

Article

# Diverse Synthesis of Fused Polyheterocyclic Compounds via [3 + 2] Cycloaddition of In Situ-Generated Heteroaromatic *N*-Ylides and Electron-Deficient Olefins

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**Abstract:** [3 + 2] Cycloaddition reactions of heteroaromatic *N*-ylides with electron-deficient olefins have been developed. The heteroaromatic *N*-ylides, in situ generated from *N*-phenacylbenzothiazolium bromides, can smoothly react with maleimides under very mild conditions, affording fused polycyclic octahydropyrrolo[3,4-*c*]pyrroles in good-to-excellent isolated yields. This reaction concept could also be extended to 3-trifluoroethylidene oxindoles and benzylidenemalononitriles as electron-deficient olefins for accessing highly functionalized polyheterocyclic compounds. A gram-scale experiment was also carried out to verify the practicability of the methodology.

**Keywords:** [3 + 2] cycloaddition; diverse synthesis; heteroaromatic *N*-ylides; electron-deficient olefins; fused polyheterocycles



**Citation:** Wang, Z.-H.; Zhang, T.; Shen, L.-W.; Yang, X.; Zhang, Y.-P.; You, Y.; Zhao, J.-Q.; Yuan, W.-C. Diverse Synthesis of Fused Polyheterocyclic Compounds via [3 + 2] Cycloaddition of In Situ-Generated Heteroaromatic *N*-Ylides and Electron-Deficient Olefins. *Molecules* **2023**, *28*, 4410. <https://doi.org/10.3390/molecules28114410>

Academic Editor: Gianfranco Favi

Received: 16 May 2023  
 Revised: 25 May 2023  
 Accepted: 26 May 2023  
 Published: 29 May 2023



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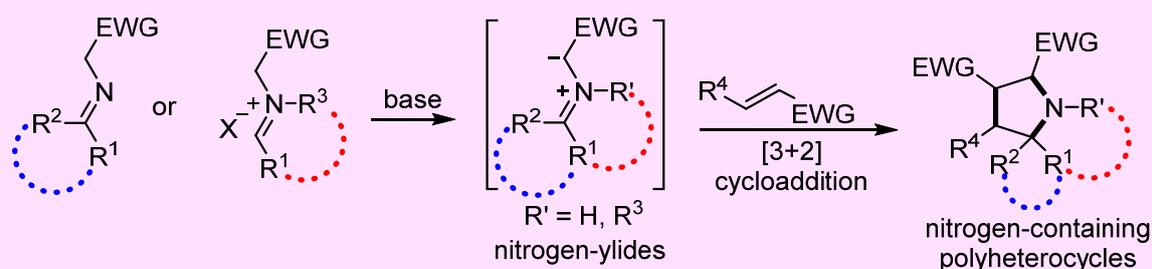
## 1. Introduction

Polyheterocyclic skeletons are frequently found as the common backbone in a variety of natural alkaloids and synthetic organic molecules with remarkable biological activities [1–4]. As shown in Figure 1, the oxo-evodiamine analogue (**I**), YM-201627 (**II**), and camptothecin (**III**) have been verified to be tumor inhibitors. Spirocyclic furan analog (**IV**) has been identified as a potent inhibitor of bacterial phenylalanyl-*t*-RNA synthetase. Spirotryprostatin A (**V**) has been isolated as a novel cell cycle inhibitor in mammals. Therefore, the construction of highly functionalized polyheterocyclic compounds continues to be an important area of research in modern organic synthetic chemistry. A large number of efficient synthetic tactics have been developed for the synthesis of various functionalized polyheterocycles [5–10]. Among the various reported methods, [3 + 2] cycloaddition has become one of the most powerful and straightforward synthetic approaches that can be used to construct polycyclic compounds [11–16].

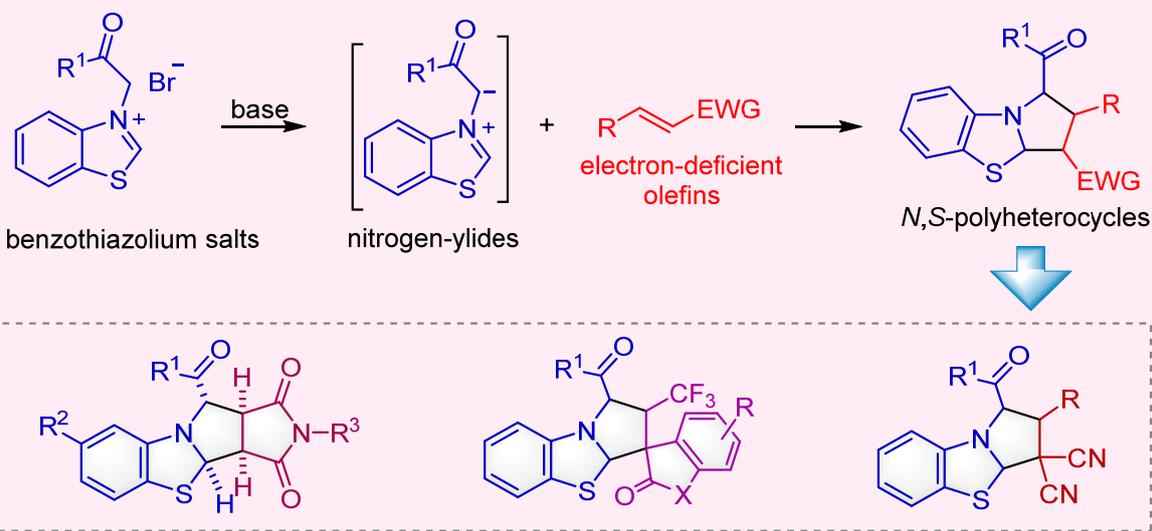
Nitrogen-ylides, in situ generated from imines or heteroarenium salts, have proven to be versatile and valuable three-atom 4π-component synthons for accessing diverse nitrogen-containing heterocyclic compounds (Scheme 1, top) [17–22]. Various types of [3 + 2] cycloadditions involving imines have been sufficiently reported [23–32]. In contrast, the study of the use of heteroarenium salts for [3 + 2] cycloadditions remains relatively underdeveloped, which may be due to the extra stability of the aromaticity of aromatic heterocyclic ring. Thus far, heteroarenium salts derived from quinoline, isoquinoline, pyridine, and benzothiazole have been successfully used in various annulation processes to access diverse nitrogen-containing polyheterocycles [33–44]. In particular, benzothiazolium salts serving as heteroaromatic *N*-ylide precursors are extremely valuable for the simple

and efficient synthesis of *N,S*-polyheterocyclic derivatives which are frequently found in natural products and pharmaceuticals [45–48]. However, a literature search revealed that, although many types of electron-deficient olefins acting as  $2\pi$ -component have been successfully applied in [3 + 2] cycloaddition with various three-atom  $4\pi$ -component partners [11–16,49,50], the related [3 + 2] cycloaddition reaction concerning the heteroaromatic *N*-ylides, in situ generated from benzothiazolium salts, with diverse electron-deficient olefins is very limited [51–56]. In this context, given the importance of *N,S*-polyheterocyclic scaffolds in medicinal and natural product chemistry and the great potential of the benzothiazolium salts for cycloaddition, expanding the application of benzothiazolium salts in the reaction with different type of electron-deficient olefins for the [3 + 2] cycloaddition to access structurally diverse polyheterocyclic compounds is highly desired. Therefore, based on our unremitting efforts in developing new synthetic methods for the construction of structurally diverse heterocyclic compounds [57–61], the [3 + 2] cycloaddition reactions of benzothiazolium salts and diverse electron-deficient olefins including maleimides, 3-trifluoroethylidene oxindoles, and benzylidenemalononitriles have been realized, furnishing varieties of functionalized fused polyheterocyclic compounds (Scheme 1, bottom). Herein, we hope to report the results of our study.

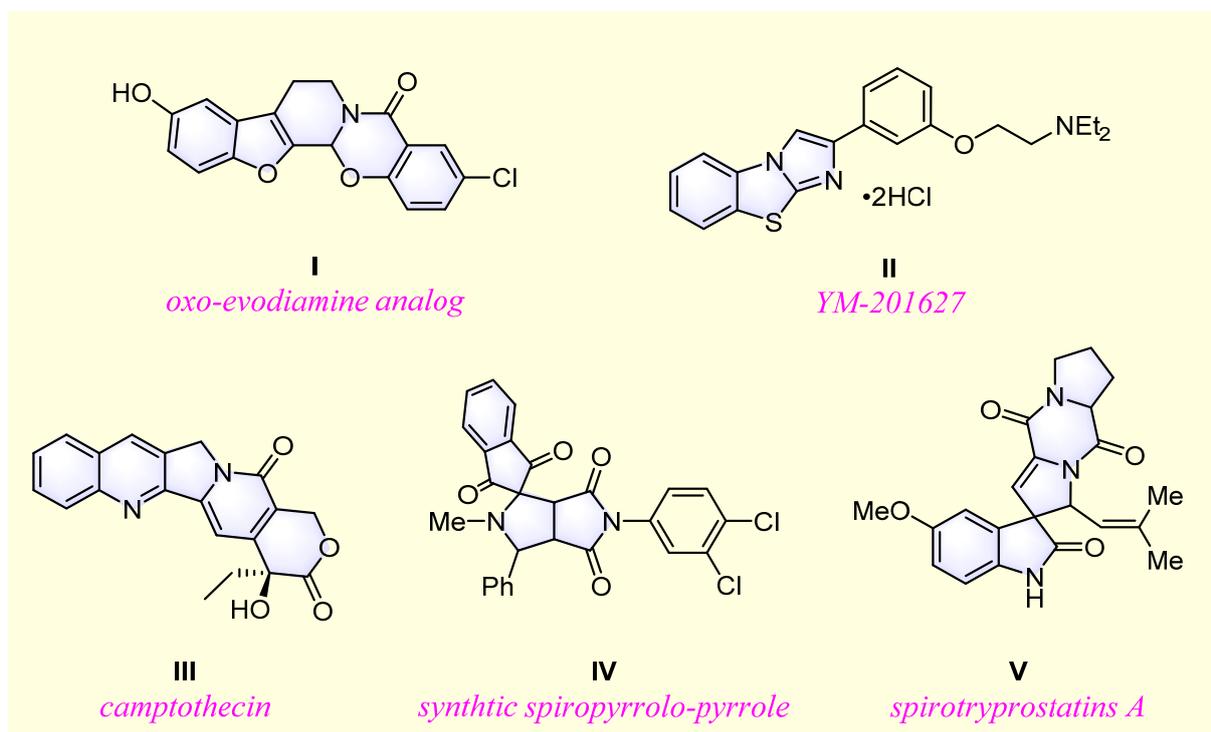
### The application of of nitrogen-ylides in [3+2] cycloaddition



### The construction of *N,S*-polyheterocyclic scaffold through [3+2] cycloaddition



**Scheme 1.** Profile of [3 + 2] cycloaddition of nitrogen-ylides in situ generated from imines or heteroarenium salts and the strategy for the diverse synthesis of structurally diverse fused polyheterocyclic compounds in this study.



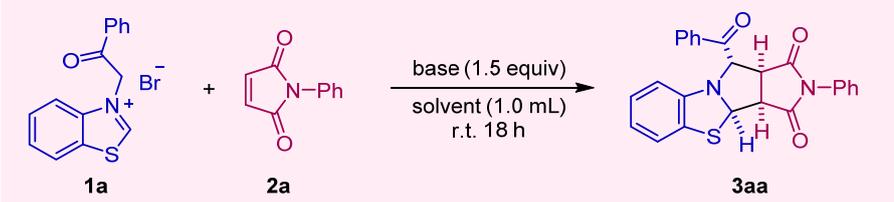
**Figure 1.** Representative biologically active molecules containing fused polyheterocyclic skeleton.

## 2. Results and Discussion

Initially, optimization of the reaction conditions was conducted by choosing benzothiazolium salt **1a** and *N*-phenylmaleimide **2a** as the model substrates (Table 1). Several inorganic bases were first tested in DCM at room temperature, and the use of  $\text{Na}_2\text{CO}_3$  gave product **3aa** in a relatively high yield (entry 3 vs. entries 1, 2, and 4). Interestingly, triethylamine furnished trace product (entry 5). Upon further solvent examination (entries 6–9), the toluene was found to be an appropriate medium to yield the corresponding cycloaddition product with a 99% yield (entry 6). As a result, the best reaction condition consisted of a 1.5 equivalent of  $\text{Na}_2\text{CO}_3$  and toluene as the solvent at room temperature.

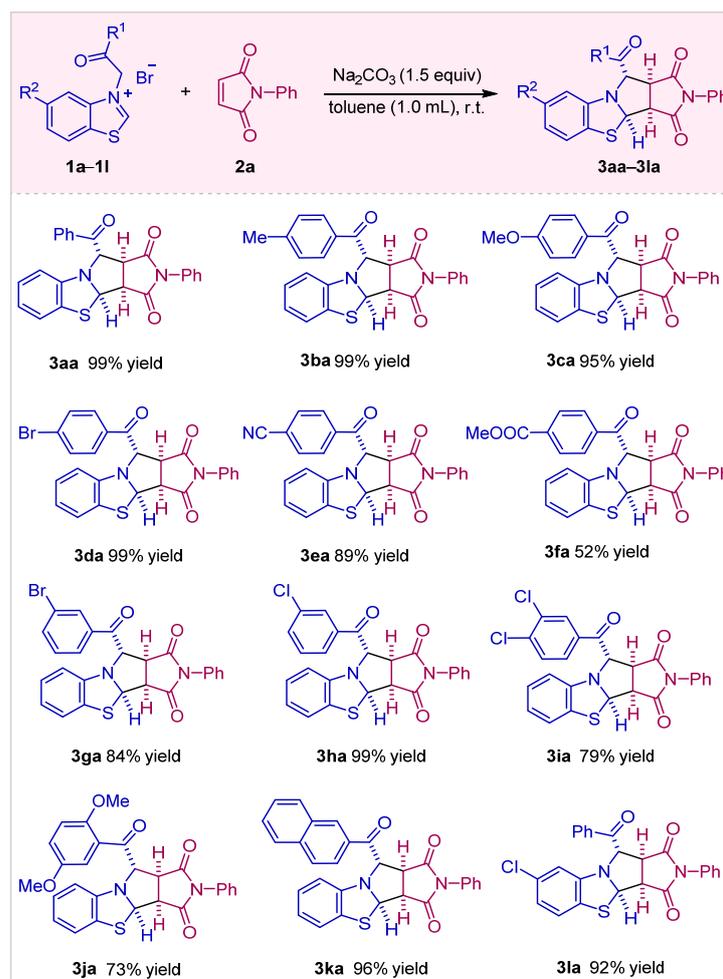
To verify the scalability of the developed [3 + 2] cycloaddition, the optimal reaction conditions were applied to other benzothiazolium salts (Scheme 2). The electronic nature and size of the substituents on benzoyl group showed little influence on the reactivity of the reaction, and the desired products **3ba–3ha** could be isolated in good to excellent yields (52–99%). Benzothiazolium salts **1i** and **1j** with two substituents on the benzene ring delivered good yields for **3ia** (79%) and **3ja** (73%). As for the introduction of naphthyl to benzothiazolium salt, the reaction also proceeded smoothly to provide the corresponding octahydropyrrolo[3,4-*c*]pyrrole **3ka** with a 96% yield. A smooth conversion of the substrate **1l**-bearing chlorine substituent on benzothiazole was observed in the reaction with **2a** to give product **3la** in a 92% yield.

