted substrates proceeded well to furnish the products in 70% and 52% yields, respectively (**3d** and **3n**). Ynals bearing both the weak and strong electron-poor groups reacted smoothly (**3j-s**). Unluckily, aliphatic ynal did not afford the corresponding product in this transformation (**3t**). We next examined the scope of substituted 2-alkylpyridines and ynals in this tandem process. A series of pyridines with ester groups were compatible with the standard conditions, resulting in the formation of the corresponding product in good yields (**3u-3ae**). For example, the ester groups bearing primary, secondary and tertiary alkyl groups reacted successfully and delivered the products in 68%-86% yields (**3v-y**). To our delight, the substrates containing the unsaturated alkene or alkyne groups participated well in the tandem reaction, providing the desired products

in good yields and showing good functional group tolerance (**3z**-**3ae**). It is worth mentioning that 2-pyridyl acetone was suitable and formed **3af** in 88% yield. Furthermore, both the electron-rich and electron-deficient groups on the pyridine ring could be applied to the indolizine thione scaffold (**3ag** and **3ah**). Gratifyingly, the reaction could be performed on large scale synthesis and achieved the product in good yield (**3a**).

Scheme 2. Substrate Scope of 2-Alkylpyridines and Ynals[a]

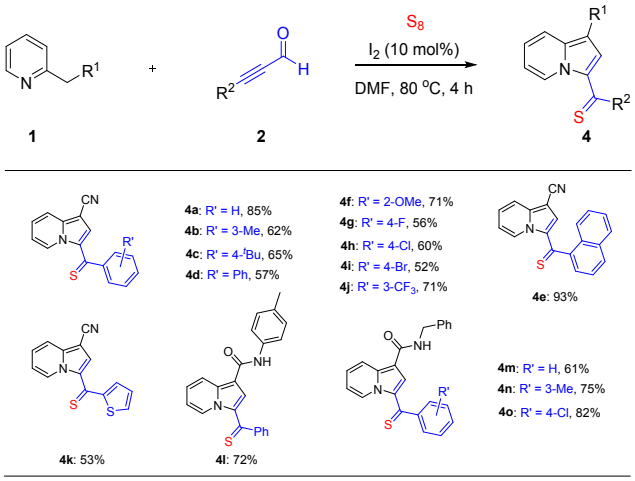


[a] Reaction conditions: **1a** (0.2 mmol), **2** (0.2 mmol) with S_8 (12.8 mg, 0.05 mmol) in DMF (1.0 mL) under argon at 80 °C for 1 h. [b] 2 mmol scale of the reaction.

Besides esters and ketone, the heterocycle bearing nitrile and amides were

important to the biological activities. However, no corresponding products were detected under the catalyst-free conditions when 2-pyridylacetonitriles or 2-pyridylacetamides replaced 2-pyridylacetates as the activating moieties. Fortunately, the desired products were obtained in satisfactory yields when catalytic amounts of I_2 was added.[15] We subsequently concentrated on the generality of the multicomponent reaction under the I_2-catalyzed conditions (Scheme 3). A variety of substituents were compatible with the conditions, such as methyl, *tert*-butyl, phenyl, methoxy, fluoro, chloro, bromo, and trifluoromethyl groups (**4b-j**). Interestingly, the ynal with a naphthalene moiety led to the product in excellent yield (**4e**). Notably, the heterocycle ynal was also perfectly tolerated in the reaction, giving the thienyl produced **4k** in 53% yield. As an alternative to nitrile, we found that both the aromatic and aliphatic amides were also applicable to afford indolizine thiones in good yields (**4l-o**).

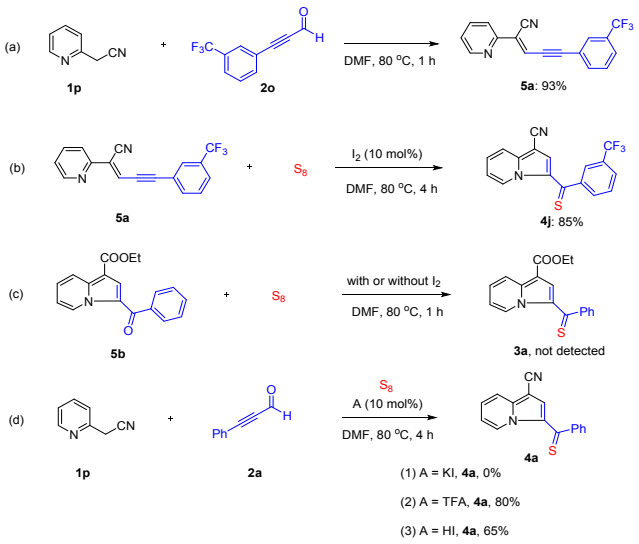
Scheme 3. I_2-Catalyzed Aminothiation of 2-Alkylpyridines with Ynals and Elemental Sulfur[a]



[a] Reaction conditions: **1** (0.2 mmol), **2** (0.2 mmol), S_8 (12.8 mg, 0.05 mmol) with I_2 (10 mol%) in DMF (1.0 mL) under argon at 80 °C for 4 h.

To gain insight into the reaction mechanism, some control experiments were conducted and the results were summarized in Scheme 4. At first, the reaction of 2-pyridyl acetonitrile **1p** and **2o** under the catalyst-free conditions afforded **5a** in 93% yield (Scheme 4a).[16] Next, the intermediate **5a** was converted into the desired product **4j** in 85% yield catalyzed by I_2 (Scheme 4b). These results proved that the three-component annulation underwent an enyne intermediate. Although an enyne intermediate has been proposed for the formation of indolizines, it has not been isolated in previous work.[13-14] The reaction of **5b** and elemental sulfur with or without I_2 could not yield **3a**, which inferred that the direct thiation of the carbonyl group was not involved in this process (Scheme 4c). In order to determine the catalytic role of I_2, some additives were added to the reaction system, and acids were advantageous for the formation of **4a**. The results indicated that this transformation may be an acid-catalyzed process (Scheme 4d).

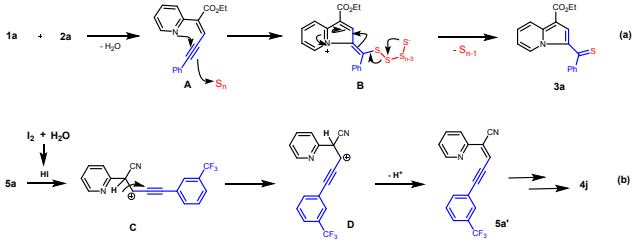
Scheme 4. Control Experiments



Based on above results and previous reports, a plausible mechanism was proposed in Scheme 5. Initially, an enyne intermediate **A** was formed through Knoevenagel

condensation of **1a** with **2a**. Then the intermediate **A** underwent intramolecular nucleophilic attack and activation of elemental sulfur to render intermediate **B**. Finally, the indolizine thione product **3a** was formed via the cleavage of disulfide bond (Scheme 5a). On the other hand, **5a** in *cis* configuration was isomerized into **5a'** through electrophilic addition and elimination process, which was subsequently converted into the desired product **4j** via aminothiation with elemental sulfur (Scheme 5b).

Scheme 5. Possible Reaction Mechanism



In conclusion, we have developed an efficient tandem annulation for the synthesis of indolizine thiones from 2-alkylpyridines with ynals and elemental sulfur. The advantages of the present method include metal-free process, user-friendly elemental sulfur as the sulfur source, one-pot three-component reaction, tandem C-C/C-N/C-S bonds formation, readily available starting materials, wide substrate scope, high functional group tolerance, etc. The ability to incorporate ester, carbonyl, cyano and amide groups into the products makes this reaction potentially valuable for further synthetic transformation. Further investigations on the detailed mechanism are currently underway in our laboratory.

EXPERIMENTAL SECTION

General Information: ^{1}H and $^{13}C\{^{1}H\}$ NMR spectra were obtained on a 400 and

100 MHz NMR spectrometer. The chemical shifts are referenced to signals at 7.26 and 77.0 ppm, respectively, and chloroform was used as the solvent with TMS as the internal standard unless otherwise noted. Mass spectra were recorded on a GC-MS spectrometer at an ionization voltage of 70 eV equipped with a DB-WAX capillary column (internal diameter: 0.25 mm, length: 30 m). Elemental analyses were performed with a Vario EL elemental analyzer. High resolution mass spectra (HRMS) (TOF) were measured using an electrospray ionization (ESI) mass spectrometry. Silica gel (300-400 mesh) was used for flash column chromatography, eluting (unless otherwise stated) with ethyl acetate/petroleum ether (PE) (60-90 ^{o}C) mixture.

The 2-pyridylacetates **1a**, **1b**, **1o**, 2-pyridylacetone **1m**, 2-pyridylacetonitrile **1p**, and propargyl aldehydes **2a** were commercially available from Sigma-Aldrich China. Substituted 2-pyridylacetates **1c-1l** and **1n,** 2-pyridylacetamides **1q-1r**, and aryl substituted propargyl aldehydes **2b-2s** have been prepared using the literature procedure.[17] The typical experimental procedures for the preparation of starting materials and the characterization data for new compounds are given below.

General procedure for the preparation of 2-pyridylacetates (1c-1l and 1n). To a suspended solution of 2-pyridylacetic acid hydrochloride (173 mg, 1.0 mmol) and alcohol (1.5 mmol) in 5 mL dichloromethane was added triethylamine (0.27 mL, 2.0 mmol), 1,3-dicyclohexylcarbodiimide (DCC) (210 mg, 1.0 mmol) and a catalytic amount of 4-(dimethylamino)pyridine (DMAP) (6.1 mg, 0.05 mmol) at 25 ^{o}C. The reaction mixture was stirred in a preheated oil bath at 45 ^{o}C for 12 h, the reaction mixture was filtered to remove 1,3-dicyclohexylurea. The filtrate was washed with

water (3×5 mL), dried with $MgSO_4$ and concentrated under reduced pressure, the crude product was purified by column chromatography to give the pure sample.

pent-4-yn-2-yl 2-(pyridin-2-yl)acetate (1l). Yellow oil (187 mg, 92%); R_f = 0.51 (ethyl acetate/petroleum ether = 1:4); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.41 (d, J = 4.8 Hz, 1H), 7.53 (td, J = 7.7, 1.8 Hz, 1H), 7.19 (d, J = 7.8 Hz, 1H), 7.06 (dd, J = 7.2, 5.2 Hz, 1H), 4.97 – 4.89 (m, 1H), 3.73 (s, 2H), 2.38 – 2.31 (m, 2H), 1.91 (t, J = 2.7 Hz, 1H), 1.22 (d, J = 6.3 Hz, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 169.6, 153.9, 149.0, 136.3, 123.5, 121.8, 79.2, 70.3, 68.9, 43.5, 25.1, 18.6. MS (EI) m/z: 203, 188, 170, 158, 144, 131, 120, 92, 65, 41. Anal. Calcd. for $C_{12}H_{13}NO_2$ C, 70.92; H, 6.45; N, 6.89. Found: C, 70.71; H, 6.50; N, 6.83.

General procedure for the preparation of 2-pyridylacetamides (1q-1r). To a suspended solution of 2-pyridylacetic acid hydrochloride (173 mg, 1.0 mmol), amine (1.0 mmol), 1-hydroxybenzotriazole (HOBt) (135 mg, 1.0 mmol), and ethyldiisopropylamine (DIPEA) (259 mg, 2.0 mmol) in 5 mL dichloromethane was added slowly 1-(3-dimethylaminopropyl)-3-ethylcarbodiimide hydrochloride (EDCl·HCl) (192 mg, 1.0 mmol) at 0 ^{o}C. Then the reaction mixture was stirred overnight at room temperature. After completion of the reaction, the mixture was washed with water (3×5 mL), dried with Na_2SO_4 and concentrated under reduced pressure, the crude product was purified by column chromatography to give the pure sample.

General procedure for the preparation of aryl substituted propiolaldehydes (2b-2s). For the synthesis of F: To a stirred of substituted iodobenzene (1 mmol) in

triethylamine (5 mL) under argon were sequentially added $Pd(PPh_3)_2Cl_2$ (14 mg, 2 mol%), and CuI (7.6 mg, 4 mol%) at room temperature. The mixture was allowed to stirred for 10 min. Then propargyl alcohol (1.1 mmol) was added. The mixture was allowed to stir overnight. After the reaction was finished, water (5 mL) was added and the solution was extracted with ethyl acetate (3×5 mL), the combined extract was dried with anhydrous $MgSO_4$. Solvent was removed, and the residue was separated by column chromatography to give the aryl substituted propargyl alcohol F (The yields were between 90% to 99%).

For the synthesis of **(2b-2s)**: MnO_2 (652 mg, 7.5 mmol) was added to a solution of aryl substituted propargyl alcohol **F** (0.5 mmol) in dichloromethane (5 mL) at room temperature. The mixture was allowed to stir overnight. Then the solid was filtered, and the solvent were removed under reduced pressure. The residue was purified by column chromatography to give the pure aryl substituted propiolaldehydes.

General Procedure for the Preparation of indolizine thiones (3a-3aj). A mixture of 2-pyridylacetate (0.2 mmol), ynal (0.2 mmol), and elemental sulfur (12.8 mg, 0.05 mmol) in DMF (1.0 mL) was stirred in a preheated oil bath at 80 °C for 1 h in a sealed tube under argon atmosphere. After the reaction was finished, water (5 mL) was added and the solution was extracted with ethyl acetate (3×5 mL), and the combined extract was dried with anhydrous $MgSO_4$. Solvent was removed, and the residue was separated by column chromatography to give the pure sample.

Large Scale Synthesis. An oven-dried 25 mL screw cap test tube was charged with a magnetic stir bar, **1a** (330 mg, 2 mmol), **2a** (260 mg, 2 mmol), elemental sulfur (128

mg, 0.5 mmol), and DMF (6.0 mL). The tube was then evacuated and backfilled with argon three times. Then, the tube was placed in a preheated oi bath at 80 °C for 1 h. After cooling to room temperature, water (10 mL) was added and the solution was extracted with ethyl acetate (3×10 mL), the combined extract was dried with anhydrous $MgSO_4$. Solvent was removed, and the residue was separated by column chromatography (ethyl acetate/petroleum ether = 1:6) to give **3a** (464 mg, 75%).

ethyl 3-(phenylcarbonothioyl)indolizine-1-carboxylate (3a). Red solid (56 mg, 90%); mp 108−110 °C; R_f = 0.55 (ethyl acetate/petroleum ether = 1:6); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.27 (d, J = 7.1 Hz, 1H), 8.48 (d, J = 8.8 Hz, 1H), 7.68 (s, 1H), 7.65 – 7.60 (m, 1H), 7.58 – 7.54 (m, 2H), 7.49 – 7.44 (m, 1H), 7.40 (t, J = 7.3 Hz, 2H), 7.19 (t, J = 7.0 Hz, 1H), 4.36 (q, J = 7.1 Hz, 2H), 1.38 (t, J = 7.1 Hz, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 210.1, 163.7, 149.8, 141.7, 134.5, 130.3, 129.7, 129.0, 128.5, 127.9, 127.4, 119.7, 116.6, 107.5, 60.3, 14.4. MS (EI) m/z: 309, 280, 264, 236, 204, 121, 89, 77, 51. HRMS (ESI): calcd. for $C_{18}H_{16}NO_2S$ $[M+H]^+$ 310.0896; found 310.0889.

ethyl 3-(3-methylphenylcarbonothioyl)indolizine-1-carboxylate (3b). Red solid (47 mg, 73%); mp 112−114 °C; R_f = 0.52 (ethyl acetate/petroleum ether = 1:10); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.27 (d, J = 7.0 Hz, 1H), 8.48 (d, J = 8.8 Hz, 1H), 7.69 (s, 1H), 7.64 – 7.60 (m, 1H), 7.41 (s, 1H), 7.32 (d, J = 4.1 Hz, 1H), 7.28 (d, J = 4.6 Hz, 2H), 7.19 (t, J = 6.7 Hz, 1H), 4.37 (q, J = 7.1 Hz, 2H), 2.41 (s, 3H), 1.38 (t, J = 7.1 Hz, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 210.4, 163.7, 149.8, 141.7, 137.6, 134.5, 130.5, 130.2, 129.2, 129.0, 127.6, 127.4, 125.6, 119.6, 116.5, 107.4, 60.3, 21.3, 14.44.

MS (EI) m/z: 323, 294, 250, 204, 135, 89, 78, 51. HRMS (ESI): calcd. for $C_{19}H_{18}NO_2S$ $[M+H]^+$ 324.1053; found 324.1052.

ethyl 3-(2-methylphenylcarbonothioyl)indolizine-1-carboxylate (3c). Red liquid (46 mg, 71%); R_f = 0.56 (ethyl acetate/petroleum ether = 1:8); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.50 (d, J = 7.0 Hz, 1H), 8.50 (d, J = 8.7 Hz, 1H), 7.68 (t, J = 7.9 Hz, 1H), 7.46 (s, 1H), 7.31 – 7.26 (m, 2H), 7.22 (dd, J = 6.3, 3.6 Hz, 3H), 4.35 (q, J = 7.1 Hz, 2H), 2.21 (s, 3H), 1.37 (t, J = 7.1 Hz, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 211.3, 163.6, 149.0, 141.6, 134.3, 132.8, 130.6, 130.3, 128.5, 127.9, 127.6, 127.0, 125.4, 119.7, 117.1, 108.0, 60.3, 19.3, 14.4. MS (EI) m/z: 323, 294, 250, 204, 135, 89, 78, 51. HRMS (ESI): calcd. for $C_{19}H_{18}NO_2S$ $[M+H]^+$ 324.1053; found 324.1048.

ethyl 3-(3,5-dimethylphenylcarbonothioyl)indolizine-1-carboxylate (3d). Red solid (47 mg, 70%); mp 101−103 °C; R_f = 0.58 (ethyl acetate/petroleum ether = 1:6); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.26 (dt, J = 7.1, 1.0 Hz, 1H), 8.53 – 8.45 (m, 1H), 7.70 (s, 1H), 7.62 (ddd, J = 8.7, 6.9, 1.1 Hz, 1H), 7.21 – 7.16 (m, 3H), 7.11 (s, 1H), 4.37 (q, J = 7.1 Hz, 2H), 2.37 (s, 6H), 1.39 (t, J = 7.1 Hz, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 210.9, 163.8, 149.9, 141.7, 137.4, 134.6, 131.4, 130.1, 129.1, 127.5, 126.3, 119.6, 116.4, 107.4, 60.3, 21.2, 14.4. MS (EI) m/z: 337, 308, 292, 264, 232, 204, 149, 115, 89, 78, 51. HRMS (ESI): calcd. for $C_{20}H_{20}NO_2S$ $[M+H]^+$ 338.1209; found 338.1216.