Following this, the reaction scope with respect to maleimides **2** was investigated (Scheme 3). The electronic properties of the substituent on the *para*-position of the phenyl ring had almost no effect on the developed transformation, leading to products **3ab–3ad** in excellent isolated yields (89–91%). Similarly, *meta*-substituted maleimides **2e–2g** were well tolerated in [3 + 2] cycloaddition and smoothly switched into octahydropyrrolo[3,4-*c*]pyrroles **3ae–3ag** with 88–94% yields. The reaction involving maleimide **2h** also performed very well, and a good yield was produced. Moreover, *N*-alkyl substituted maleimides **2i** and **2j** were compatible with the current system, resulting in 93% and 99% yields, respectively.

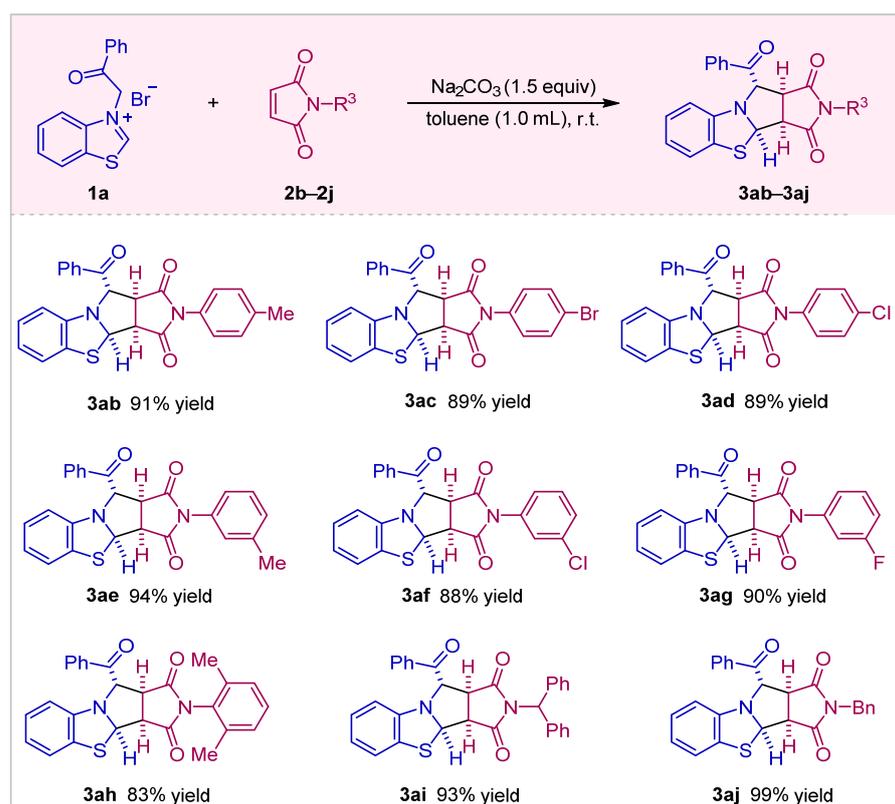
**Table 1.** Optimization of reaction conditions [a].


Entry	Base	Solvent	Yield (%) [b]
1	Cs <sub>2</sub> CO <sub>3</sub>	DCM	63
2	K <sub>3</sub> PO <sub>4</sub>	DCM	88
3	Na <sub>2</sub> CO <sub>3</sub>	DCM	95
4	K <sub>2</sub> HPO <sub>4</sub>	DCM	75
5	TEA	DCM	n.d.
6	Na <sub>2</sub> CO <sub>3</sub>	toluene	99
7	Na <sub>2</sub> CO <sub>3</sub>	DCE	75
8	Na <sub>2</sub> CO <sub>3</sub>	MeCN	33
9	Na <sub>2</sub> CO <sub>3</sub>	THF	n.d.

[a] The reaction was carried out with **1a** (0.15 mmol), **2a** (0.10 mmol), and base (0.15 mmol) in solvent (1.0 mL) at room temperature for the specified reaction time. [b] Isolated yield. n.d.—not detected.

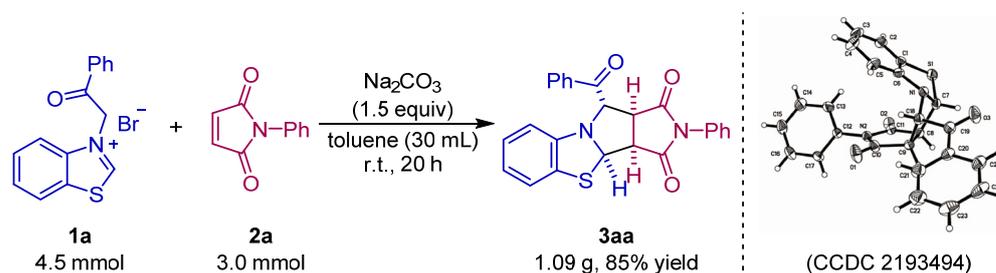


**Scheme 2.** The substrate scope of benzothiazolium salts **1**. Reaction conditions: The reaction was carried out with **1a–1l** (0.15 mmol), **2a** (0.10 mmol), and Na<sub>2</sub>CO<sub>3</sub> (0.15 mmol) in toluene (1.0 mL) at room temperature for 3 h. The yields refer to the isolated yield of product.



**Scheme 3.** The substrate scope for maleimides **2**. Reaction conditions: The reaction was carried out with **1a** (0.15 mmol), **2b-2j** (0.10 mmol), and  $\text{Na}_2\text{CO}_3$  (0.15 mmol) in toluene (1.0 mL) at room temperature for 3 h.

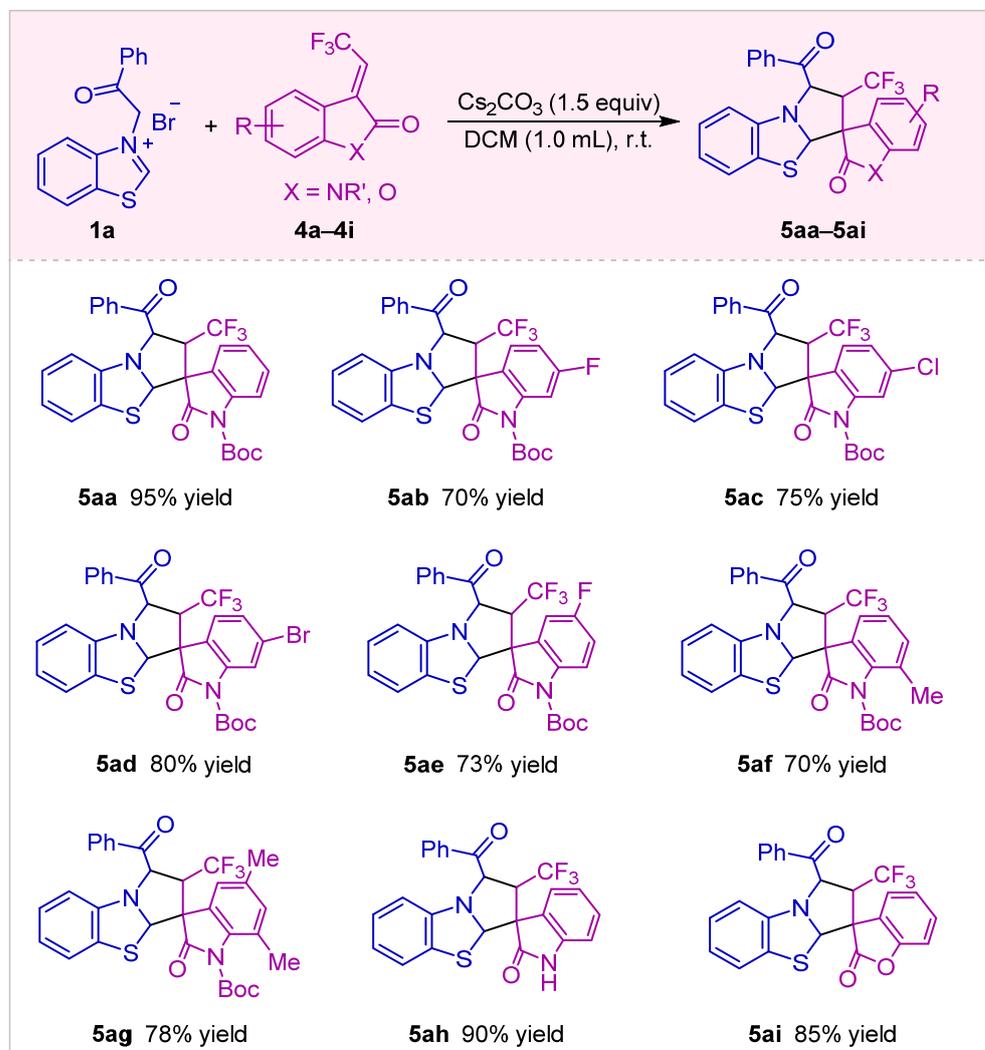
The synthetic practicability of the developed [3 + 2] cycloaddition was demonstrated by the scale-up experiment of benzothiazolium salt **1a** and *N*-phenylmaleimide **2a** under the standard conditions, and the product octahydropyrrolo[3,4-*c*]pyrrole **3aa** was isolated with a 85% yield (Scheme 4). In addition, the structure of **3aa** was unambiguously determined using single crystal X-ray diffraction analysis (Scheme 4, CCDC 2193494 (**3aa**) contains the supplementary crystallographic data for this paper. For details, see the Supporting Information).



**Scheme 4.** Scale-up experiment.

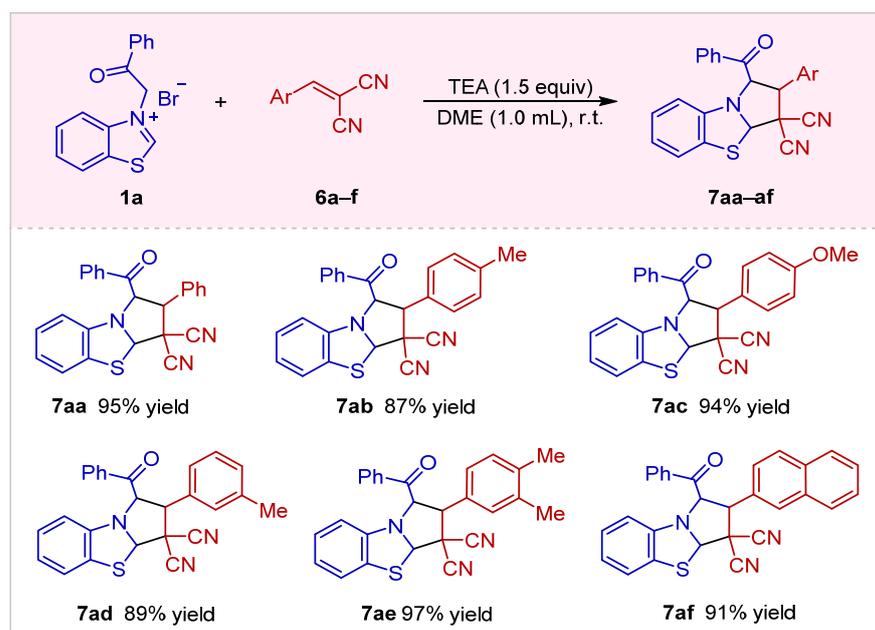
Owing to the unique properties of the trifluoromethyl unit in promoting the metabolic stability and bioavailability of many bioactive compounds [62,63], several  $\text{CF}_3$ -containing heterocyclic compounds, in particular of trifluoromethyl-substituted pyrrolidines, have been synthesized with [3 + 2] cycloaddition reaction in the past few years [64–68]. To expand the application of benzothiazolium salts in constructing spiro-pyrrolidines, the [3 + 2] cycloaddition between benzothiazolium salts and 3-trifluoroethylidene oxindoles was conducted. After a careful screening of bases and solvents (For the detail of the procedure, see Supporting Information), the reaction of benzothiazolium salt **1a** with 3-trifluoroethylidene oxindole **4a** proceeded smoothly to produce the  $\text{CF}_3$ -containing

tetrahydrobenzo[*d*]pyrrolo[2,1-*b*]thiazole **5aa** with a 95% isolated yield (Scheme 5). On this basis, other 3-trifluoroethylidene oxindoles **4b–4h** were evaluated under the optimal reaction conditions, these substrates could be smoothly converted into the corresponding cycloadducts **5ab–5ah** in good yields (70–90%). Moreover, 3-trifluoroethylidene benzofuranone was also compatible with the developed system to give product **5ai** with a 85% yield.



**Scheme 5.** The [3 + 2] cycloaddition reaction of benzothiazolium salt with 3-trifluoroethylidene oxindoles. Reaction conditions: The reaction was carried out with **1a** (0.15 mmol), **4a–4i** (0.10 mmol), and  $\text{Cs}_2\text{CO}_3$  (0.15 mmol) in DCM (1.0 mL) at room temperature for 18 h.

Encouraged by the above success, we questioned whether the application of benzothiazolium salt can be further expanded. Subsequently, many benzyldenemalononitriles **6** were surveyed via reaction with **1a**. The reaction optimization study demonstrated that triethylamine (TEA) was the best base for promoting the transformation (For the detail of the procedure, see Supporting Information). The reaction between **1a** and **6a** could furnish the desired product **7aa** in 95% yield (Scheme 6). Further studies indicated that the substituents on the aryl ring (Ar) of benzyldenemalononitriles have a limited effect on the reactivity of the reaction. The benzyldenemalononitriles **6b–6f** were compatible with the reaction condition to give the corresponding products **7ab–7af** in 87–97% yields.