ethyl 3-(4-(tert-butyl)phenylcarbonothioyl)indolizine-1-carboxylate (3e). Red solid (63 mg, 86%); mp 71−73 °C; R_f = 0.66 (ethyl acetate/petroleum ether = 1:10); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.25 (d, J = 7.1 Hz, 1H), 8.48 (d, J = 8.8 Hz, 1H),

7.75 (s, 1H), 7.64 – 7.59 (m, 1H), 7.56 – 7.52 (m, 2H), 7.44 – 7.40 (m, 2H), 7.19 (td, *J* = 7.0, 1.4 Hz, 1H), 4.38 (q, *J* = 7.1 Hz, 2H), 1.41 (d, *J* = 7.1 Hz, 3H), 1.37 (s, 9H). $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$): δ = 210.2, 163.8, 153.4, 147.1, 141.6, 134.5, 130.0, 129.0, 128.6, 127.4, 124.9, 119.6, 116.3, 107.3, 60.3, 34.8, 31.1, 14.4. MS (EI) m/z: 365, 336, 320, 232, 204, 147, 124, 78, 44. HRMS (ESI): calcd. for $C_{22}H_{24}NO_2S$ $[M+H]^+$ 366.1522; found 366.1527.

ethyl 3-(naphthalene-1-carbonothioyl)indolizine-1-carboxylate (3f). Red solid (57 mg, 80%); mp 115−117 °C; R_f = 0.52 (ethyl acetate/petroleum ether = 1:6); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.64 (d, *J* = 6.6 Hz, 1H), 8.52 (d, *J* = 8.8 Hz, 1H), 7.88 (t, *J* = 7.5 Hz, 3H), 7.73 – 7.68 (m, 1H), 7.53 (d, *J* = 7.1 Hz, 1H), 7.46 – 7.36 (m, 4H), 7.30 (td, *J* = 7.0, 1.2 Hz, 1H), 4.28 (q, *J* = 7.0 Hz, 2H), 1.31 (d, *J* = 7.1 Hz, 3H). $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$): δ = 209.3, 163.5, 146.6, 141.7, 135.2, 133.5, 130.8, 130.3, 129.1, 128.3, 128.0, 127.7, 126.4, 125.9, 125.5, 124.9, 124.3, 119.8, 117.3, 108.2, 60.3, 14.3. MS (EI) m/z: 359, 330, 284, 254, 156, 142, 104, 78, 44. HRMS (ESI): calcd. for $C_{22}H_{18}NO_2S$ $[M+H]^+$ 360.1053; found 360.1055.

ethyl 3-(benzo[d][1,3]dioxole-5-carbonothioyl)indolizine-1-carboxylate (3g). Red solid (43 mg, 61%); mp 133−135 °C; R_f = 0.35 (ethyl acetate/petroleum ether = 1:10); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.08 (d, *J* = 7.1 Hz, 1H), 8.46 (d, *J* = 8.8 Hz, 1H), 7.71 (s, 1H), 7.63 – 7.56 (m, 1H), 7.22 (d, *J* = 1.2 Hz, 1H), 7.18 – 7.09 (m, 2H), 6.82 (d, *J* = 8.1 Hz, 1H), 6.05 (s, 2H), 4.38 (q, *J* = 7.1 Hz, 2H), 1.39 (t, *J* = 7.1 Hz, 3H). $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$): δ = 208.6, 163.8, 149.8, 147.5, 144.1, 141.7, 134.5, 129.8, 128.5, 127.4, 123.9, 119.7, 116.2, 109.9, 107.4, 107.2, 101.6, 60.3, 14.4.

MS (EI) m/z: 353, 324, 308, 280, 232, 204, 177, 139, 110, 89, 78, 51. HRMS (ESI): calcd. for $C_{19}H_{16}NO_4S$ $[M+H]^+$ 354.0795; found 354.0791.

ethyl 3-(4-methoxyphenylcarbonothioyl)indolizine-1-carboxylate (3h). Red solid (46 mg, 68%); mp 118−120 °C; R_f = 0.48 (ethyl acetate/petroleum ether = 1:6); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.11 (d, J = 7.1 Hz, 1H), 8.48 (d, J = 8.8 Hz, 1H), 7.71 (s, 1H), 7.64 (d, J = 8.8 Hz, 2H), 7.62 – 7.57 (m, 1H), 7.19 – 7.14 (m, 1H), 6.94 (d, J = 8.8 Hz, 2H), 4.42 – 4.36 (m, 2H), 3.90 (s, 3H), 1.41 (t, J = 7.1 Hz, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 209.2, 163.9, 161.7, 142.6, 141.6, 134.4, 131.0, 129.6, 128.4, 127.3, 119.6, 116.0, 113.2, 107.0, 60.2, 55.4, 14.4. MS (EI) m/z: 339, 310, 267, 207, 133, 111, 89, 73, 44. HRMS (ESI): calcd. for $C_{19}H_{18}NO_3S$ $[M+H]^+$ 340.1002; found 340.1022.

ethyl 3-(2-methoxyphenylcarbonothioyl)indolizine-1-carboxylate (3i). Red solid (41 mg, 60%); mp 145−147 °C; R_f = 0.28 (ethyl acetate/petroleum ether = 1:10); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.47 (d, J = 7.0 Hz, 1H), 8.46 (d, J = 8.8 Hz, 1H), 7.65 (t, J = 7.8 Hz, 1H), 7.54 (s, 1H), 7.40 – 7.35 (m, 1H), 7.29 (dd, J = 7.5, 1.5 Hz, 1H), 7.25 – 7.20 (m, 1H), 7.02 (t, J = 7.4 Hz, 1H), 6.97 (d, J = 8.3 Hz, 1H), 4.35 (q, J = 7.1 Hz, 2H), 3.73 (s, 3H), 1.37 (t, J = 7.1 Hz, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 207.8, 163.8, 154.2, 141.5, 138.6, 134.8, 130.2, 129.6, 129.0, 128.7, 127.6, 120.5, 119.7, 116.8, 111.5, 107.9, 60.3, 55.8, 14.4. MS (EI) m/z: 339, 306, 278, 260, 234, 204, 89, 78, 45. HRMS (ESI): calcd. for $C_{19}H_{18}NO_3S$ $[M+H]^+$ 340.1002; found 340.1000.

ethyl 3-(4-fluorophenylcarbonothioyl)indolizine-1-carboxylate (3j). Red solid

(35 mg, 54%); mp 129−131 °C; R_f = 0.46 (ethyl acetate/petroleum ether = 1:10); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.22 (d, J = 7.1 Hz, 1H), 8.49 (d, J = 8.8 Hz, 1H), 7.67 – 7.62 (m, 2H), 7.61 – 7.55 (m, 2H), 7.23 – 7.18 (m, 1H), 7.10 (t, J = 8.6 Hz, 2H), 4.37 (q, J = 7.1 Hz, 2H), 1.39 (t, J = 7.1 Hz, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 208.1, 163.8 (d, J = 250 Hz), 163.7, 145.9 (d, J = 3 Hz), 141.8, 134.5, 130.7 (d, J = 8 Hz), 130.4, 128.7, 127.4, 119.7, 116.7, 114.9 (d, J = 21 Hz), 107.6, 60.4, 14.4. MS (EI) m/z: 327, 298, 282, 254, 232, 204, 139, 107, 95, 78, 51. HRMS (ESI): calcd. for $C_{18}H_{15}FNO_2S$ $[M+H]^+$ 328.0802; found 328.0801.

ethyl 3-(3-fluorophenylcarbonothioyl)indolizine-1-carboxylate (3k). Red solid (53 mg, 81%); mp 132−134 °C; R_f = 0.58 (ethyl acetate/petroleum ether = 1:7); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.27 (d, J = 7.1 Hz, 1H), 8.49 (d, J = 8.8 Hz, 1H), 7.69 – 7.63 (m, 2H), 7.37 (td, J = 7.8, 5.7 Hz, 1H), 7.33 – 7.27 (m, 2H), 7.22 (td, J = 7.0, 1.3 Hz, 1H), 7.19 – 7.13 (m, 1H), 4.37 (q, J = 7.1 Hz, 2H), 1.39 (t, J = 7.1 Hz, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 207.3, 163.6, 162.1 (d, J = 245 Hz), 151.3 (d, J = 7 Hz), 141.9, 134.4, 130.6, 129.3 (d, J = 8 Hz), 128.9, 127.4, 124.9 (d, J = 2 Hz), 119.8, 116.9, 116.4 (d, J = 21 Hz), 115.6 (d, J = 23 Hz), 107.9, 60.4, 14.4. MS (EI) m/z: 327, 298, 282, 254, 232, 204, 139, 107, 89, 78, 43. HRMS (ESI): calcd. for $C_{18}H_{15}FNO_2S$ $[M+H]^+$ 328.0802; found 328.0805.

ethyl 3-(4-chlorophenylcarbonothioyl)indolizine-1-carboxylate (3l). Red solid (35 mg, 52%); mp 135−137 °C; R_f = 0.60 (ethyl acetate/petroleum ether = 1:7); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.25 (d, J = 7.1 Hz, 1H), 8.51 (d, J = 8.8 Hz, 1H), 7.69 – 7.64 (m, 2H), 7.52 (d, J = 8.4 Hz, 2H), 7.39 (d, J = 8.4 Hz, 2H), 7.23 (dd, J = 7.5,

6.5 Hz, 1H), 4.37 (q, J = 7.1 Hz, 2H), 1.39 (t, J = 7.1 Hz, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 207.9, 163.6, 148.0, 141.9, 136.0, 134.5, 130.5, 129.9, 128.7, 128.2, 127.5, 119.8, 116.8, 107.8, 60.4, 14.4. MS (EI) m/z: 343, 314, 270, 235, 204, 155, 117, 89, 78, 43. HRMS (ESI): calcd. for $C_{18}H_{14}ClNNaO_2S$ $[M+Na]^+$ 366.0326; found 366.0331.

ethyl 3-(4-bromophenylcarbonothioyl)indolizine-1-carboxylate (3m). Red solid (42 mg, 55%); mp 133−135 °C; R_f = 0.48 (ethyl acetate/petroleum ether = 1:10); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.27 (d, J = 7.1 Hz, 1H), 8.52 (d, J = 8.8 Hz, 1H), 7.70 – 7.66 (m, 2H), 7.58 – 7.54 (m, 2H), 7.48 – 7.45 (m, 2H), 7.24 (td, J = 7.0, 1.3 Hz, 1H), 4.40 (q, J = 7.1 Hz, 2H), 1.41 (t, J = 7.1 Hz, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 207.7, 163.6, 148.4, 141.9, 134.3, 131.1, 130.6, 130.0, 128.7, 127.4, 124.2, 119.8, 116.8, 107.8, 60.4, 14.4. MS (EI) m/z: 388, 360, 342, 314, 279, 234, 204, 132, 117, 95, 78, 51. HRMS (ESI): calcd. for $C_{18}H_{15}BrNO_2S$ $[M+H]^+$ 388.0001; found 388.0009.

ethyl 3-(3,5-difluorophenylcarbonothioyl)indolizine-1-carboxylate (3n). Red solid (36 mg, 52%); mp 150−152 °C; R_f = 0.48 (ethyl acetate/petroleum ether = 1:10); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.27 (dt, J = 7.1, 1.0 Hz, 1H), 8.55 – 8.49 (m, 1H), 7.73 – 7.68 (m, 1H), 7.65 (s, 1H), 7.26 (t, J = 3.5 Hz, 1H), 7.09 – 7.04 (m, 2H), 6.91 (tt, J = 8.7, 2.3 Hz, 1H), 4.39 (q, J = 7.1 Hz, 2H), 1.39 (d, J = 7.1 Hz, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 204.9, 163.5, 162.1 (dd, J = 249, 12 Hz), 151.9 (t, J = 9 Hz), 142.1, 134.2, 131.1, 128.9, 127.5, 119.9, 117.2, 111.5 (d, J = 27 Hz), 108.4, 104.6 (t, J = 25 Hz), 60.5, 14.4. MS (EI) m/z: 345, 316, 300, 272, 232, 204, 157, 125,

89, 78, 51. HRMS (ESI): calcd. for $C_{18}H_{14}F_2NO_2S$ $[M+H]^+$ 346.0708; found 346.0703.

ethyl 3-(3-(trifluoromethyl)phenylcarbonothioyl)indolizine-1-carboxylate (3o). Red solid (49 mg, 65%); mp 154−156 °C; R_f = 0.54 (ethyl acetate/petroleum ether = 1:6); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.30 (d, J = 7.0 Hz, 1H), 8.52 (d, J = 8.8 Hz, 1H), 7.82 (s, 1H), 7.70 (dd, J = 13.6, 7.0 Hz, 3H), 7.60 (s, 1H), 7.54 (t, J = 7.7 Hz, 1H), 7.26 (s, 1H), 4.37 (q, J = 7.1 Hz, 2H), 1.38 (t, J = 7.1 Hz, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 206.9, 163.5, 150.0, 142.0, 134.5, 131.3, 130.8, 130.5 (q, J = 33 Hz), 128.8, 128.4, 127.5, 126.0 (q, J = 4 Hz), 125.2 (q, J = 4 Hz), 123.8 (q, J = 271 Hz), 119.8, 117.1, 108.2, 60.4, 14.4. MS (EI) m/z: 377, 348, 332, 304, 232, 204, 189, 89, 78, 51. HRMS (ESI): calcd. for $C_{19}H_{15}F_3NO_2S$ $[M+H]^+$ 378.0770; found 378.0775.

ethyl 3-(4-acetylphenylcarbonothioyl)indolizine-1-carboxylate (3p). Red solid (35 mg, 50%); mp 155−157 °C; R_f = 0.31 (ethyl acetate/petroleum ether = 1:6); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.33 (d, J = 7.0 Hz, 1H), 8.52 (d, J = 8.8 Hz, 1H), 8.00 (d, J = 8.2 Hz, 2H), 7.73 – 7.68 (m, 1H), 7.64 – 7.59 (m, 3H), 7.26 (s, 1H), 4.36 (q, J = 7.1 Hz, 2H), 2.67 (s, 3H), 1.38 (t, J = 7.1 Hz, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 207.8, 197.6, 163.5, 153.5, 142.0, 137.4, 134.4, 130.8, 128.9, 128.4, 128.0, 127.5, 119.9, 117.1, 108.2, 60.5, 26.7, 14.4. MS (EI) m/z: 351, 322, 306, 279, 234, 204, 153, 117, 95, 78, 43. HRMS (ESI): calcd. for $C_{20}H_{18}NO_3S$ $[M+H]^+$ 352.1002; found 352.1006.

ethyl 3-(4-(methoxycarbonyl)phenylcarbonothioyl)indolizine-1-carboxylate

(3q). Red solid (39 mg, 53%); mp 131−133 °C; R_f = 0.40 (ethyl acetate/petroleum ether = 1:7); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.32 (d, J = 7.0 Hz, 1H), 8.51 (d, J = 8.8 Hz, 1H), 8.07 (d, J = 8.1 Hz, 2H), 7.71 – 7.66 (m, 1H), 7.59 (d, J = 6.5 Hz, 3H), 7.25 (d, J = 3.9 Hz, 1H), 4.35 (q, J = 7.1 Hz, 2H), 3.96 (s, 3H), 1.37 (t, J = 7.1 Hz, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 207.8, 166.6, 163.5, 153.3, 141.9, 134.4, 130.8, 130.6, 129.2, 128.9, 128.2, 127.5, 119.8, 117.1, 108.1, 60.4, 52.3, 14.4. MS (EI) m/z: 367, 338, 322, 294, 234, 204, 153, 117, 95, 63. HRMS (ESI): calcd. for $C_{20}H_{18}NO_4S$ $[M+H]^+$ 368.0951; found 368.0947.

ethyl 3-(4-cyanophenylcarbonothioyl)indolizine-1-carboxylate (3r). Red solid (36 mg, 54%); mp 162−164 °C; R_f = 0.26 (ethyl acetate/petroleum ether = 1:10); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.25 (d, J = 7.0 Hz, 1H), 8.47 (d, J = 8.8 Hz, 1H), 7.69 – 7.63 (m, 3H), 7.56 – 7.52 (m, 2H), 7.50 (s, 1H), 7.22 (td, J = 7.1, 1.4 Hz, 1H), 4.31 (q, J = 7.1 Hz, 2H), 1.32 (t, J = 7.1 Hz, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 205.7, 163.3, 153.0, 142.0, 134.2, 131.8, 131.2, 128.8, 128.7, 127.5, 119.9, 118.4, 117.4, 112.7, 108.5, 60.5, 14.4. MS (EI) m/z: 334, 305, 289, 261, 232, 204, 146, 114, 78, 51. HRMS (ESI): calcd. for $C_{19}H_{15}N_2O_2S$ $[M+H]^+$ 335.0849; found 335.0843.

ethyl 3-(4-nitrophenylcarbonothioyl)indolizine-1-carboxylate (3s). Red solid (41 mg, 58%); mp 190−192 °C; R_f = 0.40 (ethyl acetate/petroleum ether = 1:7); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.27 (d, J = 7.0 Hz, 1H), 8.48 (d, J = 8.7 Hz, 1H), 8.24 – 8.15 (m, 2H), 7.71 – 7.65 (m, 1H), 7.63 – 7.54 (m, 2H), 7.49 (s, 1H), 7.24 (td, J = 7.0, 1.4 Hz, 1H), 4.30 (q, J = 7.1 Hz, 2H), 1.31 (t, J = 7.1 Hz, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 205.1, 163.3, 154.6, 147.9, 142.1, 134.3, 131.3, 128.8, 128.7,

127.5, 123.3, 120.0, 117.5, 108.7, 60.6, 14.4. HRMS (ESI): calcd. for $C_{18}H_{15}N_2O_4S$ $[M+H]^+$ 355.0747; found 355.0752.

methyl 3-(phenylcarbonothioyl)indolizine-1-carboxylate (3u). Red solid (49 mg, 84%); mp 128−130 °C; R_f = 0.50 (ethyl acetate/petroleum ether = 1:7); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.28 (d, J = 7.1 Hz, 1H), 8.50 (d, J = 8.8 Hz, 1H), 7.68 (s, 1H), 7.67 – 7.62 (m, 1H), 7.58 – 7.55 (m, 2H), 7.46 (dt, J = 2.8, 2.1 Hz, 1H), 7.43 – 7.38 (m, 2H), 7.22 (td, J = 7.0, 1.4 Hz, 1H), 3.88 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 210.4, 164.1, 149.8, 141.8, 134.6, 130.3, 129.7, 129.0, 128.5, 127.9, 127.5, 119.6, 116.7, 107.1, 51.4. MS (EI) m/z: 295, 264, 235, 218, 131, 121, 89, 77, 51. HRMS (ESI): calcd. for $C_{17}H_{14}NO_2S$ $[M+H]^+$ 296.0740; found 296.0729.