**Scheme 6.** The [3 + 2] cycloaddition reaction of benzothiazolium salt with various benzylidenemalononitriles. Reaction conditions: The reaction was carried out with **1a** (0.15 mmol), **6a–6f** (0.10 mmol), and TEA (0.15 mmol) in 1,2-dimethoxyethane (DME, 1.0 mL) at room temperature for 3 h.

### 3. Materials and Methods

#### 3.1. General Information

Reagents were purchased from commercial sources and were used as received unless mentioned otherwise. Reactions were monitored with TLC. The NMR spectra were recorded with a Bruker Avance NEO 400 or 300.  $^1\text{H}$  NMR and  $^{13}\text{C}$  NMR spectra were recorded in  $\text{CDCl}_3$  or  $\text{DMSO-}d_6$ .  $^1\text{H}$  NMR chemical shifts are reported in ppm relative to tetramethylsilane (TMS) with the solvent resonance employed as the internal standard ( $\text{CDCl}_3$  at 7.26 ppm,  $\text{DMSO-}d_6$  at 2.50 ppm). Data are reported as follows: chemical shift, multiplicity (s = singlet, br s = broad singlet, d = doublet, t = triplet, q = quartet, m = multiplet), coupling constants (Hz), and integration.  $^{13}\text{C}$  NMR chemical shifts are reported in ppm from tetramethylsilane (TMS) with the solvent resonance as the internal standard ( $\text{CDCl}_3$  at 77.16 ppm,  $\text{DMSO-}d_6$  at 39.52 ppm). Melting points products were recorded on a Büchi Melting Point B-545. The HRMS was recorded with an Agilent 6545 LC/Q-TOF mass spectrometer.

#### 3.2. General Experimental Procedures for the Synthesis of Compounds **3** (Schemes 2 and 3)

In an ordinary vial charged with a magnetic stirring bar, *N*-phenacylbenzothiazolium bromides **1** (0.15 mmol, 1.5 equiv), maleimides **2** (0.1 mmol, 1.0 equiv),  $\text{Na}_2\text{CO}_3$  (0.15 mmol, 1.5 equiv), and toluene (1.0 mL) were successively added. Then, the mixture was stirred at room temperature for the indicated time. Products **3** were isolated using flash chromatography on silica gel.

**10-Benzoyl-2-phenyl-3a,3b,10,10a-tetrahydro-1H-benzol[d]pyrrolo[3',4':3,4]pyrrolo[2,1-b]thiazole-1,3(2H)-dione (3aa):** Eluent: petroleum ether/EtOAc = 4:1, white solid (42.2 mg, 99% yield);  $R_f$  = 0.50 (petroleum ether/EtOAc = 3:1); m.p. 190.2–192.4 °C;  $^1\text{H}$  NMR (400 MHz,  $\text{DMSO-}d_6$ )  $\delta$  8.18 (d,  $J$  = 7.4 Hz, 2H, Ar-H), 7.71 (dd,  $J$  = 7.2 Hz, 1H, Ar-H), 7.64–7.54 (m, 2H, Ar-H), 7.36–7.28 (m, 4H, Ar-H), 7.21 (d,  $J$  = 7.6 Hz, 1H, Ar-H), 7.08 (dd,  $J$  = 7.7 Hz, 1H, Ar-H), 6.87 (dd,  $J$  = 7.5 Hz, 1H, Ar-H), 6.46 (dd,  $J$  = 6.7, 3.0 Hz, 2H, Ar-H), 6.31 (s, 1H, N-CH), 5.47 (d,  $J$  = 8.3 Hz, 1H, S-CH-N), 4.13 (d,  $J$  = 7.8 Hz, 1H, CH), 3.66 (t,  $J$  = 8.1 Hz, 1H, CH);  $^{13}\text{C}$  NMR (101 MHz,  $\text{DMSO-}d_6$ )  $\delta$  195.2 (C=O), 176.3 (C=O), 173.4 (C=O), 146.5, 133.9, 133.8, 132.0, 129.1, 128.8, 128.7, 128.5, 126.7, 126.2, 125.2, 122.6, 121.8, 110.4, 71.3 (N-C), 68.3 (S-C-N), 50.3 (CH), 47.9 (CH); IR (neat)  $\nu$  3068, 2968, 1773, 1696, 1683, 1595, 1577, 1499, 1461, 1448, 1389,

1320, 1292, 1222, 1204, 1176, 1163, 991, 747, 688  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[M + H]^+$  calcd for  $\text{C}_{25}\text{H}_{19}\text{N}_2\text{O}_3\text{S}$  427.1111; found 427.1119.

*10-(4-Methylbenzoyl)-2-phenyl-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4':3,4]pyrrolo[2,1-b]thiazole-1,3(2H)-dione (3ba)*: Eluent: petroleum ether/EtOAc = 4:1, white solid (43.6 mg, 99% yield);  $R_f$  = 0.54 (petroleum ether/EtOAc = 3:1); m.p. 195.4–197.3  $^{\circ}\text{C}$ ;  $^1\text{H}$  NMR (400 MHz,  $\text{DMSO-}d_6$ )  $\delta$  8.07 (d,  $J$  = 8.1 Hz, 2H, Ar-H), 7.40 (d,  $J$  = 8.0 Hz, 2H, Ar-H), 7.34–7.30 (m, 3H, Ar-H), 7.29 (d,  $J$  = 8.2 Hz, 1H, Ar-H), 7.20 (d,  $J$  = 7.6 Hz, 1H, Ar-H), 7.07 (dd,  $J$  = 7.7 Hz, 1H, Ar-H), 6.87 (dd,  $J$  = 7.5 Hz, 1H, Ar-H), 6.45 (dd,  $J$  = 6.4, 3.1 Hz, 2H, Ar-H), 6.25 (s, 1H, N-CH), 5.46 (d,  $J$  = 8.3 Hz, 1H, S-CH-N), 4.09 (d,  $J$  = 7.8 Hz, 1H, CH), 3.64 (t,  $J$  = 8.1 Hz, 1H, CH), 2.40 (s, 3H,  $\text{CH}_3$ );  $^{13}\text{C}$  NMR (101 MHz,  $\text{DMSO-}d_6$ )  $\delta$  194.7 (C=O), 176.4 (C=O), 173.4 (C=O), 146.6, 144.6, 132.1, 131.4, 129.4, 129.3, 128.8, 128.5, 126.7, 126.2, 125.2, 122.6, 121.8, 110.4, 71.4 (N-C), 68.2 (S-C-N), 50.3 (CH), 48.0 (CH), 21.3 ( $\text{CH}_3$ ); IR (neat)  $\nu$  3063, 3025, 2940, 1776, 1708, 1677, 1603, 1578, 1495, 1468, 1453, 1387, 1256, 1224, 1207, 1176, 1165, 1024, 990, 803, 751, 687  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[M + H]^+$  calcd for  $\text{C}_{26}\text{H}_{21}\text{N}_2\text{O}_3\text{S}$  441.1267; found 441.1275.

*10-(4-Methoxybenzoyl)-2-phenyl-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4':3,4]pyrrolo[2,1-b]thiazole-1,3(2H)-dione (3ca)*: Eluent: petroleum ether/EtOAc = 4:1, white solid (43.4 mg, 95% yield);  $R_f$  = 0.35 (petroleum ether/EtOAc = 3:1); m.p. 189.0–189.7  $^{\circ}\text{C}$ ;  $^1\text{H}$  NMR (400 MHz,  $\text{DMSO-}d_6$ )  $\delta$  8.16 (d,  $J$  = 8.7 Hz, 2H, Ar-H), 7.37–7.27 (m, 4H, Ar-H), 7.21 (d,  $J$  = 7.6 Hz, 1H, Ar-H), 7.12 (d,  $J$  = 8.7 Hz, 2H, Ar-H), 7.07 (dd,  $J$  = 7.6 Hz, 1H, Ar-H), 6.87 (dd,  $J$  = 7.5 Hz, 1H, Ar-H), 6.47–6.43 (m, 2H, Ar-H), 6.24 (s, 1H, N-CH), 5.46 (d,  $J$  = 8.3 Hz, 1H, S-CH-N), 4.10 (d,  $J$  = 7.8 Hz, 1H, CH), 3.86 (s, 3H,  $\text{OCH}_3$ ), 3.64 (t,  $J$  = 8.1 Hz, 1H, CH);  $^{13}\text{C}$  NMR (101 MHz,  $\text{DMSO-}d_6$ )  $\delta$  193.4 (C=O), 176.4 (C=O), 173.4 (C=O), 163.7, 146.6, 132.1, 131.6, 128.7, 128.5, 126.7, 126.5, 126.1, 125.2, 122.6, 121.8, 114.1, 110.4, 71.4 (N-C), 68.0 (S-C), 55.7 ( $\text{OCH}_3$ ), 50.3 (CH), 48.0 (CH); IR (neat)  $\nu$  3060, 2917, 2847, 1777, 1707, 1675, 1596, 1574, 1495, 1469, 1388, 1320, 1254, 1226, 1207, 1173, 1164, 1022, 819, 752, 688  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[M + H]^+$  calcd for  $\text{C}_{26}\text{H}_{21}\text{N}_2\text{O}_4\text{S}$  457.1217; found 457.1227.

*10-(4-Bromobenzoyl)-2-phenyl-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4':3,4]pyrrolo[2,1-b]thiazole-1,3(2H)-dione (3da)*: Eluent: petroleum ether/EtOAc = 4:1, white solid (50.0 mg, 99% yield);  $R_f$  = 0.57 (petroleum ether/EtOAc = 3:1); m.p. 177.5–179.2  $^{\circ}\text{C}$ ;  $^1\text{H}$  NMR (400 MHz,  $\text{DMSO-}d_6$ )  $\delta$  8.07 (d,  $J$  = 8.4 Hz, 2H, Ar-H), 7.82 (d,  $J$  = 8.3 Hz, 2H, Ar-H), 7.37–7.26 (m, 4H, Ar-H), 7.21 (d,  $J$  = 7.6 Hz, 1H, Ar-H), 7.08 (dd,  $J$  = 7.7 Hz, 1H, Ar-H), 6.87 (dd,  $J$  = 7.5 Hz, 1H, Ar-H), 6.44 (dd,  $J$  = 6.5, 3.1 Hz, 2H, Ar-H), 6.28 (s, 1H, N-CH), 5.43 (d,  $J$  = 8.4 Hz, 1H, S-CH-N), 4.13 (d,  $J$  = 7.8 Hz, 1H, CH), 3.63 (t,  $J$  = 8.1 Hz, 1H, CH);  $^{13}\text{C}$  NMR (101 MHz,  $\text{DMSO-}d_6$ )  $\delta$  194.6 (C=O), 176.3 (C=O), 173.3 (C=O), 146.4, 133.1, 132.0, 131.8, 131.0, 128.7, 128.5, 128.0, 126.7, 126.2, 125.2, 122.6, 121.9, 110.4, 71.3 (N-C), 68.4 (S-C-N), 50.3 (CH), 47.7 (CH); IR (neat)  $\nu$  3064, 2925, 2849, 1777, 1707, 1680, 1581, 1498, 1467, 1452, 1391, 1256, 1220, 1210, 1180, 1168, 1068, 1026, 1006, 859, 806, 755, 687  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[M + H]^+$  calcd for  $\text{C}_{25}\text{H}_{18}\text{BrN}_2\text{O}_3\text{S}$  505.0216, 507.0198; found 505.0218, 507.0203.

*4-(1,3-Dioxo-2-phenyl-2,3,3a,3b,10,10a-hexahydro-1H-benzo[d]pyrrolo[3',4':3,4]pyrrolo[2,1-b]thiazole-10-carbonyl)benzotrile (3ea)*: Eluent: petroleum ether/EtOAc = 4:1, white solid (40.2 mg, 89% yield);  $R_f$  = 0.24 (petroleum ether/EtOAc = 3:1); m.p. 182.1–184.3  $^{\circ}\text{C}$ ;  $^1\text{H}$  NMR (400 MHz,  $\text{DMSO-}d_6$ )  $\delta$  8.26 (d,  $J$  = 8.2 Hz, 2H, Ar-H), 8.08 (d,  $J$  = 8.2 Hz, 2H, Ar-H), 7.38–7.27 (m, 4H, Ar-H), 7.22 (d,  $J$  = 7.5 Hz, 1H, Ar-H), 7.09 (dd,  $J$  = 7.6 Hz, 1H, Ar-H), 6.88 (dd,  $J$  = 7.5 Hz, 1H, Ar-H), 6.50–6.41 (m, 2H, Ar-H), 6.35 (s, 1H, N-CH), 5.42 (d,  $J$  = 8.4 Hz, 1H, S-CH-N), 4.17 (d,  $J$  = 7.8 Hz, 1H, CH), 3.64 (t,  $J$  = 8.1 Hz, 1H, CH);  $^{13}\text{C}$  NMR (101 MHz,  $\text{DMSO-}d_6$ )  $\delta$  195.0 (C=O), 176.2 (C=O), 173.3 (C=O), 146.4, 137.7, 132.7, 132.0, 129.6, 128.7, 128.5, 126.7, 126.2, 125.2, 122.7, 122.0, 118.1, 115.5, 110.5, 71.2 (N-C), 68.7 (S-C-N), 50.3 (CH), 47.5 (CH); IR (neat)  $\nu$  3060, 2964, 2920, 2850, 2229, 1777, 1703, 1678, 1579, 1499, 1466, 1448, 1387, 1195, 1177, 1171, 1009, 752, 742, 686  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[M + H]^+$  calcd for  $\text{C}_{26}\text{H}_{18}\text{N}_3\text{O}_3\text{S}$  452.1063; found 452.1070.

*Methyl 4-(1,3-dioxo-2-phenyl-2,3,3a,3b,10,10a-hexahydro-1H-benzo[d]pyrrolo[3',4':3,4]pyrrolo[2,1-b]thiazole-10-carbonyl) benzoate (3fa)*: Eluent: petroleum ether/EtOAc = 4:1, white solid (25.2 mg, 52% yield);  $R_f$  = 0.31 (petroleum ether/EtOAc = 3:1); m.p. 183.9–186.2  $^{\circ}\text{C}$ ;  $^1\text{H}$

NMR (400 MHz, DMSO- $d_6$ )  $\delta$  8.26 (d,  $J$  = 8.5 Hz, 2H, Ar-H), 8.13 (d,  $J$  = 8.4 Hz, 2H, Ar-H), 7.36–7.26 (m, 4H, Ar-H), 7.21 (d,  $J$  = 8.2 Hz, 1H, Ar-H), 7.08 (dd,  $J$  = 7.3 Hz, 1H, Ar-H), 6.88 (dd,  $J$  = 7.5 Hz, 1H, Ar-H), 6.50–6.40 (m, 2H, Ar-H), 6.32 (s, 1H, N-CH), 5.44 (d,  $J$  = 8.4 Hz, 1H, S-CH-N), 4.14 (d,  $J$  = 7.9 Hz, 1H, CH), 3.89 (s, 3H, CH<sub>3</sub>), 3.65 (t,  $J$  = 8.1 Hz, 1H, CH); <sup>13</sup>C NMR (101 MHz, DMSO- $d_6$ )  $\delta$  195.1 (C=O), 176.2 (C=O), 173.3 (C=O), 165.5 (C=O), 146.4, 137.7, 133.6, 132.0, 129.4, 129.3, 128.7, 128.5, 126.7, 126.2, 125.2, 122.6, 122.0, 110.5, 71.2 (N-C), 68.6 (S-C-N), 52.6 (CH<sub>3</sub>), 50.3 (CH), 47.7 (CH); IR (neat)  $\nu$  3058, 2953, 2920, 2850, 1777, 1726, 1706, 1685, 1575, 1496, 1467, 1388, 1283, 1258, 1223, 1179, 1169, 1106, 1014, 868, 755, 707, 687 cm<sup>-1</sup>; HRMS (ESI)  $m/z$ : [M + H]<sup>+</sup> calcd for C<sub>27</sub>H<sub>21</sub>N<sub>2</sub>O<sub>5</sub>S 485.1166; found 485.1171.

*10-(3-Bromobenzoyl)-2-phenyl-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4']pyrrolo[2,1-b]thiazole-1,3(2H)-dione (3ga)*: Eluent: petroleum ether/EtOAc = 4:1, white solid (42.4 mg, 84% yield);  $R_f$  = 0.48 (petroleum ether/EtOAc = 3:1); m.p. 177.5–179.2 °C; <sup>1</sup>H NMR (400 MHz, DMSO- $d_6$ )  $\delta$  8.28 (s, 1H, Ar-H), 8.15 (d,  $J$  = 7.9 Hz, 1H, Ar-H), 7.90 (d,  $J$  = 9.0 Hz, 1H, Ar-H), 7.56 (dd,  $J$  = 7.9 Hz, 1H, Ar-H), 7.37–7.28 (m, 4H, Ar-H), 7.21 (d,  $J$  = 8.2 Hz, 1H, Ar-H), 7.09 (dd,  $J$  = 8.1 Hz, 1H, Ar-H), 6.88 (dd,  $J$  = 7.5 Hz, 1H, Ar-H), 6.51–6.39 (m, 2H, Ar-H), 6.31 (s, 1H, N-CH), 5.46 (d,  $J$  = 8.4 Hz, 1H, S-CH-N), 4.13 (d,  $J$  = 7.9 Hz, 1H, CH), 3.63 (t,  $J$  = 8.1 Hz, 1H, CH); <sup>13</sup>C NMR (101 MHz, DMSO- $d_6$ )  $\delta$  194.3 (C=O), 176.2 (C=O), 173.3 (C=O), 146.5, 136.3, 136.1, 132.0, 131.7, 131.0, 128.7, 128.5, 128.0, 126.7, 126.2, 125.1, 122.6, 122.0, 121.9, 110.4, 71.3 (N-C), 68.6 (S-C-N), 50.2 (CH), 47.8 (CH); IR (neat)  $\nu$  3061, 2963, 2923, 2850, 1779, 1709, 1698, 1681, 1566, 1499, 1464, 1450, 1390, 1369, 1220, 1210, 1182, 1164, 1135, 1030, 843, 767, 744, 694 cm<sup>-1</sup>; HRMS (ESI)  $m/z$ : [M + H]<sup>+</sup> calcd for C<sub>25</sub>H<sub>18</sub>BrN<sub>2</sub>O<sub>3</sub>S 505.0216, 507.0198; found 505.0218, 507.0206.

*10-(3-Chlorobenzoyl)-2-phenyl-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4']pyrrolo[2,1-b]thiazole-1,3(2H)-dione (3ha)*: Eluent: petroleum ether/EtOAc = 4:1, white solid (45.6 mg, 99% yield);  $R_f$  = 0.51 (petroleum ether/EtOAc = 3:1); m.p. 185.7–186.2 °C; <sup>1</sup>H NMR (400 MHz, DMSO- $d_6$ )  $\delta$  8.14 (s, 1H, Ar-H), 8.11 (d,  $J$  = 7.9 Hz, 1H, Ar-H), 7.77 (d,  $J$  = 9.2 Hz, 1H, Ar-H), 7.63 (dd,  $J$  = 7.9 Hz, 1H, Ar-H), 7.39–7.26 (m, 4H, Ar-H), 7.21 (d,  $J$  = 7.5 Hz, 1H, Ar-H), 7.09 (dd,  $J$  = 7.7 Hz, 1H, Ar-H), 6.88 (dd,  $J$  = 7.5 Hz, 1H, Ar-H), 6.53–6.37 (m, 2H, Ar-H), 6.31 (s, 1H, N-CH), 5.46 (d,  $J$  = 8.4 Hz, 1H, S-CH-N), 4.13 (d,  $J$  = 7.9 Hz, 1H, CH), 3.63 (t,  $J$  = 8.1 Hz, 1H, CH); <sup>13</sup>C NMR (101 MHz, DMSO- $d_6$ )  $\delta$  194.4 (C=O), 176.2 (C=O), 173.3 (C=O), 146.5, 135.9, 133.6, 133.5, 132.0, 130.8, 128.8, 128.7, 128.5, 127.7, 126.7, 126.2, 125.1, 122.6, 121.9, 110.4, 71.3 (N-C), 68.6 (S-C-N), 50.2 (CH), 47.8 (CH); IR (neat)  $\nu$  3064, 2977, 2920, 2850, 1780, 1708, 1678, 1579, 1498, 1466, 1450, 1387, 1253, 1222, 1196, 1180, 1162, 1028, 841, 753, 742, 685 cm<sup>-1</sup>; HRMS (ESI)  $m/z$ : [M + H]<sup>+</sup> calcd for C<sub>25</sub>H<sub>18</sub>ClN<sub>2</sub>O<sub>3</sub>S 461.0721, 463.0700; found 461.0728, 463.0706.

*10-(3,4-Dichlorobenzoyl)-2-phenyl-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4']pyrrolo[2,1-b]thiazole-1,3(2H)-dione (3ia)*: Eluent: petroleum ether/EtOAc = 4:1, white solid (39.1 mg, 79% yield);  $R_f$  = 0.51 (petroleum ether/EtOAc = 3:1); m.p. 212.4–213.7 °C; <sup>1</sup>H NMR (400 MHz, DMSO- $d_6$ )  $\delta$  8.31 (d,  $J$  = 2.0 Hz, 1H, Ar-H), 8.08 (dd,  $J$  = 8.4, 2.0 Hz, 1H, Ar-H), 7.88 (d,  $J$  = 8.4 Hz, 1H, Ar-H), 7.40–7.28 (m, 4H, Ar-H), 7.22 (d,  $J$  = 7.5 Hz, 1H, Ar-H), 7.09 (dd,  $J$  = 7.3 Hz, 1H, Ar-H), 6.88 (dd,  $J$  = 7.4 Hz, 1H, Ar-H), 6.53–6.39 (m, 2H, Ar-H), 6.31 (s, 1H, N-CH), 5.45 (d,  $J$  = 8.4 Hz, 1H, S-CH-N), 4.14 (d,  $J$  = 7.9 Hz, 1H, CH), 3.63 (t,  $J$  = 8.1 Hz, 1H, CH); <sup>13</sup>C NMR (101 MHz, DMSO- $d_6$ )  $\delta$  193.7 (C=O), 176.2 (C=O), 173.3 (C=O), 146.4, 136.6, 134.3, 132.0, 131.7, 131.1, 131.0, 129.1, 128.8, 128.6, 126.7, 126.2, 125.2, 122.7, 122.0, 110.4, 71.3 (N-C), 68.6 (S-C-N), 50.2 (CH), 47.7 (CH); IR (neat)  $\nu$  3098, 3063, 2973, 2963, 1778, 1708, 1685, 1578, 1498, 1469, 1450, 1387, 1344, 1264, 1220, 1169, 1027, 969, 807, 801, 756, 714, 686, 671 cm<sup>-1</sup>; HRMS (ESI)  $m/z$ : [M + H]<sup>+</sup> calcd for C<sub>25</sub>H<sub>17</sub>Cl<sub>2</sub>N<sub>2</sub>O<sub>3</sub>S 495.0331, 497.0307, 499.0288; found 495.0336, 497.0312, 499.0295.

*10-(2,5-Dimethoxybenzoyl)-2-phenyl-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4']pyrrolo[2,1-b]thiazole-1,3(2H)-dione (3ja)*: Eluent: petroleum ether/EtOAc = 4:1, white solid (35.5 mg, 73% yield);  $R_f$  = 0.29 (petroleum ether/EtOAc = 3:1); m.p. 197.5–199.2 °C; <sup>1</sup>H NMR (400 MHz, DMSO- $d_6$ )  $\delta$  7.35–7.29 (m, 3H, Ar-H), 7.23 (d,  $J$  = 2.8 Hz, 1H, Ar-H), 7.20–7.12 (m, 3H, Ar-H), 7.05 (dd,  $J$  = 7.3 Hz, 1H, Ar-H), 6.89 (d,  $J$  = 7.9 Hz, 1H, Ar-H), 6.83 (dd,  $J$  = 7.5 Hz, 1H, Ar-H), 6.54–6.39 (m, 2H, Ar-H), 6.04 (s, 1H, N-CH), 5.49 (d,  $J$  = 8.4 Hz, 1H, S-CH-N),

4.10 (d,  $J = 7.8$  Hz, 1H, CH), 3.91 (s, 3H, CH<sub>3</sub>), 3.76 (s, 3H, CH<sub>3</sub>), 3.63 (t,  $J = 8.1$  Hz, 1H, CH); <sup>13</sup>C NMR (101 MHz, DMSO-*d*<sub>6</sub>)  $\delta$  198.1 (C=O), 176.2 (C=O), 173.4 (C=O), 153.0, 152.3, 146.7, 132.1, 128.7, 128.5, 126.7, 126.1, 125.7, 125.1, 122.4, 121.6, 119.9, 114.5, 113.5, 110.3, 71.6 (N-C), 71.3 (S-C-N), 56.3 (OCH<sub>3</sub>), 55.6 (OCH<sub>3</sub>), 50.4 (CH), 47.7 (CH); IR (neat)  $\nu$  3060, 3011, 2948, 2923, 2830, 1779, 1711, 1675, 1577, 1494, 1458, 1416, 1378, 1222, 1188, 1173, 1013, 836, 811, 743, 731, 690, 622 cm<sup>-1</sup>; HRMS (ESI)  $m/z$ : [M + H]<sup>+</sup> calcd for C<sub>27</sub>H<sub>23</sub>N<sub>2</sub>O<sub>5</sub>S 487.1322; found 487.1330.

*10-(2-Naphthoyl)-2-phenyl-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4':3,4]pyrrolo[2,1-b]-thiazole-1,3(2H)-dione (3ka)*: Eluent: petroleum ether/EtOAc = 4:1, white solid (45.8 mg, 96% yield);  $R_f = 0.51$  (petroleum ether/EtOAc = 3:1); m.p. 201.3–203.2 °C; <sup>1</sup>H NMR (400 MHz, DMSO-*d*<sub>6</sub>)  $\delta$  8.90 (s, 1H, Ar-H), 8.15 (dd,  $J = 8.6, 1.4$  Hz, 1H, Ar-H), 8.10 (dd,  $J = 9.4$  Hz, 2H, Ar-H), 8.03 (d,  $J = 8.1$  Hz, 1H, Ar-H), 7.71 (dd,  $J = 7.0$  Hz, 1H, Ar-H), 7.65 (dd,  $J = 7.0$  Hz, 1H, Ar-H), 7.43 (d,  $J = 8.0$  Hz, 1H, Ar-H), 7.37–7.30 (m, 3H, Ar-H), 7.22 (d,  $J = 7.1$  Hz, 1H, Ar-H), 7.11 (dd,  $J = 7.7$  Hz, 1H, Ar-H), 6.88 (dd,  $J = 7.5$  Hz, 1H, Ar-H), 6.51–6.46 (m, 2H, Ar-H), 6.45 (s, 1H, N-CH), 5.53 (d,  $J = 8.3$  Hz, 1H, S-CH-N), 4.17 (d,  $J = 7.9$  Hz, 1H, CH), 3.69 (t,  $J = 8.1$  Hz, 1H, CH); <sup>13</sup>C NMR (101 MHz, DMSO-*d*<sub>6</sub>)  $\delta$  195.1 (C=O), 176.4 (C=O), 173.4 (C=O), 146.6, 135.3, 132.1, 131.9, 131.3, 131.1, 129.7, 129.1, 128.7, 128.5, 128.4, 127.8, 127.2, 126.7, 126.2, 125.2, 124.4, 122.6, 121.8, 110.5, 71.4 (N-C), 68.3 (S-C-N), 50.4 (CH), 48.1 (CH); IR (neat)  $\nu$  3059, 2919, 2849, 1781, 1708, 1680, 1497, 1462, 1381, 1274, 1179, 1154, 1124, 1024, 1002, 815, 746, 690 cm<sup>-1</sup>; HRMS (ESI)  $m/z$ : [M + H]<sup>+</sup> calcd for C<sub>29</sub>H<sub>21</sub>N<sub>2</sub>O<sub>3</sub>S 477.1267; found 477.1276.