2,2,2-trifluoroethyl 3-(phenylcarbonothioyl)indolizine-1-carboxylate (3v). Red solid (62 mg, 86%); mp 126−128 °C; R_f = 0.47 (ethyl acetate/petroleum ether = 1:10); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.22 – 11.18 (m, 1H), 8.45 – 8.39 (m, 1H), 7.73 (s, 1H), 7.69 – 7.64 (m, 1H), 7.58 (dd, J = 5.2, 3.2 Hz, 2H), 7.51 – 7.47 (m, 1H), 7.44 – 7.40 (m, 2H), 7.22 (td, J = 7.0, 1.4 Hz, 1H), 4.71 (q, J = 8.5 Hz, 2H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 211.6, 161.7, 149.6, 141.6, 134.7, 130.7, 130.1, 129.0, 128.6, 128.0, 127.5, 123.1 (q, J = 276 Hz), 119.4, 116.8, 104.9, 59.9 (q, J = 36 Hz). MS (EI) m/z: 363, 286, 235, 131, 121, 89, 77, 51. HRMS (ESI): calcd. for $C_{18}H_{13}F_3NO_2S$ $[M+H]^+$ 364.0614; found 364.0611.

isopropyl 3-(phenylcarbonothioyl)indolizine-1-carboxylate (3w). Red solid (52 mg, 81%); mp 100−102 °C; R_f = 0.38 (ethyl acetate/petroleum ether = 1:10); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.29 (d, J = 7.1 Hz, 1H), 8.48 (d, J = 8.8 Hz, 1H), 7.68 (s,

1H), 7.66 – 7.61 (m, 1H), 7.60 – 7.56 (m, 2H), 7.49 – 7.45 (m, 1H), 7.43 – 7.39 (m, 2H), 7.20 (td, J = 7.0, 1.3 Hz, 1H), 5.27 (dt, J = 12.5, 6.3 Hz, 1H), 1.37 (d, J = 6.3 Hz, 6H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 209.9, 163.3, 149.7, 141.7, 134.5, 130.2, 129.7, 129.0, 128.5, 127.9, 127.4, 119.7, 116.5, 108.0, 67.8, 22.0. MS (EI) m/z: 323, 280, 264, 236, 204, 132, 121, 89, 77, 43. HRMS (ESI): calcd. for $C_{19}H_{18}NO_2S$ $[M+H]^+$ 324.1053; found 324.1059.

cyclohexyl 3-(phenylcarbonothioyl)indolizine-1-carboxylate (3x). Red solid (57 mg, 79%); mp 110−112 °C; R_f = 0.41 (ethyl acetate/petroleum ether = 1:10); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.30 – 11.26 (m, 1H), 8.50 – 8.45 (m, 1H), 7.69 (s, 1H), 7.65 – 7.60 (m, 1H), 7.59 – 7.55 (m, 2H), 7.49 – 7.45 (m, 1H), 7.43 – 7.38 (m, 2H), 7.19 (td, J = 7.0, 1.4 Hz, 1H), 5.06 – 4.99 (m, 1H), 2.02 – 1.95 (m, 2H), 1.81 – 1.74 (m, 2H), 1.61 – 1.51 (m, 3H), 1.44 (dddd, J = 13.6, 10.6, 7.0, 3.3 Hz, 2H), 1.36 – 1.28 (m, 1H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 210.0, 163.2, 149.8, 141.6, 134.5, 130.2, 129.7, 129.1, 128.5, 127.8, 127.4, 119.7, 116.5, 108.1, 72.8, 31.8, 25.3, 23.8. HRMS (ESI): calcd. for $C_{22}H_{22}NO_2S$ $[M+H]^+$ 364.1366; found 364.1363.

***tert*-pentyl 3-(phenylcarbonothioyl)indolizine-1-carboxylate (3y).** Red liquid (48 mg, 68%); R_f = 0.63 (ethyl acetate/petroleum ether = 1:10); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.31 (d, J = 7.1 Hz, 1H), 8.43 (d, J = 8.8 Hz, 1H), 7.65 (s, 1H), 7.64 – 7.59 (m, 1H), 7.59 – 7.54 (m, 2H), 7.45 (d, J = 7.2 Hz, 1H), 7.39 (t, J = 7.3 Hz, 2H), 7.19 (td, J = 7.0, 1.2 Hz, 1H), 1.93 (q, J = 7.5 Hz, 2H), 1.57 (s, 6H), 0.93 (t, J = 7.5 Hz, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 209.6, 163.1, 149.7, 141.5, 134.4, 130.1, 129.7, 129.4, 128.5, 127.8, 127.4, 119.7, 116.4, 109.2, 83.6, 33.5, 25.8, 8.3.

HRMS (ESI): calcd. for $C_{21}H_{22}NO_2S$ $[M+H]^+$ 352.1366; found 352.1367.

allyl 3-(phenylcarbonothioyl)indolizine-1-carboxylate (3z). Red solid (51 mg, 80%); mp 102−104 °C; R_f = 0.51 (ethyl acetate/petroleum ether = 1:10); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.28 (d, J = 7.1 Hz, 1H), 8.50 (d, J = 8.8 Hz, 1H), 7.71 (s, 1H), 7.67 – 7.62 (m, 1H), 7.59 – 7.56 (m, 2H), 7.47 (d, J = 7.2 Hz, 1H), 7.41 (t, J = 7.3 Hz, 2H), 7.24 – 7.19 (m, 1H), 6.10 – 5.97 (m, 1H), 5.37 (dd, J = 17.2, 1.3 Hz, 1H), 5.27 (dd, J = 10.4, 1.0 Hz, 1H), 4.82 (d, J = 5.7 Hz, 2H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 210.3, 163.3, 149.7, 141.7, 134.5, 132.3, 130.3, 129.8, 129.0, 128.5, 127.9, 127.4, 119.6, 118.3, 116.6, 107.0, 64.9. MS (EI) m/z: 321, 280, 264, 236, 204, 121, 89, 77, 39. HRMS (ESI): calcd. for $C_{19}H_{16}NO_2S$ $[M+H]^+$ 322.0896; found 322.0886.

hept-1-en-3-yl 3-(phenylcarbonothioyl)indolizine-1-carboxylate (3aa). Red liquid (54 mg, 72%); R_f = 0.56 (ethyl acetate/petroleum ether = 1:12); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.28 (d, J = 7.1 Hz, 1H), 8.49 (d, J = 8.8 Hz, 1H), 7.71 (s, 1H), 7.64 (t, J = 7.4 Hz, 1H), 7.60 – 7.56 (m, 2H), 7.49 – 7.46 (m, 1H), 7.41 (dd, J = 7.9, 6.7 Hz, 2H), 7.20 (td, J = 7.0, 1.3 Hz, 1H), 5.89 (ddd, J = 17.1, 10.5, 6.4 Hz, 1H), 5.50 (dd, J = 13.3, 6.4 Hz, 1H), 5.33 – 5.27 (m, 1H), 5.20 (d, J = 10.5 Hz, 1H), 1.79 – 1.66 (m, 2H), 1.39 – 1.33 (m, 4H), 0.89 (t, J = 6.9 Hz, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 210.1, 163.1, 149.7, 141.7, 136.7, 134.6, 130.2, 129.8, 129.0, 128.6, 127.8, 127.4, 126.8, 119.7, 116.6, 107.6, 74.9, 33.9, 27.3, 22.3, 13.9. MS (EI) m/z: 377, 280, 264, 236, 204, 121, 89, 78, 41. HRMS (ESI): calcd. for $C_{23}H_{24}NO_2S$ $[M+H]^+$ 378.1522; found 378.1519.

cyclohex-3-en-1-ylmethyl 3-(phenylcarbonothioyl)indolizine-1-carboxylate (3ab). Red solid (47 mg, 63%); mp 92−94 °C; R_f = 0.63 (ethyl acetate/petroleum ether = 1:10); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.27 (d, J = 7.1 Hz, 1H), 8.46 (d, J = 8.8 Hz, 1H), 7.70 (s, 1H), 7.66 – 7.62 (m, 1H), 7.57 (dd, J = 5.2, 3.2 Hz, 2H), 7.49 – 7.45 (m, 1H), 7.41 (dd, J = 7.2, 5.8 Hz, 2H), 7.20 (td, J = 7.0, 1.4 Hz, 1H), 5.66 (dd, J = 10.8, 2.7 Hz, 2H), 4.23 (d, J = 6.2 Hz, 2H), 2.20 – 2.07 (m, 4H), 1.89 – 1.80 (m, 2H), 1.42 – 1.33 (m, 1H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 210.2, 163.8, 149.7, 141.6, 134.6, 130.3, 129.8, 129.1, 128.6, 127.9, 127.4, 127.0, 125.4, 119.6, 116.6, 107.5, 68.6, 33.1, 28.3, 25.3, 24.3. MS (EI) m/z: 375, 280, 264, 236, 204, 121, 89, 79, 41. HRMS (ESI): calcd. for $C_{23}H_{22}NO_2S$ $[M+H]^+$ 376.1366; found 376.1365.