*10-Benzoyl-7-chloro-2-phenyl-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4':3,4]pyrrolo[2,1-b]-thiazole-1,3(2H)-dione (3la)*: Eluent: petroleum ether/EtOAc = 4:1, white solid (42.4 mg, 92% yield);  $R_f = 0.15$  (petroleum ether/EtOAc = 3:1); m.p. 175.1–177.1 °C; <sup>1</sup>H NMR (400 MHz, DMSO-*d*<sub>6</sub>)  $\delta$  8.19 (d,  $J = 7.4$  Hz, 2H, Ar-H), 7.71 (dd,  $J = 7.4$  Hz, 1H, Ar-H), 7.61 (dd,  $J = 7.6$  Hz, 2H, Ar-H), 7.48 (d,  $J = 1.9$  Hz, 1H, Ar-H), 7.37 (dd,  $J = 5.5, 1.9$  Hz, 3H, Ar-H), 7.21 (d,  $J = 8.2$  Hz, 1H, Ar-H), 6.87 (dd,  $J = 8.2, 1.9$  Hz, 1H, Ar-H), 6.64–6.52 (m, 2H, Ar-H), 6.37 (s, 1H, N-CH), 5.59 (d,  $J = 8.3$  Hz, 1H, S-CH-N), 4.10 (d,  $J = 7.8$  Hz, 1H, CH), 3.67 (t,  $J = 8.1$  Hz, 1H, CH); <sup>13</sup>C NMR (101 MHz, DMSO-*d*<sub>6</sub>)  $\delta$  195.0 (C=O), 176.1 (C=O), 173.2 (C=O), 148.3, 133.9, 133.6, 132.0, 130.7, 129.2, 128.9, 128.8, 128.6, 126.4, 124.4, 123.4, 121.2, 110.3, 72.1 (N-C), 68.5 (S-C-N), 50.2 (CH), 48.3 (CH); IR (neat)  $\nu$  3078, 3058, 2963, 2817, 1788, 1722, 1706, 1682, 1595, 1578, 1498, 1458, 1448, 1381, 1251, 1227, 1196, 1166, 1153, 1020, 989, 867, 806, 752, 698, 691, 682 cm<sup>-1</sup>; HRMS (ESI)  $m/z$ : [M + H]<sup>+</sup> calcd for C<sub>25</sub>H<sub>18</sub>ClN<sub>2</sub>O<sub>3</sub>S 461.0721, 463.0700; found 461.0722, 463.0701.

*10-Benzoyl-2-(p-tolyl)-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4':3,4]pyrrolo[2,1-b]thiazole-1,3(2H)-dione (3ab)*: Eluent: petroleum ether/EtOAc = 4:1, white solid (40.1 mg, 91% yield);  $R_f = 0.15$  (petroleum ether/EtOAc = 6:1); m.p. 185.7–187.5 °C; <sup>1</sup>H NMR (400 MHz, DMSO-*d*<sub>6</sub>)  $\delta$  8.17 (d,  $J = 7.5$  Hz, 2H, Ar-H), 7.70 (dd,  $J = 7.3$  Hz, 1H, Ar-H), 7.59 (dd,  $J = 7.6$  Hz, 2H, Ar-H), 7.30 (d,  $J = 8.0$  Hz, 1H, Ar-H), 7.20 (d,  $J = 7.5$  Hz, 1H, Ar-H), 7.12 (d,  $J = 8.1$  Hz, 2H, Ar-H), 7.07 (dd,  $J = 7.6$  Hz, 1H, Ar-H), 6.86 (dd,  $J = 7.5$  Hz, 1H, Ar-H), 6.33 (d,  $J = 8.1$  Hz, 2H, Ar-H), 6.29 (s, 1H, N-CH), 5.46 (d,  $J = 8.3$  Hz, 1H, S-CH-N), 4.10 (d,  $J = 7.8$  Hz, 1H, CH), 3.63 (t,  $J = 8.1$  Hz, 1H, CH), 2.26 (s, 3H, CH<sub>3</sub>); <sup>13</sup>C NMR (101 MHz, DMSO-*d*<sub>6</sub>)  $\delta$  195.2 (C=O), 176.4 (C=O), 173.4 (C=O), 146.5, 138.1, 133.9, 133.8, 129.4, 129.2, 129.1, 128.8, 126.4, 126.1, 125.2, 122.6, 121.8, 110.4, 71.3 (N-C), 68.3 (S-C-N), 50.2 (CH), 47.8 (CH), 20.7 (CH<sub>3</sub>); IR (neat)  $\nu$  2999, 2954, 2920, 2849, 1777, 1698, 1686, 1675, 1514, 1459, 1449, 1395, 1309, 1253, 1238, 1224, 1170, 1157, 847, 784, 703, 682, 640, 609 cm<sup>-1</sup>; HRMS (ESI)  $m/z$ : [M + H]<sup>+</sup> calcd for C<sub>26</sub>H<sub>21</sub>N<sub>2</sub>O<sub>3</sub>S 441.1267; found 441.1273.

*10-Benzoyl-2-(4-bromophenyl)-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4':3,4]pyrrolo[2,1-b]-thiazole-1,3(2H)-dione (3ac)*: Eluent: petroleum ether/EtOAc = 4:1, white solid (45.0 mg, 89% yield);  $R_f = 0.15$  (petroleum ether/EtOAc = 6:1); m.p. 180.4–183.7 °C; <sup>1</sup>H NMR (400 MHz, DMSO-*d*<sub>6</sub>)  $\delta$  8.17 (d,  $J = 7.7$  Hz, 2H, Ar-H), 7.70 (dd,  $J = 7.3$  Hz, 1H, Ar-H), 7.59 (dd,  $J = 7.6$  Hz, 2H, Ar-H), 7.55 (d,  $J = 8.4$  Hz, 2H, Ar-H), 7.31 (d,  $J = 8.0$  Hz, 1H, Ar-H), 7.20 (d,  $J = 7.6$  Hz, 1H, Ar-H), 7.07 (dd,  $J = 7.7$  Hz, 1H, Ar-H), 6.86 (dd,  $J = 7.5$  Hz, 1H, Ar-H), 6.43 (d,  $J = 8.5$  Hz, 2H, Ar-H), 6.31 (s, 1H, N-CH), 5.45 (d,  $J = 8.4$  Hz, 1H, S-CH-N), 4.12 (d,

$J = 7.8$  Hz, 1H, CH), 3.66 (t,  $J = 8.1$  Hz, 1H, CH);  $^{13}\text{C}$  NMR (101 MHz, DMSO- $d_6$ )  $\delta$  195.1 (C=O), 176.1 (C=O), 173.1 (C=O), 146.5, 134.8, 133.9, 131.8, 131.2, 129.1, 128.8, 128.6, 126.2, 125.1, 122.6, 121.9, 121.6, 110.5, 71.4 (N-C), 68.3 (S-C-N), 50.4 (CH), 47.9 (CH); IR (neat)  $\nu$  3094, 3059, 2917, 2849, 1786, 1708, 1690, 1579, 1488, 1463, 1450, 1389, 1257, 1226, 1165, 1063, 1010, 845, 799, 738, 726, 705, 695, 634, 604  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{25}\text{H}_{18}\text{BrN}_2\text{O}_3\text{S}$  505.0216, 507.0198; found 505.0217, 507.0203.

**10-Benzoyl-2-(4-chlorophenyl)-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4']pyrrolo[2,1-b]thiazole-1,3(2H)-dione (3ad)**: Eluent: petroleum ether/EtOAc = 4:1, white solid (41.0 mg, 89% yield);  $R_f = 0.15$  (petroleum ether/EtOAc = 6:1); m.p. 182.3–185.4 °C;  $^1\text{H}$  NMR (400 MHz, DMSO- $d_6$ )  $\delta$  8.18 (d,  $J = 8.1$  Hz, 2H, Ar-H), 7.69 (dd,  $J = 7.3$  Hz, 1H, Ar-H), 7.58 (dd,  $J = 7.6$  Hz, 2H, Ar-H), 7.36 (d,  $J = 8.5$  Hz, 2H, Ar-H), 7.27 (d,  $J = 7.8$  Hz, 1H, Ar-H), 7.17 (d,  $J = 7.6$  Hz, 1H, Ar-H), 7.06 (dd,  $J = 7.7$  Hz, 1H, Ar-H), 6.86 (dd,  $J = 7.5$  Hz, 1H, Ar-H), 6.50 (d,  $J = 8.8$  Hz, 2H, Ar-H), 6.28 (s, 1H, N-CH), 5.47 (d,  $J = 8.2$  Hz, 1H, S-CH-N), 4.13 (d,  $J = 7.9$  Hz, 1H, CH), 3.68 (t,  $J = 8.1$  Hz, 1H, CH);  $^{13}\text{C}$  NMR (101 MHz, DMSO- $d_6$ )  $\delta$  194.7 (C=O), 176.0 (C=O), 173.0 (C=O), 146.3, 133.8, 133.7, 133.2, 130.6, 129.0, 128.7, 128.6, 128.1, 126.0, 125.2, 122.5, 121.8, 110.3, 71.4 (N-C), 68.2 (S-C-N), 50.3 (CH), 47.9 (CH); IR (neat)  $\nu$  3060, 2984, 2919, 2850, 1787, 1709, 1690, 1579, 1491, 1465, 1450, 1390, 1260, 1227, 1168, 1083, 1016, 735, 700, 636, 605  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{25}\text{H}_{18}\text{ClN}_2\text{O}_3\text{S}$  461.0721, 463.0700; found 461.0730, 463.0711.

**10-Benzoyl-2-(*m*-tolyl)-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4']pyrrolo[2,1-b]thiazole-1,3(2H)-dione (3ae)**: Eluent: petroleum ether/EtOAc = 4:1, white solid (41.4 mg, 94% yield);  $R_f = 0.15$  (petroleum ether/EtOAc = 6:1); m.p. 187.9–190.1 °C;  $^1\text{H}$  NMR (400 MHz, DMSO- $d_6$ )  $\delta$  8.17 (d,  $J = 7.3$  Hz, 2H, Ar-H), 7.71 (dd,  $J = 7.4$  Hz, 1H, Ar-H), 7.60 (dd,  $J = 7.6$  Hz, 2H, Ar-H), 7.31 (d,  $J = 7.9$  Hz, 1H, Ar-H), 7.21 (dd,  $J = 7.7$  Hz, 2H, Ar-H), 7.13 (d,  $J = 7.6$  Hz, 1H, Ar-H), 7.09 (dd,  $J = 8.2$  Hz, 1H, Ar-H), 6.89 (dd,  $J = 7.3$  Hz, 1H, Ar-H), 6.38 (d,  $J = 7.8$  Hz, 1H, Ar-H), 6.30 (s, 1H, Ar-H), 6.01 (s, 1H, N-CH), 5.46 (d,  $J = 8.3$  Hz, 1H, S-CH-N), 4.11 (d,  $J = 7.8$  Hz, 1H, CH), 3.63 (t,  $J = 8.1$  Hz, 1H, CH), 2.21 (s, 3H, CH<sub>3</sub>);  $^{13}\text{C}$  NMR (101 MHz, DMSO- $d_6$ )  $\delta$  195.1 (C=O), 176.4 (C=O), 173.4 (C=O), 146.6, 138.3, 133.9, 133.8, 132.0, 129.1, 128.8, 128.5, 127.1, 126.2, 125.2, 123.8, 122.6, 121.8, 110.4, 71.3 (N-C), 68.3 (S-C-N), 50.3 (CH), 47.8 (CH), 20.8 (CH<sub>3</sub>); IR (neat)  $\nu$  3059, 2963, 2919, 2850, 1785, 1708, 1685, 1596, 1579, 1490, 1460, 1446, 1383, 1256, 1231, 1224, 1186, 1168, 1130, 1028, 1016, 986, 884, 844, 768, 742, 704, 690, 630, 605, 735, 700, 636, 607  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{26}\text{H}_{21}\text{N}_2\text{O}_3\text{S}$  441.1267; found 441.1275.

**10-Benzoyl-2-(3-chlorophenyl)-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4']pyrrolo[2,1-b]thiazole-1,3(2H)-dione (3af)**: Eluent: petroleum ether/EtOAc = 4:1, white solid (40.6 mg, 88% yield);  $R_f = 0.15$  (petroleum ether/EtOAc = 6:1); m.p. 213.4–214.7 °C;  $^1\text{H}$  NMR (400 MHz, DMSO- $d_6$ )  $\delta$  8.17 (d,  $J = 7.3$  Hz, 2H, Ar-H), 7.70 (dd,  $J = 7.4$  Hz, 1H, Ar-H), 7.59 (dd,  $J = 7.6$  Hz, 2H, Ar-H), 7.45–7.36 (m, 2H, Ar-H), 7.34 (d,  $J = 8.0$  Hz, 1H, Ar-H), 7.23 (d,  $J = 6.9$  Hz, 1H, Ar-H), 7.10 (dd,  $J = 7.7$  Hz, 1H, Ar-H), 6.88 (dd,  $J = 7.5$  Hz, 1H, Ar-H), 6.57 (dt,  $J = 7.4, 1.7$  Hz, 1H, Ar-H), 6.33 (s, 1H, N-CH), 6.32–6.31 (m, 1H, Ar-H), 5.45 (d,  $J = 8.3$  Hz, 1H, S-CH-N), 4.13 (d,  $J = 7.8$  Hz, 1H, CH), 3.67 (t,  $J = 8.1$  Hz, 1H, CH);  $^{13}\text{C}$  NMR (101 MHz, DMSO- $d_6$ )  $\delta$  195.0 (C=O), 176.1 (C=O), 173.0 (C=O), 146.5, 133.9, 133.2, 132.9, 130.4, 129.1, 128.8, 128.6, 126.5, 126.2, 125.5, 125.2, 122.6, 122.0, 110.5, 71.4 (N-C), 68.3 (S-C-N), 50.4 (CH), 47.9 (CH); IR (neat)  $\nu$  3064, 2952, 2921, 2850, 1779, 1710, 1676, 1593, 1577, 1477, 1460, 1448, 1382, 1255, 1240, 1222, 1174, 1153, 979, 848, 783, 748, 740, 684, 678, 630  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{25}\text{H}_{18}\text{ClN}_2\text{O}_3\text{S}$  461.0721, 463.0700; found 461.0729, 463.0705.