prop-2-yn-1-yl 3-(phenylcarbonothioyl)indolizine-1-carboxylate (3ac). Red solid (50 mg, 78%); mp 99−101 °C; R_f = 0.28 (ethyl acetate/petroleum ether = 1:10); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.23 (d, J = 6.8 Hz, 1H), 8.49 (d, J = 8.6 Hz, 1H), 7.71 (s, 1H), 7.64 (t, J = 7.7 Hz, 1H), 7.56 (d, J = 7.3 Hz, 2H), 7.47 (d, J = 7.0 Hz, 1H), 7.41 (d, J = 7.3 Hz, 2H), 7.20 (t, J = 6.7 Hz, 1H), 4.90 (s, 2H), 2.51 (s, 1H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 210.7, 162.7, 149.6, 141.7, 134.6, 130.5, 129.8, 128.9, 128.5, 127.9, 127.4, 119.5, 116.7, 106.0, 77.8, 74.8, 51.6. MS (EI) m/z: 319, 280, 264, 236, 204, 191, 159, 131, 121, 89, 77, 39. HRMS (ESI): calcd. for $C_{19}H_{13}NNaO_2S$ $[M+Na]^+$ 342.0559; found 342.0567.

but-3-yn-2-yl 3-(phenylcarbonothioyl)indolizine-1-carboxylate (3ad). Red solid (48 mg, 73%); mp 131−133 °C; R_f = 0.38 (ethyl acetate/petroleum ether = 1:10); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.24 (d, J = 7.0 Hz, 1H), 8.50 (d, J = 8.8 Hz, 1H), 7.71

(s, 1H), 7.67 – 7.62 (m, 1H), 7.57 (d, *J* = 7.2 Hz, 2H), 7.47 (d, *J* = 7.2 Hz, 1H), 7.42 (d, *J* = 7.5 Hz, 2H), 7.21 (t, *J* = 6.8 Hz, 1H), 5.73 – 5.66 (m, 1H), 2.50 (d, *J* = 1.8 Hz, 1H), 1.63 (d, *J* = 6.7 Hz, 3H). $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$): δ = 210.7, 162.5, 149.7, 141.8, 134.6, 130.4, 129.8, 128.9, 128.5, 127.9, 127.5, 119.7, 116.6, 106.6, 82.3, 73.0, 59.9, 21.3. MS (EI) m/z: 333, 280, 264, 236, 204, 191, 132, 121, 89, 77, 51. HRMS (ESI): calcd. for $C_{20}H_{16}NO_2S$ $[M+H]^+$ 334.0896; found 334.0894.

pent-4-yn-2-yl 3-(phenylcarbonothioyl)indolizine-1-carboxylate (3ae). Red solid (48 mg, 69%); mp 98−100 °C; R_f = 0.61 (ethyl acetate/petroleum ether = 1:10); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.26 (d, *J* = 7.0 Hz, 1H), 8.50 (d, *J* = 8.7 Hz, 1H), 7.71 (s, 1H), 7.66 – 7.61 (m, 1H), 7.57 (d, *J* = 7.3 Hz, 2H), 7.46 (d, *J* = 7.2 Hz, 1H), 7.40 (t, *J* = 7.4 Hz, 2H), 7.20 (t, *J* = 6.9 Hz, 1H), 5.27 (dt, *J* = 12.2, 6.1 Hz, 1H), 2.60 (dd, *J* = 5.6, 2.4 Hz, 2H), 2.03 (t, *J* = 2.4 Hz, 1H), 1.47 (d, *J* = 6.3 Hz, 3H). $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$): δ = 210.2, 162.9, 149.7, 141.6, 134.6, 130.3, 129.8, 129.2, 128.5, 127.8, 127.4, 119.7, 116.5, 107.4, 79.7, 70.5, 68.5, 25.6, 19.2. MS (EI) m/z: 347, 280, 264, 236, 204, 131, 121, 89, 77, 39. HRMS (ESI): calcd. for $C_{21}H_{18}NO_2S$ $[M+H]^+$ 348.1053; found 348.1058.

1-(3-(phenylcarbonothioyl)indolizin-1-yl)ethan-1-one (3af). Red solid (49 mg, 88%); mp 98−100 °C; R_f = 0.42 (ethyl acetate/petroleum ether = 1:8); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.23 (d, *J* = 7.0 Hz, 1H), 8.71 (d, *J* = 8.8 Hz, 1H), 7.67 (dd, *J* = 8.4, 7.4 Hz, 1H), 7.57 (dd, *J* = 6.4, 4.9 Hz, 3H), 7.47 (d, *J* = 7.4 Hz, 1H), 7.41 (t, *J* = 7.4 Hz, 2H), 7.23 (t, *J* = 7.0 Hz, 1H), 2.46 (s, 3H). $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$): δ = 210.0, 193.3, 149.7, 141.3, 134.3, 131.3, 129.8, 128.6, 128.5, 127.9, 127.3, 120.6,

117.3, 115.3, 27.7. MS (EI) m/z: 279, 264, 235, 202, 191, 121, 89, 77, 43. Anal. Calcd. for $C_{17}H_{13}NOS$ C, 73.09; H, 4.69; N, 5.01. Found: C, 72.81; H, 4.78; N, 5.09.

methyl 6-methyl-3-(phenylcarbonothioyl)indolizine-1-carboxylate (3ag). Red solid (36 mg, 58%); mp 118−120 °C; R_f = 0.57 (ethyl acetate/petroleum ether = 1:10); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.20 (s, 1H), 8.38 (d, J = 8.9 Hz, 1H), 7.62 (s, 1H), 7.55 (d, J = 7.1 Hz, 2H), 7.51 (d, J = 9.0 Hz, 1H), 7.45 (d, J = 7.1 Hz, 1H), 7.40 (t, J = 7.3 Hz, 2H), 3.87 (s, 3H), 2.49 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 209.7, 164.2, 149.9, 140.4, 134.5, 133.1, 129.6, 128.8, 128.5, 127.9, 127.0, 125.7, 118.9, 107.1, 51.3, 18.7. MS (EI) m/z: 309, 294, 232, 138, 121, 89, 77, 51. HRMS (ESI): calcd. for $C_{18}H_{16}NO_2S$ $[M+H]^+$ 310.0896; found 310.0898.

methyl 6-bromo-3-(phenylcarbonothioyl)indolizine-1-carboxylate (3ah). Red solid (40 mg, 54%); mp 148−150 °C; R_f = 0.61 (ethyl acetate/petroleum ether = 1:10); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.46 (d, J = 0.9 Hz, 1H), 8.38 (d, J = 9.3 Hz, 1H), 7.69 (dd, J = 9.3, 1.7 Hz, 1H), 7.64 (s, 1H), 7.57 – 7.54 (m, 2H), 7.48 (dd, J = 7.9, 1.8 Hz, 1H), 7.41 (t, J = 7.4 Hz, 2H), 3.88 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 211.8, 163.8, 149.6, 139.7, 134.0, 132.9, 130.1, 128.5, 128.4, 128.0, 127.1, 120.1, 111.7, 107.5, 51.5. MS (EI) m/z: 374, 342, 314, 294, 234, 190, 131, 121, 89, 77, 51. HRMS (ESI): calcd. for $C_{17}H_{12}BrNNaO_2S$ $[M+Na]^+$ 395.9664; found 395.9671.

methyl 6-methyl-3-(3-methylphenylcarbonothioyl)indolizine-1-carboxylate (3ai). Red solid (39 mg, 61%); mp 140−142 °C; R_f = 0.42 (ethyl acetate/petroleum ether = 1:10); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.41 (s, 1H), 8.39 (d, J = 8.8 Hz, 1H), 7.55 (d, J = 8.8 Hz, 1H), 7.38 (s, 1H), 7.29 (d, J = 6.4 Hz, 1H), 7.24 – 7.17 (m, 3H),

3.84 (s, 3H), 2.51 (s, 3H), 2.20 (s, 3H). $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$): δ = 210.6, 164.0, 149.1, 140.3, 134.2, 133.4, 132.8, 130.3, 128.3, 127.9, 127.6, 127.0, 125.9, 125.5, 119.0, 107.6, 51.3, 19.3, 18.7. MS (EI) m/z: 323, 290, 264, 231, 145, 115, 102, 65, 39. HRMS (ESI): calcd. for $C_{19}H_{18}NO_2S$ $[M+H]^+$ 324.1053; found 324.1055.

methyl 3-(4-(methoxycarbonyl)phenylcarbonothioyl)-6-methylindolizine-1-carboxylate (3aj). Red solid (57 mg, 77%); mp 159−161 °C; R_f = 0.28 (ethyl acetate/petroleum ether = 1:7); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.20 (s, 1H), 8.38 (d, J = 8.9 Hz, 1H), 8.06 (d, J = 8.3 Hz, 2H), 7.57 – 7.51 (m, 4H), 3.95 (s, 3H), 3.85 (s, 3H), 2.48 (s, 3H). $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$): δ = 207.1, 166.5, 163.9, 153.4, 140.5, 134.2, 133.6, 130.5, 129.2, 128.7, 128.1, 127.6, 125.7, 118.9, 107.5, 52.2, 51.4, 18.7. MS (EI) m/z: 367, 280, 264, 236, 204, 131, 121, 89, 77, 41. HRMS (ESI): calcd. for $C_{20}H_{18}NO_4S$ $[M+H]^+$ 368.0951; found 368.0947.

General procedure for the preparation of indolizine thiones (4a-4o). A mixture of 2-pyridylacetonitrile or 2-pyridylacetamide (0.2 mmol), ynal (0.2 mmol), elemental sulfur (12.8 mg, 0.05 mmol), and I_2 (5 mg, 10 mol%) in DMF (1.0 mL) was stirred in a preheated oil bath at 80 °C for 4 h in a sealed tube under argon atmosphere. After the reaction was finished, water (5 mL) was added and the solution was extracted with ethyl acetate (3×5 mL), and the combined extract was dried with anhydrous $MgSO_4$. Solvent was removed, and the residue was separated by column chromatography to give the pure sample.

3-(phenylcarbonothioyl)indolizine-1-carbonitrile (4a). Red solid (45 mg, 85%); mp 126−128 °C; R_f = 0.38 (ethyl acetate/petroleum ether = 1:7); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.16 (d, J = 7.1 Hz, 1H), 7.90 (d, J = 8.7 Hz, 1H), 7.69 – 7.65 (m, 1H), 7.57 – 7.54 (m, 2H), 7.52 (s, 1H), 7.49 (t, J = 4.8 Hz, 1H), 7.41 (t, J = 7.4 Hz, 2H), 7.27 (d, J = 5.8 Hz, 1H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 211.7, 149.4, 142.6, 134.4, 130.3, 130.1, 129.2, 128.5, 128.1, 127.6, 117.8, 117.1, 114.5, 86.5. MS (EI) m/z: 262, 229, 185, 141, 114, 95, 78, 51. HRMS (ESI): calcd. for $C_{16}H_{11}N_2S$ $[M+H]^+$ 263.0638; found 263.0635.

3-(3-methylphenylcarbonothioyl)indolizine-1-carbonitrile (4b). Red solid (34 mg, 62%); mp 127−129 °C; R_f = 0.52 (ethyl acetate/petroleum ether = 1:7); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.15 (dt, J = 7.1, 1.0 Hz, 1H), 7.89 (dt, J = 8.7, 1.2 Hz, 1H), 7.68 – 7.64 (m, 1H), 7.52 (s, 1H), 7.38 (s, 1H), 7.34 – 7.29 (m, 3H), 7.24 (dd, J = 7.0, 1.3 Hz, 1H), 2.41 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 212.1, 149.4, 142.6, 137.9, 134.4, 131.2, 130.0, 129.2, 129.2, 127.9, 127.6, 125.7, 117.7, 117.0, 114.6,

86.4, 21.3. MS (EI) m/z: 276, 243, 185, 137, 114, 91, 78, 51. HRMS (ESI): calcd. for $C_{17}H_{13}N_2S$ $[M+H]^+$ 277.0794; found 277.0794.

3-(4-(tert-butyl)phenylcarbonothioyl)indolizine-1-carbonitrile (4c). Red solid (41 mg, 65%); mp 64−66 °C; R_f = 0.43 (ethyl acetate/petroleum ether = 1:7); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.11 (dt, J = 7.1, 1.0 Hz, 1H), 7.88 (dt, J = 8.7, 1.2 Hz, 1H), 7.66 – 7.61 (m, 1H), 7.56 (s, 1H), 7.54 – 7.51 (m, 2H), 7.44 – 7.41 (m, 2H), 7.23 (td, J = 7.0, 1.4 Hz, 1H), 1.37 (s, 9H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 211.6, 154.2, 146.7, 142.5, 134.3, 129.8, 129.0, 128.6, 127.5, 125.0, 117.7, 116.8, 114.6, 86.2, 34.9, 31.1. MS (EI) m/z: 318, 302, 287, 261, 229, 185, 161, 137, 115, 91, 78, 51, 41. HRMS (ESI): calcd. for $C_{20}H_{19}N_2S$ $[M+H]^+$ 319.1263; found 319.1259.

3-([1,1'-biphenyl]-4-carbonothioyl)indolizine-1-carbonitrile (4d). Brown solid (38 mg, 57%); mp 173−175 °C; R_f = 0.31 (ethyl acetate/petroleum ether = 1:7); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.14 (d, J = 7.1 Hz, 1H), 7.91 (d, J = 8.7 Hz, 1H), 7.68 – 7.64 (m, 7H), 7.62 (s, 1H), 7.49 (t, J = 7.5 Hz, 2H), 7.41 (t, J = 7.3 Hz, 1H), 7.26 (s, 1H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 210.9, 148.1, 143.5, 142.7, 140.0, 134.4, 130.0, 129.31, 129.0, 128.9, 127.9, 127.6, 127.1, 126.8, 117.8, 117.0, 114.6, 86.5. HRMS (ESI): calcd. for $C_{22}H_{15}N_2S$ $[M+H]^+$ 339.0950; found 339.0949.

3-(naphthalene-1-carbonothioyl)indolizine-1-carbonitrile (4e). Brown solid (58 mg, 93%); mp 173−175 °C; R_f = 0.43 (ethyl acetate/petroleum ether = 1:7); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.52 (d, J = 7.0 Hz, 1H), 7.95 – 7.91 (m, 2H), 7.91 – 7.87 (m, 1H), 7.82 (d, J = 8.5 Hz, 1H), 7.72 – 7.68 (m, 1H), 7.57 – 7.53 (m, 1H), 7.53 – 7.48 (m, 1H), 7.47 (dd, J = 7.1, 1.2 Hz, 1H), 7.41 (ddd, J = 8.2, 6.8, 1.3 Hz, 1H), 7.33 (td, J

= 7.0, 1.2 Hz, 1H), 7.23 (s, 1H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 211.0, 146.2, 142.3, 134.8, 133.3, 130.7, 130.0, 129.6, 128.7, 128.0, 127.6, 126.5, 126.0, 125.2, 124.8, 124.5, 117.8, 117.7, 114.1, 87.1. MS (EI) m/z: 312, 279, 185, 156, 142, 78, 51. HRMS (ESI): calcd. for $C_{20}H_{13}N_2S$ $[M+H]^+$ 313.0794; found 313.0791.

3-(2-methoxyphenylcarbonothioyl)indolizine-1-carbonitrile (4f). Green solid (41 mg, 71%); mp 171−173 °C; R_f = 0.26 (ethyl acetate/petroleum ether = 1:7); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.35 (d, J = 7.1 Hz, 1H), 7.87 (d, J = 8.7 Hz, 1H), 7.69 – 7.65 (m, 1H), 7.42 – 7.37 (m, 1H), 7.36 (s, 1H), 7.29 – 7.26 (m, 2H), 7.02 (td, J = 7.5, 0.8 Hz, 1H), 6.97 (d, J = 8.4 Hz, 1H), 3.73 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 209.6, 154.0, 142.3, 138.1, 134.5, 130.2, 130.1, 129.2, 129.0, 127.7, 120.6, 117.7, 117.4, 114.6, 111.3, 86.8, 55.7. MS (EI) m/z: 292, 259, 231, 216, 185, 166, 138, 114, 78, 51. HRMS (ESI): calcd. for $C_{17}H_{13}N_2OS$ $[M+H]^+$ 293.0743; found 293.0742.

3-(4-fluorophenylcarbonothioyl)indolizine-1-carbonitrile (4g). Brown solid (31 mg, 56%); mp 181−183 °C; R_f = 0.33 (ethyl acetate/petroleum ether = 1:7); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.09 (dt, J = 7.1, 1.0 Hz, 1H), 7.93 – 7.88 (m, 1H), 7.70 – 7.65 (m, 1H), 7.60 – 7.56 (m, 2H), 7.50 (s, 1H), 7.28 – 7.24 (m, 1H), 7.13 – 7.08 (m, 2H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 209.6, 164.2 (d, J = 251 Hz), 145.5 (d, J = 3 Hz), 142.7, 134.3, 130.7 (d, J = 8 Hz), 130.2, 128.8, 127.5, 117.8, 117.2, 115.1 (d, J = 22 Hz), 114.4, 86.6. MS (EI) m/z: 279, 247, 185, 139, 114, 95, 78, 51. HRMS (ESI): calcd. for $C_{16}H_{10}FN_2S$ $[M+H]^+$ 281.0543; found 281.0540.

3-(4-chlorophenylcarbonothioyl)indolizine-1-carbonitrile (4h). Brown solid (36

mg, 60%); mp 201−203 °C; R_f = 0.32 (ethyl acetate/petroleum ether = 1:7); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.12 (d, J = 7.1 Hz, 1H), 7.91 (d, J = 8.7 Hz, 1H), 7.71 – 7.66 (m, 1H), 7.52 – 7.49 (m, 3H), 7.41 – 7.38 (m, 2H), 7.28 (dd, J = 7.0, 1.2 Hz, 1H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 209.4, 147.5, 142.7, 136.7, 134.2, 130.3, 129.8, 128.9, 128.3, 127.5, 117.8, 117.3, 114.3, 86.8. MS (EI) m/z: 296, 259, 185, 155, 130, 108, 78, 51. HRMS (ESI): calcd. for $C_{16}H_{10}ClN_2S$ $[M+H]^+$ 297.0248; found 297.0243.