**10-Benzoyl-2-(3-fluorophenyl)-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4']pyrrolo[2,1-b]thiazole-1,3(2H)-dione (3ag)**: Eluent: petroleum ether/EtOAc = 4:1, white solid (40.0 mg, 90% yield);  $R_f = 0.15$  (petroleum ether/EtOAc = 6:1); m.p. 190.7–192.1 °C;  $^1\text{H}$  NMR (400 MHz, DMSO- $d_6$ )  $\delta$  8.18 (d,  $J = 7.2$  Hz, 2H, Ar-H), 7.70 (dd,  $J = 7.4$  Hz, 1H, Ar-H), 7.60 (dd,  $J = 7.6$  Hz, 2H, Ar-H), 7.44–7.36 (m, 1H, Ar-H), 7.36–7.32 (m, 1H, Ar-H), 7.25–7.18 (m, 2H, Ar-H), 7.10 (dd,  $J = 7.2$  Hz, 1H, Ar-H), 6.88 (dd,  $J = 7.5$  Hz, 1H, Ar-H), 6.41 (d,  $J = 8.7$  Hz, 1H, Ar-H), 6.33 (s, 1H, N-CH), 6.26–6.09 (m, 1H, Ar-H), 5.46 (d,  $J = 8.3$  Hz,

1H, S-CH-N), 4.14 (d,  $J = 7.9$  Hz, 1H, CH), 3.68 (dd,  $J = 8.1$  Hz, 1H, CH);  $^{13}\text{C}$  NMR (101 MHz, DMSO- $d_6$ )  $\delta$  195.0 (C=O), 176.1 (C=O), 173.0 (C=O), 161.6 (d,  $J = 244.8$  Hz, 1C), 146.5, 133.9, 133.4 (d,  $J = 10.2$  Hz, 1C), 130.5 (d,  $J = 8.8$  Hz, 1C), 129.1, 128.8, 126.2, 125.2, 122.9 (d,  $J = 3.0$  Hz, 1C), 122.6, 121.9, 115.6 (d,  $J = 20.8$  Hz, 1C), 113.8 (d,  $J = 23.6$  Hz, 1C), 110.5, 71.4 (N-C), 68.3 (S-C-N), 50.4 (CH), 47.9 (CH); IR (neat)  $\nu$  3055, 2969, 2918, 1780, 1702, 1681, 1594, 1579, 1490, 1461, 1450, 1386, 1320, 1291, 1255, 1224, 1180, 1162, 1136, 995, 899, 787, 744, 721, 681, 606  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{25}\text{H}_{18}\text{FN}_2\text{O}_3\text{S}$  445.1017; found 445.1024.

10-Benzoyl-2-(2,6-dimethylphenyl)-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4':3,4]pyrrolo[2,1-b]thiazole-1,3(2H)-dione (**3ah**): Eluent: petroleum ether/EtOAc = 4:1, white solid (37.7 mg, 83% yield);  $R_f = 0.23$  (petroleum ether/EtOAc = 6:1); m.p. 201.3–203.1  $^\circ\text{C}$ ;  $^1\text{H}$  NMR (400 MHz, DMSO- $d_6$ )  $\delta$  8.20 (d,  $J = 7.3$  Hz, 2H, Ar-H), 7.71 (dd,  $J = 7.4$  Hz, 1H, Ar-H), 7.64–7.56 (m, 2H, Ar-H), 7.22 (d,  $J = 8.0$  Hz, 1H, Ar-H), 7.17 (d,  $J = 7.6$  Hz, 1H, Ar-H), 7.11 (dd,  $J = 7.6$  Hz, 2H, Ar-H), 7.06–6.95 (m, 2H, Ar-H), 6.78 (dd,  $J = 7.8$  Hz, 1H, Ar-H), 6.21 (s, 1H, N-CH), 5.69 (d,  $J = 8.7$  Hz, 1H, S-CH-N), 4.36 (d,  $J = 9.5$  Hz, 1H, CH), 3.90 (t,  $J = 8.6$  Hz, 1H, CH), 1.98 (s, 3H,  $\text{CH}_3$ ), 1.07 (s, 3H,  $\text{CH}_3$ );  $^{13}\text{C}$  NMR (101 MHz, DMSO- $d_6$ )  $\delta$  195.3 (C=O), 176.1 (C=O), 172.8 (C=O), 145.8, 136.0, 135.6, 134.9, 133.9, 133.8, 130.4, 129.0, 128.8, 128.1, 126.0, 125.4, 122.4, 121.4, 109.9, 70.5 (N-C), 67.6 (S-C-N), 50.3 (CH), 47.7 (CH), 17.4 ( $\text{CH}_3$ ), 15.6 ( $\text{CH}_3$ ); IR (neat)  $\nu$  3060, 2965, 2920, 1780, 1706, 1684, 1596, 1577, 1466, 1446, 1368, 1232, 1192, 1173, 1028, 772, 740, 687  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{27}\text{H}_{23}\text{N}_2\text{O}_3\text{S}$  455.1424; found 455.1427.

2-Benzhydryl-10-benzoyl-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4':3,4]pyrrolo[2,1-b]thiazole-1,3(2H)-dione (**3ai**): Eluent: petroleum ether/EtOAc = 4:1, white solid (48.0 mg, 93% yield);  $R_f = 0.33$  (petroleum ether/EtOAc = 6:1); m.p. 204.3–205.7  $^\circ\text{C}$ ;  $^1\text{H}$  NMR (400 MHz, DMSO- $d_6$ )  $\delta$  8.15 (d,  $J = 7.2$  Hz, 2H, Ar-H), 7.69 (dd,  $J = 7.4$  Hz, 1H, Ar-H), 7.63–7.53 (m, 2H, Ar-H), 7.26 (dd,  $J = 5.0, 1.8$  Hz, 3H, Ar-H), 7.18 (d,  $J = 7.3$  Hz, 1H, Ar-H), 7.14–7.07 (m, 4H, Ar-H), 7.07–7.02 (m, 1H, Ar-H), 6.95 (dd,  $J = 6.8, 2.9$  Hz, 2H, Ar-H), 6.86 (dd,  $J = 7.8$  Hz, 1H, Ar-H), 6.58 (d,  $J = 7.6$  Hz, 2H, Ar-H), 6.16 (s, 1H, N-CH), 6.07 (s, 1H, N-CHPh<sub>2</sub>), 5.64 (d,  $J = 8.6$  Hz, 1H, S-CH-N), 4.04 (d,  $J = 9.1$  Hz, 1H, CH), 3.69 (t,  $J = 8.5$  Hz, 1H, CH);  $^{13}\text{C}$  NMR (101 MHz, DMSO- $d_6$ )  $\delta$  195.2 (C=O), 176.6 (C=O), 173.7 (C=O), 145.7, 137.3, 137.2, 133.8, 133.7, 129.0, 128.8, 128.3, 128.2, 128.2, 127.7, 127.5, 127.0, 126.0, 124.8, 122.2, 121.4, 109.9, 70.7 (N-C), 67.9 (S-C-N), 58.0 (N-CHPh<sub>2</sub>), 50.0 (CH), 47.8 (CH); IR (neat)  $\nu$  3059, 2970, 2919, 1781, 1703, 1596, 1579, 1494, 1465, 1448, 1383, 1354, 1230, 1164, 1076, 1027, 743, 695, 605  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{32}\text{H}_{25}\text{N}_2\text{O}_3\text{S}$  517.1580; found 517.1586.

10-Benzoyl-2-benzyl-3a,3b,10,10a-tetrahydro-1H-benzo[d]pyrrolo[3',4':3,4]pyrrolo[2,1-b]thiazole-1,3(2H)-dione (**3aj**): Eluent: petroleum ether/EtOAc = 4:1, white solid (43.6 mg, 99% yield);  $R_f = 0.18$  (petroleum ether/EtOAc = 6:1); m.p. 179.3–182.1  $^\circ\text{C}$ ;  $^1\text{H}$  NMR (400 MHz, DMSO- $d_6$ )  $\delta$  8.17 (d,  $J = 7.3$  Hz, 2H, Ar-H), 7.70 (t,  $J = 7.4$  Hz, 1H, Ar-H), 7.59 (t,  $J = 7.6$  Hz, 2H, Ar-H), 7.18–7.05 (m, 4H, Ar-H), 7.04 (d,  $J = 7.6$  Hz, 1H, Ar-H), 6.99 (t,  $J = 7.2$  Hz, 1H, Ar-H), 6.80 (t,  $J = 7.2$  Hz, 1H, Ar-H), 6.65 (d,  $J = 7.0$  Hz, 2H, Ar-H), 6.11 (s, 1H, N-CH), 5.54 (d,  $J = 8.5$  Hz, 1H, S-CH-N), 4.38–4.16 (m, 2H,  $\text{CH}_2$ ), 4.02 (d,  $J = 8.2$  Hz, 1H, CH), 3.65 (t,  $J = 8.3$  Hz, 1H, CH);  $^{13}\text{C}$  NMR (101 MHz, DMSO- $d_6$ )  $\delta$  195.3 (C=O), 177.2 (C=O), 174.0 (C=O), 145.8, 135.2, 133.9, 133.8, 129.0, 128.8, 128.5, 126.9, 126.5, 125.9, 124.9, 122.2, 121.5, 109.8, 70.7 (N-C), 67.7 (S-C-N), 50.3 (CH), 47.8 (CH), 42.0 ( $\text{CH}_2$ ); IR (neat)  $\nu$  3061, 2970, 2922, 1781, 1700, 1595, 1579, 1465, 1448, 1428, 1395, 1340, 1227, 1164, 1154, 1026, 1001, 872, 741, 730, 694, 605  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{26}\text{H}_{21}\text{N}_2\text{O}_3\text{S}$  441.1267; found 441.1275.

### 3.3. Experimental Procedures for the Scale-Up Experiment (Scheme 4)

To a solution of benzothiazolium salt **1a** (4.5 mmol, 1.5 equiv) and *N*-phenylmaleimide **2a** (3.0 mmol, 1.0 equiv) in toluene (30 mL) was added  $\text{Na}_2\text{CO}_3$  (4.5 mmol, 1.5 equiv) successively. Then, the mixture was stirred at room temperature for 20 h. The product **3aa** (1.09 g, 85% yield) was isolated using flash chromatography on silica gel.

### 3.4. General Experimental Procedures for Synthesis of Compounds 5 (Scheme 5)

In an ordinary vial charged with a magnetic stirring bar, *N*-phenacylbenzothiazolium bromide **1a** (0.15 mmol, 1.5 equiv), **4** (0.1 mmol, 1.0 equiv), Na<sub>2</sub>CO<sub>3</sub> (0.15 mmol, 1.5 equiv), and DCM (1.0 mL) were successively added. The mixture was stirred at room temperature for 20 h. Products **5** were isolated using flash chromatography on silica gel.

*Tert*-butyl 1-benzoyl-2'-oxo-2-(trifluoromethyl)-1,2-dihydro-3aH-spiro[benzo[d]pyrrolo[2,1-b]thiazole-3,3'-indoline]-1'-carboxylate (**5aa**): Eluent: petroleum ether/EtOAc = 40:1, white solid (53.8 mg, 95% yield); *R*<sub>f</sub> = 0.33 (petroleum ether/EtOAc = 20:1); m.p. 160.7–162.2 °C; <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) δ 8.16 (d, *J* = 7.0 Hz, 2H, Ar-H), 7.95 (d, *J* = 8.2 Hz, 1H, Ar-H), 7.71 (dd, *J* = 7.4 Hz, 1H, Ar-H), 7.65–7.54 (m, 2H, Ar-H), 7.31 (dd, *J* = 7.4 Hz, 1H, Ar-H), 7.02–6.91 (m, 1H, Ar-H), 6.88–6.81 (m, 1H, Ar-H), 6.80–6.72 (m, 2H, Ar-H), 6.47 (dd, *J* = 8.0 Hz, 2H, Ar-H), 6.05 (s, 1H, N-CH-S), 5.49 (d, *J* = 9.7 Hz, 1H, N-CH), 4.45–4.26 (m, 1H, CF<sub>3</sub>-CH), 1.66 (s, 9H, C(CH<sub>3</sub>)<sub>3</sub>); <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>) δ 197.0 (C=O), 171.9 (C=O), 148.6, 147.1, 140.3, 135.4, 134.5, 129.7, 129.4, 128.7, 126.9, 126.1, 125.8, 124.5 (q, *J* = 278.9 Hz, 1C, CF<sub>3</sub>), 123.8, 122.7, 121.9, 121.8, 115.3, 108.9, 85.4 (C<sub>Boc</sub>), 81.0 (N-C-S), 66.2 (N-C), 62.2 (C-CONBoc), 54.7 (q, *J* = 28.5 Hz, 1C, CF<sub>3</sub>-C), 28.1 ((CH<sub>3</sub>)<sub>3</sub>); IR (neat) *ν* 3059, 2982, 2971, 2934, 1756, 1731, 1692, 1578, 1473, 1467, 1448, 1396, 1369, 1299, 1273, 1253, 1210, 1173, 1146, 1117, 1081, 972, 840, 759, 745, 699, 654 cm<sup>-1</sup>; HRMS (ESI) *m/z*: [M + H]<sup>+</sup> calcd for C<sub>30</sub>H<sub>26</sub>F<sub>3</sub>N<sub>2</sub>O<sub>4</sub>S 567.1560; found 567.1565.

*Tert*-butyl 1-benzoyl-6'-fluoro-2'-oxo-2-(trifluoromethyl)-1,2-dihydro-3aH-spiro[benzo[d]pyrrolo[2,1-b]thiazole-3,3'-indoline]-1'-carboxylate (**5ab**): Eluent: petroleum ether/EtOAc = 40:1, white solid (40.9 mg, 70% yield); *R*<sub>f</sub> = 0.37 (petroleum ether/EtOAc = 20:1); m.p. 173.2–174.8 °C; <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) δ 8.14 (d, *J* = 7.3 Hz, 2H, Ar-H), 7.79–7.67 (m, 2H, Ar-H), 7.66–7.52 (m, 2H, Ar-H), 7.06–6.89 (m, 1H, Ar-H), 6.87–6.70 (m, 2H, Ar-H), 6.58–6.50 (m, 1H, Ar-H), 6.48 (d, *J* = 7.9 Hz, 1H, Ar-H), 6.41–6.26 (m, 1H, Ar-H), 5.98 (s, 1H, N-CH-S), 5.46 (d, *J* = 9.5 Hz, 1H, N-CH), 4.47–4.22 (m, 1H, CF<sub>3</sub>-CH), 1.66 (s, 9H, C(CH<sub>3</sub>)<sub>3</sub>); <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) δ 196.7 (C=O), 171.9 (C=O), 163.3 (d, *J* = 247.1 Hz, 1C), 148.4, 147.1, 141.7 (d, *J* = 12.5 Hz, 1C), 135.5, 134.5, 129.4, 128.8, 127.0 (d, *J* = 9.8 Hz, 1C), 126.8, 126.3, 124.6 (q, *J* = 278.9 Hz, 1C, CF<sub>3</sub>), 122.1, 122.0, 118.2 (d, *J* = 3.4 Hz, 1C), 110.7 (d, *J* = 22.7 Hz, 1C), 109.0, 104.2 (d, *J* = 29.8 Hz, 1C), 85.9 (C<sub>Boc</sub>), 81.0 (N-C-S), 66.1 (N-C), 62.0 (C-CONBoc), 54.5 (q, *J* = 28.5 Hz, 1C, CF<sub>3</sub>-C), 28.2 ((CH<sub>3</sub>)<sub>3</sub>); IR (neat) *ν* 3058, 2987, 2971, 2935, 1762, 1731, 1692, 1606, 1597, 1579, 1497, 1473, 1447, 1396, 1368, 1359, 1326, 1299, 1270, 1257, 1237, 1209, 1179, 1145, 1128, 1112, 1083, 1031, 889, 861, 848, 813, 755, 746 cm<sup>-1</sup>; HRMS (ESI) *m/z*: [M + H]<sup>+</sup> calcd for C<sub>30</sub>H<sub>25</sub>F<sub>4</sub>N<sub>2</sub>O<sub>4</sub>S 585.1466; found 585.1474.