3-(4-bromophenylcarbonothioyl)indolizine-1-carbonitrile (4i). Brown solid (35 mg, 52%); mp 202−204 °C; R_f = 0.34 (ethyl acetate/petroleum ether = 1:7); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.13 (d, J = 7.1 Hz, 1H), 7.91 (d, J = 8.7 Hz, 1H), 7.71 – 7.67 (m, 1H), 7.58 – 7.54 (m, 2H), 7.51 (s, 1H), 7.46 – 7.41 (m, 2H), 7.29 (dd, J = 7.0, 1.3 Hz, 1H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 209.4, 148.0, 142.7, 134.2, 131.3, 130.4, 130.0, 128.9, 127.5, 125.0, 117.9, 117.4, 114.3, 86.8. MS (EI) m/z: 341, 309, 281, 259, 229, 216, 185, 141, 114, 88, 78, 51. HRMS (ESI): calcd. for $C_{16}H_{10}BrN_2S$ $[M+H]^+$ 340.9743; found 340.9737.

3-(3-(trifluoromethyl)phenylcarbonothioyl)indolizine-1-carbonitrile (4j). Red solid (47 mg, 71%); mp 132−134 °C; R_f = 0.31 (ethyl acetate/petroleum ether = 1:7); ^{1}H NMR (400 MHz, $CDCl_3$): 11.17 (dt, J = 7.1, 0.9 Hz, 1H), 7.92 (dt, J = 8.7, 1.1 Hz, 1H), 7.80 (s, 1H), 7.75 – 7.68 (m, 3H), 7.55 (t, J = 7.8 Hz, 1H), 7.45 (s, 1H), 7.31 (td, J = 7.0, 1.3 Hz, 1H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ =208.4, 149.5, 142.8, 134.2, 131.3, 130.8, 130.6 (q, J = 33 Hz), 129.0, 128.6, 127.5, 126.5 (q, J = 4 Hz), 125.0 (q,

J = 4 Hz), 123.6 (q, *J* = 271 Hz), 117.8, 117.6, 114.2, 87.1. HRMS (ESI): calcd. for $C_{17}H_{10}F_3N_2S$ $[M+H]^+$ 331.0511; found 331.0514.

3-(thiophene-2-carbonothioyl)indolizine-1-carbonitrile (4k). Red solid (28 mg, 53%); mp 171−173 °C; R_f = 0.33 (ethyl acetate/petroleum ether = 1:7); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 10.53 – 10.50 (m, 1H), 7.85 (dt, *J* = 8.8, 1.1 Hz, 1H), 7.75 – 7.72 (m, 2H), 7.57 – 7.53 (m, 1H), 7.43 (dd, *J* = 3.8, 1.1 Hz, 1H), 7.18 – 7.16 (m, 1H), 7.13 (dd, *J* = 7.0, 1.3 Hz, 1H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 198.7, 155.3, 142.7, 135.3, 133.0, 129.6, 129.0, 128.2, 127.4, 127.1, 117.8, 116.0, 114.9, 85.7. MS (EI) m/z: 267, 235, 209, 185, 134, 127, 99, 78, 51. HRMS (ESI): calcd. for $C_{14}H_9N_2S_2$ $[M+H]^+$ 269.0202; found 269.0199.

3-(phenylcarbonothioyl)-N-(p-tolyl)indolizine-1-carboxamide (4l). Red solid (53 mg, 72%); mp 78−80 °C; R_f = 0.5 (ethyl acetate/petroleum ether = 1:4); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.25 (d, *J* = 7.0 Hz, 1H), 8.61 (d, *J* = 8.8 Hz, 1H), 7.85 (s, 1H), 7.60 – 7.53 (m, 3H), 7.46 (s, 1H), 7.41 (d, *J* = 8.3 Hz, 2H), 7.38 – 7.32 (m, 3H), 7.19 (t, *J* = 7.0 Hz, 1H), 7.07 (d, *J* = 8.1 Hz, 2H), 2.29 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 208.6, 161.8, 149.7, 141.9, 135.1, 134.1, 133.9, 130.0, 129.5, 129.3, 128.5, 127.9, 127.1, 124.2, 120.5, 120.3, 116.9, 110.8, 20.8. HRMS (ESI): calcd. for $C_{23}H_{19}N_2OS$ $[M+H]^+$ 371.1213; found 371.1212.

N-benzyl-3-(phenylcarbonothioyl)indolizine-1-carboxamide (4m). Red solid (45 mg, 61%); mp 68−70 °C; R_f = 0.32 (ethyl acetate/petroleum ether = 1:4); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 11.28 (d, *J* = 7.1 Hz, 1H), 8.70 (d, *J* = 8.8 Hz, 1H), 7.63 – 7.59 (m, 1H), 7.52 (dd, *J* = 5.1, 3.1 Hz, 2H), 7.40 – 7.37 (m, 2H), 7.35 (d, *J* = 3.3 Hz,

2H), 7.31 (d, J = 4.4 Hz, 4H), 7.29 – 7.27 (m, 1H), 7.22 – 7.18 (m, 1H), 6.34 (d, J = 4.4 Hz, 1H), 4.58 (d, J = 5.8 Hz, 2H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 208.5, 163.5, 149.8, 141.9, 138.2, 134.1, 130.0, 129.5, 128.6, 128.4, 127.9, 127.8, 127.4, 127.1, 124.0, 120.4, 116.9, 110.4, 43.3. HRMS (ESI): calcd. for $C_{23}H_{19}N_2OS$ $[M+H]^+$ 371.1213; found 371.1210.

N-benzyl-3-(3-methylphenylcarbonothioyl)indolizine-1-carboxamide (4n). Red solid (58 mg, 75%); mp 72−74 °C; R_f = 0.50 (ethyl acetate/petroleum ether = 1:3); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.27 (d, J = 7.1 Hz, 1H), 8.69 (d, J = 8.8 Hz, 1H), 7.61 – 7.57 (m, 1H), 7.37 (d, J = 5.3 Hz, 2H), 7.31 (d, J = 4.4 Hz, 4H), 7.29 – 7.26 (m, 2H), 7.22 (d, J = 7.2 Hz, 2H), 7.18 (dd, J = 7.0, 1.4 Hz, 1H), 6.39 (t, J = 5.5 Hz, 1H), 4.57 (d, J = 5.8 Hz, 2H), 2.36 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 208.8, 163.5, 149.9, 141.8, 138.3, 137.7, 134.1, 130.2, 129.9, 129.1, 128.6, 127.8, 127.6, 127.4, 127.1, 125.4, 124.1, 120.4, 116.8, 110.3, 43.3, 21.3. HRMS (ESI): calcd. for $C_{24}H_{21}N_2OS$ $[M+H]^+$ 385.1369; found 385.1367.

N-benzyl-3-(4-chlorophenylcarbonothioyl)indolizine-1-carboxamide (4o). Red solid (66 mg, 82%); mp 73−75 °C; R_f = 0.39 (ethyl acetate/petroleum ether = 1:4); ^1H NMR (400 MHz, $CDCl_3$): δ = 11.24 (dt, J = 7.1, 1.0 Hz, 1H), 8.68 (d, J = 8.8 Hz, 1H), 7.63 – 7.58 (m, 1H), 7.45 – 7.42 (m, 2H), 7.37 (s, 1H), 7.30 (t, J = 3.4 Hz, 5H), 7.26 (d, J = 3.8 Hz, 2H), 7.23 – 7.19 (m, 1H), 6.52 (s, 1H), 4.55 (d, J = 5.8 Hz, 2H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 206.1, 163.4, 148.0, 142.0, 138.2, 135.6, 134.0, 130.3, 129.7, 128.6, 128. 1, 127.8, 127.5, 127.1, 123.9, 120.5, 117.1, 110.6, 43.4. HRMS (ESI): calcd. for $C_{23}H_{18}ClN_2OS$ $[M+H]^+$ 405.0823; found 405.0820.

(Z)-2-(pyridin-2-yl)-5-(3-(trifluoromethyl)phenyl)pent-2-en-4-ynenitrile (5a). Red solid (55 mg, 93%); mp 102−104 °C; R_f = 0.39 (ethyl acetate/petroleum ether = 1:6); ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.62 – 8.55 (m, 1H), 7.83 – 7.70 (m, 4H), 7.67 – 7.59 (m, 2H), 7.49 (t, J = 7.8 Hz, 1H), 7.30 (dd, J = 7.5, 4.7 Hz, 1H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ = 149.8, 148.9, 137.3, 135.4, 131.1 (q, J = 33 Hz), 129.0, 128.8 (q, J = 4 Hz), 126.2 (q, J = 4 Hz), 124.6, 124.4, 123.4 (q, J = 271 Hz), 123.3, 122.7, 121.4, 115.9, 102.2, 87.4. MS (EI) m/z: 298, 278, 229, 79, 52. Anal. Calcd. for $C_{17}H_9F_3N_2$ C, 68.46; H, 3.04; N, 9.39. Found: C, 68.20; H, 3.11; N, 9.33.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.

^{1}H and ^{13}C NMR spectra (PDF)

Crystallographic datas (CIF)

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Notes

The authors declare no competing financial interest.

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