*Tert*-butyl 1-benzoyl-6'-chloro-2'-oxo-2-(trifluoromethyl)-1,2-dihydro-3aH-spiro[benzo[d]pyrrolo[2,1-b]thiazole-3,3'-indoline]-1'-carboxylate (**5ac**): Eluent: petroleum ether/EtOAc = 40:1, white solid (45.1 mg, 75% yield); *R*<sub>f</sub> = 0.37 (petroleum ether/EtOAc = 20:1); m.p. 165.4–167.0 °C; <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) δ 8.14 (d, *J* = 7.2 Hz, 2H, Ar-H), 8.02 (d, *J* = 2.0 Hz, 1H, Ar-H), 7.72 (dd, *J* = 7.4 Hz, 1H, Ar-H), 7.65–7.53 (m, 2H, Ar-H), 7.06–6.90 (m, 1H, Ar-H), 6.87–6.69 (m, 3H, Ar-H), 6.48 (d, *J* = 8.0 Hz, 1H, Ar-H), 6.31 (d, *J* = 8.2 Hz, 1H, Ar-H), 5.98 (s, 1H, N-CH-S), 5.46 (d, *J* = 9.5 Hz, 1H, N-CH), 4.48–4.21 (m, 1H, CF<sub>3</sub>-CH), 1.66 (s, 9H, C(CH<sub>3</sub>)<sub>3</sub>); <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>) δ 196.7 (C=O), 171.6 (C=O), 148.4, 147.0, 141.4, 135.7, 135.5, 134.5, 129.4, 128.8, 126.7, 126.6, 126.3, 124.6 (d, *J* = 279.0 Hz, 1C, CF<sub>3</sub>), 123.9, 122.1, 122.0, 121.2, 116.2, 109.0, 85.9 (C<sub>Boc</sub>), 81.0 (N-C-S), 66.1 (N-C), 62.2 (C-CONBoc), 54.6 (q, *J* = 28.6 Hz, 1C, CF<sub>3</sub>-C), 28.2 ((CH<sub>3</sub>)<sub>3</sub>); IR (neat) *ν* 2981, 2936, 1764, 1735, 1687, 1604, 1596, 1581, 1483, 1469, 1448, 1426, 1396, 1367, 1354, 1321, 1275, 1238, 1210, 1182, 1165, 1142, 1125, 1086, 1081, 1011, 971, 747, 740 cm<sup>-1</sup>; HRMS (ESI) *m/z*: [M + H]<sup>+</sup> calcd for C<sub>30</sub>H<sub>25</sub>ClF<sub>3</sub>N<sub>2</sub>O<sub>4</sub>S 601.1170, 603.1153; found 601.1178, 603.1164.

*Tert*-butyl 1-benzoyl-6'-bromo-2'-oxo-2-(trifluoromethyl)-1,2-dihydro-3aH-spiro[benzo[d]pyrrolo[2,1-b]thiazole-3,3'-indoline]-1'-carboxylate (**5ad**): Eluent: petroleum ether/EtOAc = 40:1, white solid (51.6 mg, 80% yield); *R*<sub>f</sub> = 0.37 (petroleum ether/EtOAc = 20:1); m.p. 179.7–181.6 °C; <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>) δ 8.18 (d, *J* = 1.8 Hz, 1H, Ar-H), 8.14 (d, *J* = 7.1 Hz, 2H, Ar-H), 7.71 (dd, *J* = 7.3 Hz, 1H, Ar-H), 7.65–7.54 (m, 2H, Ar-H), 7.06–6.91 (m, 2H, Ar-H), 6.87–6.70

(m, 2H, Ar-H), 6.48 (d,  $J = 7.9$  Hz, 1H, Ar-H), 6.25 (d,  $J = 8.2$  Hz, 1H, Ar-H), 5.98 (s, 1H, N-CH-S), 5.46 (d,  $J = 9.4$  Hz, 1H, N-CH), 4.49–4.20 (m, 1H, CF<sub>3</sub>-CH), 1.66 (s, 9H, C(CH<sub>3</sub>)<sub>3</sub>); <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>)  $\delta$  196.6 (C=O), 171.5 (C=O), 148.4, 147.0, 141.5, 135.5, 134.5, 129.4, 128.7, 126.9, 126.8, 126.7, 126.3, 124.6 (q,  $J = 279.2$  Hz, 1C, CF<sub>3</sub>), 123.6, 122.1, 122.0, 121.7, 118.9, 108.9, 85.9 (C<sub>Boc</sub>), 80.9 (N-C-S), 66.0 (N-C), 62.2 (C-CONBoc), 54.5 (q,  $J = 28.6$  Hz, 1C, CF<sub>3</sub>-C), 28.1 ((CH<sub>3</sub>)<sub>3</sub>); IR (neat)  $\nu$  2981, 2935, 1764, 1733, 1686, 1598, 1580, 1468, 1448, 1396, 1367, 1353, 1319, 1274, 1237, 1209, 1181, 1165, 1142, 1126, 1089, 1029, 1010, 972, 871, 833, 798, 765, 748, 740, 653 cm<sup>-1</sup>; HRMS (ESI)  $m/z$ : [M + H]<sup>+</sup> calcd for C<sub>30</sub>H<sub>25</sub>BrF<sub>3</sub>N<sub>2</sub>O<sub>4</sub>S 645.0665, 647.0649; found 645.0672, 647.0655.

*Tert-butyl 1-benzoyl-5'-fluoro-2'-oxo-2-(trifluoromethyl)-1,2-dihydro-3aH-spiro[benzo[d]pyrrolo[2,1-b]thiazole-3,3'-indoline]-1'-carboxylate (5ae)*: Eluent: petroleum ether/EtOAc = 40:1, white solid (42.7 mg, 73% yield);  $R_f = 0.37$  (petroleum ether/EtOAc = 20:1); m.p. 150.7–152.5 °C; <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>)  $\delta$  8.16 (d,  $J = 7.2$  Hz, 2H, Ar-H), 7.94 (dd,  $J = 9.1, 4.7$  Hz, 1H, Ar-H), 7.72 (dd,  $J = 7.4$  Hz, 1H, Ar-H), 7.67–7.53 (m, 2H, Ar-H), 7.07–6.94 (m, 2H, Ar-H), 6.87–6.73 (m, 2H, Ar-H), 6.51 (d,  $J = 7.8$  Hz, 1H, Ar-H), 6.11 (d,  $J = 6.9$  Hz, 1H, Ar-H), 5.99 (s, 1H, N-CH-S), 5.49 (d,  $J = 9.4$  Hz, 1H, N-CH), 4.53–4.15 (m, 1H, CF<sub>3</sub>-CH), 1.65 (s, 9H, C(CH<sub>3</sub>)<sub>3</sub>); <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>)  $\delta$  196.6 (C=O), 171.5 (C=O), 159.1 (d,  $J = 243.6$  Hz, 1C), 148.6, 146.9, 136.5 (d,  $J = 2.5$  Hz, 1C), 135.5, 134.5, 129.4, 128.8, 126.5 (d,  $J = 16.4$  Hz, 1C), 126.4, 124.6 (q,  $J = 278.9$  Hz, 1C, CF<sub>3</sub>), 124.5 (d,  $J = 8.7$  Hz, 1C), 122.2, 122.0, 116.6, 116.4 (d,  $J = 13.6$  Hz, 1C), 113.5 (d,  $J = 26.1$  Hz, 1C), 109.0, 85.6 (C<sub>Boc</sub>), 80.9 (N-C-S), 65.8 (N-C), 62.6 (C-CONBoc), 54.5 (q,  $J = 28.6$  Hz, 1C, CF<sub>3</sub>-C), 28.2 ((CH<sub>3</sub>)<sub>3</sub>); IR (neat)  $\nu$  3058, 2983, 2936, 1798, 1761, 1741, 1735, 1690, 1607, 1594, 1579, 1481, 1471, 1450, 1396, 1371, 1343, 1324, 1295, 1272, 1242, 1212, 1172, 1145, 1125, 1084, 999, 819, 747, 732, 641 cm<sup>-1</sup>; HRMS (ESI)  $m/z$ : [M + H]<sup>+</sup> calcd for C<sub>30</sub>H<sub>25</sub>F<sub>4</sub>N<sub>2</sub>O<sub>4</sub>S 585.1466; found 585.1470.

*Tert-butyl 1-benzoyl-7'-methyl-2'-oxo-2-(trifluoromethyl)-1,2-dihydro-3aH-spiro[benzo[d]pyrrolo[2,1-b]thiazole-3,3'-indoline]-1'-carboxylate (5af)*: Eluent: petroleum ether/EtOAc = 40:1, white solid (40.6 mg, 70% yield);  $R_f = 0.37$  (petroleum ether/EtOAc = 20:1); m.p. 167.8–170.2 °C; <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  8.16 (d,  $J = 7.8$  Hz, 2H, Ar-H), 7.71 (dd,  $J = 7.3$  Hz, 1H, Ar-H), 7.65–7.56 (m, 2H, Ar-H), 7.12 (d,  $J = 7.7$  Hz, 1H, Ar-H), 6.95 (dd,  $J = 7.5$  Hz, 1H, Ar-H), 6.83–6.69 (m, 3H, Ar-H), 6.44 (d,  $J = 7.8$  Hz, 1H, Ar-H), 6.31 (d,  $J = 7.6$  Hz, 1H, Ar-H), 6.06 (s, 1H, N-CH-S), 5.46 (d,  $J = 9.8$  Hz, 1H, N-CH), 4.41–4.22 (m, 1H, CF<sub>3</sub>-CH), 2.26 (s, 3H, CH<sub>3</sub>), 1.64 (s, 9H, C(CH<sub>3</sub>)<sub>3</sub>); <sup>13</sup>C NMR (101 MHz, CDCl<sub>3</sub>)  $\delta$  197.2 (C=O), 172.9 (C=O), 148.5, 147.1, 138.9, 135.5, 134.5, 132.7, 129.4, 128.8, 127.2, 126.0, 124.5 (q,  $J = 279.3$  Hz, 1C, CF<sub>3</sub>), 124.0, 123.8, 123.5, 121.9, 121.8, 109.0, 85.7 (C<sub>Boc</sub>), 80.5 (N-C-S), 66.3 (N-C), 62.2 (C-CONBoc), 55.1 (q,  $J = 28.6$  Hz, 1C, CF<sub>3</sub>-C), 27.9 ((CH<sub>3</sub>)<sub>3</sub>), 19.8 (CH<sub>3</sub>); IR (neat)  $\nu$  3056, 3011, 2984, 2965, 2923, 1735, 1697, 1596, 1577, 1473, 1448, 1396, 1368, 1353, 1296, 1272, 1248, 1203, 1177, 1144, 1116, 1033, 999, 971, 843, 781, 756, 744, 696 cm<sup>-1</sup>; HRMS (ESI)  $m/z$ : [M + H]<sup>+</sup> calcd for C<sub>31</sub>H<sub>28</sub>F<sub>3</sub>N<sub>2</sub>O<sub>4</sub>S 581.1716; found 581.1721.

*Tert-butyl 1-benzoyl-5',7'-dimethyl-2'-oxo-2-(trifluoromethyl)-1,2-dihydro-3aH-spiro[benzo[d]pyrrolo[2,1-b]thiazole-3,3'-indoline]-1'-carboxylate (5ag)*: Eluent: petroleum ether/EtOAc = 40:1, white solid (46.4 mg, 78% yield);  $R_f = 0.37$  (petroleum ether/EtOAc = 20:1); m.p. 168.7–170.7 °C; <sup>1</sup>H NMR (300 MHz, CDCl<sub>3</sub>)  $\delta$  8.17 (d,  $J = 7.2$  Hz, 2H, Ar-H), 7.71 (dd,  $J = 7.4$  Hz, 1H, Ar-H), 7.65–7.54 (m, 2H, Ar-H), 7.03–6.94 (m, 1H, Ar-H), 6.91 (s, 1H, Ar-H), 6.84–6.69 (m, 2H, Ar-H), 6.49 (d,  $J = 7.8$  Hz, 1H, Ar-H), 6.00 (s, 2H, Ar-H, N-CH-S), 5.46 (d,  $J = 9.6$  Hz, 1H, N-CH), 4.42–4.18 (m, 1H, CF<sub>3</sub>-CH), 2.21 (s, 3H, CH<sub>3</sub>), 1.93 (s, 3H, CH<sub>3</sub>), 1.63 (s, 9H, C(CH<sub>3</sub>)<sub>3</sub>); <sup>13</sup>C NMR (75 MHz, CDCl<sub>3</sub>)  $\delta$  197.1 (C=O), 173.1 (C=O), 148.6, 147.5, 136.6, 135.6, 134.4, 133.3, 133.2, 129.4, 128.8, 127.3, 126.0, 124.6 (q,  $J = 279.1$  Hz, 1C, CF<sub>3</sub>), 124.6, 124.0, 123.6, 121.8, 121.7, 108.9, 85.4 (C<sub>Boc</sub>), 80.6 (N-C-S), 66.5 (N-C), 62.5 (C-CONBoc), 54.6 (q,  $J = 28.4$  Hz, 1C, CF<sub>3</sub>-C), 27.99 ((CH<sub>3</sub>)<sub>3</sub>), 20.8 (CH<sub>3</sub>), 19.7 (CH<sub>3</sub>); IR (neat)  $\nu$  3072, 2983, 2930, 1754, 1727, 1696, 1596, 1578, 1466, 1446, 1401, 1371, 1324, 1272, 1262, 1251, 1219, 1179, 1146, 1124, 1000, 971, 838, 827, 747, 696, 642 cm<sup>-1</sup>; HRMS (ESI)  $m/z$ : [M + H]<sup>+</sup> calcd for C<sub>32</sub>H<sub>30</sub>F<sub>3</sub>N<sub>2</sub>O<sub>4</sub>S 595.1873; found 595.1876.

*1-Benzoyl-2-(trifluoromethyl)-1,2-dihydro-3aH-spiro[benzo[d]pyrrolo[2,1-b]thiazole-3,3'-indolin]-2'-one (5ah)*: Eluent: petroleum ether/EtOAc = 4:1, white solid (42.0 mg, 90% yield);  $R_f$  = 0.20 (petroleum ether/EtOAc = 6:1); m.p. 158.7–161.7 °C;  $^1\text{H NMR}$  (300 MHz,  $\text{CDCl}_3$ )  $\delta$  9.41 (s, 1H, NH), 8.20 (d,  $J$  = 7.4 Hz, 2H, Ar-H), 7.72 (dd,  $J$  = 7.3 Hz, 1H, Ar-H), 7.66–7.53 (m, 2H, Ar-H), 7.24 (dd,  $J$  = 7.7 Hz, 1H, Ar-H), 7.10–6.90 (m, 2H, Ar-H), 6.87–6.65 (m, 3H, Ar-H), 6.51 (d,  $J$  = 7.8 Hz, 1H, Ar-H), 6.41 (d,  $J$  = 7.6 Hz, 1H, Ar-H), 6.02 (s, 1H, N-CH-S), 5.56 (d,  $J$  = 9.4 Hz, 1H, N-CH), 4.49–4.21 (m, 1H,  $\text{CF}_3$ -CH);  $^{13}\text{C NMR}$  (75 MHz,  $\text{CDCl}_3$ )  $\delta$  197.3 (C=O), 175.3 (C=O), 147.3, 141.4, 135.6, 134.4, 129.5, 129.4, 128.8, 127.0, 126.4, 126.0, 124.8 (q,  $J$  = 279.0 Hz, 1C,  $\text{CF}_3$ ), 124.2, 122.0, 121.9, 121.8, 110.7, 109.0, 80.1 (N-C-S), 66.1 (N-C), 62.2 (C-CONH), 53.7 (q,  $J$  = 28.6 Hz, 1C,  $\text{CF}_3$ -C); IR (neat)  $\nu$  3205, 3098, 3063, 2959, 2929, 1716, 1680, 1618, 1580, 1467, 1395, 1272, 1237, 1213, 1204, 1170, 1125, 1110, 1072, 1027, 1013, 964, 743, 738, 734, 698, 683  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{25}\text{H}_{18}\text{F}_3\text{N}_2\text{O}_2\text{S}$  467.1036; found 467.1038.

*1'-Benzoyl-2'-(trifluoromethyl)-1',2'-dihydro-2H,3a'H-spiro[benzofuran-3,3'-benzo[d]pyrrolo[2,1-b]thiazol]-2-one (5ai)*: Eluent: petroleum ether/EtOAc = 40:1, white solid (39.7 mg, 85% yield);  $R_f$  = 0.37 (petroleum ether/EtOAc = 20:1); m.p. 171.9–173.8 °C;  $^1\text{H NMR}$  (300 MHz,  $\text{CDCl}_3$ )  $\delta$  8.16 (d,  $J$  = 7.4 Hz, 2H, Ar-H), 7.73 (dd,  $J$  = 7.4 Hz, 1H, Ar-H), 7.67–7.54 (m, 2H, Ar-H), 7.32 (dd,  $J$  = 7.9 Hz, 1H, Ar-H), 7.16 (d,  $J$  = 8.1 Hz, 1H, Ar-H), 7.08–6.94 (m, 1H, Ar-H), 6.90–6.74 (m, 3H, Ar-H), 6.54 (d,  $J$  = 7.8 Hz, 1H, Ar-H), 6.34 (d,  $J$  = 7.7 Hz, 1H, Ar-H), 5.99 (s, 1H, N-CH-S), 5.54 (d,  $J$  = 9.1 Hz, 1H, N-CH), 4.51–4.26 (m, 1H,  $\text{CF}_3$ -CH);  $^{13}\text{C NMR}$  (75 MHz,  $\text{CDCl}_3$ )  $\delta$  196.3 (C=O), 173.6 (C=O), 153.8, 146.8, 135.5, 134.6, 130.6, 129.5, 128.8, 126.4, 126.3, 124.5 (q,  $J$  = 278.9 Hz, 1C), 123.8, 122.3, 122.1, 122.0, 111.3, 109.1, 80.7 (N-C-S), 65.6 (N-C), 60.8 (C-CO<sub>2</sub>), 54.4 (q,  $J$  = 28.6 Hz, 1C,  $\text{CF}_3$ -C); IR (neat)  $\nu$  3080, 3056, 2960, 2938, 1796, 1685, 1620, 1592, 1469, 1446, 1397, 1356, 1346, 1275, 1255, 1228, 1207, 1166, 1155, 1139, 1126, 1093, 977, 811, 752, 740, 693, 688, 652  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{25}\text{H}_{17}\text{F}_3\text{NO}_3\text{S}$  468.0876; found 468.0891.

### 3.5. General Experimental Procedures for Synthesis of Compounds 7 (Scheme 6)

In an ordinary vial charged with a magnetic stirring bar, *N*-phenacylbenzothiazolium bromide **1a** (0.15 mmol, 1.5 equiv), 2-benzylidenemalononitrile **6a–h** (0.1 mmol, 1.0 equiv), TEA (0.15 mmol, 1.5 equiv), and DEM (1.0 mL) were added. The mixture was then stirred at room temperature for 3 h. Products **7** were isolated with flash chromatography on silica gel.

*1-Benzoyl-2-phenyl-1,2-dihydrobenzo[d]pyrrolo[2,1-b]thiazole-3,3(3aH)-dicarbonitrile (7aa)*: Eluent: petroleum ether/DCM = 1:2, white solid (38.7 mg, 95% yield);  $R_f$  = 0.17 (petroleum ether/EtOAc = 6:1); m.p. 80.5–82.4 °C;  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.94–7.87 (m, 2H, Ar-H), 7.65–7.58 (m, 1H, Ar-H), 7.55–7.49 (m, 2H, Ar-H), 7.48–7.43 (m, 2H, Ar-H), 7.43–7.39 (m, 3H, Ar-H), 7.24–7.16 (m, 1H, Ar-H), 7.10–6.99 (m, 1H, Ar-H), 6.97–6.86 (m, 1H, Ar-H), 6.48 (d,  $J$  = 7.7 Hz, 1H, Ar-H), 6.07 (s, 1H, N-CH-S), 5.59 (d,  $J$  = 9.3 Hz, 1H, N-CH), 4.36 (d,  $J$  = 9.3 Hz, 1H, CH);  $^{13}\text{C NMR}$  (101 MHz,  $\text{CDCl}_3$ )  $\delta$  196.9 (C=O), 146.3, 135.1, 134.7, 130.4, 130.1, 129.7, 129.3, 128.9, 128.8, 126.7, 124.8, 122.9, 122.6, 112.3, 111.0, 109.8, 79.5 (N-C-S), 69.2 (N-C), 58.0 (C), 51.0 (CH); IR (neat)  $\nu$  3066, 2935, 2839, 2221, 1730, 1696, 1671, 1663, 1603, 1577, 1511, 1469, 1447, 1308, 1254, 1223, 1177, 1021, 832, 750, 688, 612  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{25}\text{H}_{18}\text{N}_3\text{OS}$  408.1165; found 408.1170.

*1-Benzoyl-2-(*p*-tolyl)-1,2-dihydrobenzo[d]pyrrolo[2,1-b]thiazole-3,3(3aH)-dicarbonitrile (7ab)*: Eluent: petroleum ether/DCM = 1:2, white solid (36.7 mg, 87% yield);  $R_f$  = 0.23 (petroleum ether/EtOAc = 6:1); m.p. 82.7–84.6 °C;  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.91 (d,  $J$  = 7.7 Hz, 2H, Ar-H), 7.65–7.59 (m, 1H, Ar-H), 7.49–7.43 (m, 2H, Ar-H), 7.42–7.38 (m, 2H, Ar-H), 7.23–7.17 (m, 3H, Ar-H), 7.02 (dd,  $J$  = 7.6 Hz, 1H, Ar-H), 6.91 (dd,  $J$  = 7.4 Hz, 1H, Ar-H), 6.46 (d,  $J$  = 7.7 Hz, 1H, Ar-H), 6.06 (s, 1H, N-CH-S), 5.56 (d,  $J$  = 9.4 Hz, 1H, N-CH), 4.33 (d,  $J$  = 9.3 Hz, 1H, CH), 2.34 (s, 3H,  $\text{CH}_3$ );  $^{13}\text{C NMR}$  (101 MHz,  $\text{CDCl}_3$ )  $\delta$  197.1 (C=O), 146.3, 140.5, 135.2, 134.7, 130.3, 129.3, 128.8, 128.7, 126.9, 126.7, 124.8, 122.8, 122.6, 112.4, 111.1, 109.8, 79.4 (N-C-S), 69.1 (N-C), 57.9 (C), 51.2 (CH), 21.3 ( $\text{CH}_3$ ); IR (neat)  $\nu$  3066, 2926, 2224, 2210, 1733, 1669, 1581, 1469, 1448, 1341, 1301, 1222, 1178, 1093, 1014, 828, 748, 686  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{26}\text{H}_{20}\text{N}_3\text{OS}$  422.1322; found 422.1326.

*1-Benzoyl-2-(4-methoxyphenyl)-1,2-dihydrobenzo[d]pyrrolo[2,1-b]thiazole-3,3(3aH)-dicarbonitrile (7ac)*: Eluent: petroleum ether/DCM = 1:2, white solid (41.1 mg, 94% yield);  $R_f$  = 0.23 (petroleum ether/EtOAc = 6:1); m.p. 86.3–87.9 °C;  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.90 (d,  $J$  = 7.6 Hz, 2H, Ar-H), 7.64–7.59 (m, 1H, Ar-H), 7.49–7.41 (m, 4H, Ar-H), 7.19 (d,  $J$  = 7.6 Hz, 1H, Ar-H), 7.05–6.98 (m, 1H, Ar-H), 6.94–6.88 (m, 3H, Ar-H), 6.44 (d,  $J$  = 7.9 Hz, 1H, Ar-H), 6.05 (s, 1H, N-CH-S), 5.52 (d,  $J$  = 9.2 Hz, 1H, N-CH), 4.30 (d,  $J$  = 9.5 Hz, 1H, CH), 3.79 (s, 3H,  $\text{OCH}_3$ );  $^{13}\text{C NMR}$  (101 MHz,  $\text{CDCl}_3$ )  $\delta$  197.2 (C=O), 161.1, 146.4, 135.2, 134.7, 130.2, 129.3, 128.8, 126.7, 124.9, 122.8, 122.6, 121.6, 115.0, 112.4, 111.2, 109.8, 79.3 (N-C-S), 69.3 (N-C), 57.8 (C), 55.5 ( $\text{OCH}_3$ ), 51.2 (CH); IR (neat)  $\nu$  3065, 2926, 2227, 2207, 1734, 1669, 1593, 1581, 1513, 1489, 1469, 1448, 1344, 1302, 1254, 1222, 1178, 1073, 1010, 822, 747, 687, 660  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{26}\text{H}_{20}\text{N}_3\text{O}_2\text{S}$  438.1271; found 438.1274.

*1-Benzoyl-2-(m-tolyl)-1,2-dihydrobenzo[d]pyrrolo[2,1-b]thiazole-3,3(3aH)-dicarbonitrile (7ad)*: Eluent: petroleum ether/DCM = 1:2, white solid (37.5 mg, 89% yield);  $R_f$  = 0.32 (petroleum ether/EtOAc = 6:1); m.p. 101.3–102.8 °C;  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.92–7.88 (m, 2H, Ar-H), 7.64–7.58 (m, 1H, Ar-H), 7.49–7.43 (m, 2H, Ar-H), 7.36–7.32 (m, 1H, Ar-H), 7.32–7.26 (m, 2H, Ar-H), 7.22–7.18 (m, 2H, Ar-H), 7.03 (td,  $J$  = 7.7, 1.3 Hz, 1H, Ar-H), 6.92 (td,  $J$  = 7.6, 1.1 Hz, 1H, Ar-H), 6.46 (d,  $J$  = 7.8 Hz, 1H, Ar-H), 6.06 (s, 1H, N-CH-S), 5.56 (d,  $J$  = 9.4 Hz, 1H, N-CH), 4.31 (d,  $J$  = 9.4 Hz, 1H, CH), 2.33 (s, 3H,  $\text{CH}_3$ );  $^{13}\text{C NMR}$  (101 MHz,  $\text{CDCl}_3$ )  $\delta$  197.1 (C=O), 146.3, 139.6, 135.2, 134.7, 131.2, 130.0, 129.9, 129.5, 129.3, 128.8, 126.7, 125.6, 124.9, 122.9, 122.6, 112.4, 111.1, 109.8, 79.5 (N-C-S), 69.2 (N-C), 58.0 (C), 51.0 (CH), 21.5 ( $\text{CH}_3$ ); IR (neat)  $\nu$  3064, 2955, 2920, 2850, 2228, 2214, 1682, 1579, 1465, 1448, 1296, 1245, 1224, 1210, 1180, 1027, 1001, 964, 737, 705, 686, 660  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{26}\text{H}_{20}\text{N}_3\text{OS}$  422.1322; found 422.1325.

*1-Benzoyl-2-(3,4-dimethylphenyl)-1,2-dihydrobenzo[d]pyrrolo[2,1-b]thiazole-3,3(3aH)-dicarbonitrile (7ae)*: Eluent: petroleum ether/DCM = 1:2, white solid (42.2 mg, 97% yield);  $R_f$  = 0.26 (petroleum ether/EtOAc = 6:1); m.p. 88.5–90.4 °C;  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.94–7.90 (m, 2H, Ar-H), 7.64–7.59 (m, 1H, Ar-H), 7.49–7.44 (m, 2H, Ar-H), 7.29–7.26 (m, 1H, Ar-H), 7.21–7.17 (m, 2H, Ar-H), 7.17–7.14 (m, 1H, Ar-H), 7.02 (td,  $J$  = 7.7, 1.3 Hz, 1H, Ar-H), 6.91 (td,  $J$  = 7.6, 1.1 Hz, 1H, Ar-H), 6.46 (d,  $J$  = 7.7 Hz, 1H, Ar-H), 6.05 (s, 1H, N-CH-S), 5.55 (d,  $J$  = 9.5 Hz, 1H, N-CH), 4.30 (d,  $J$  = 9.5 Hz, 1H, CH), 2.23 (s, 6H, ( $\text{CH}_3$ )<sub>2</sub>);  $^{13}\text{C NMR}$  (101 MHz,  $\text{CDCl}_3$ )  $\delta$  197.2 (C=O), 146.4, 139.2, 138.1, 135.3, 134.6, 130.8, 130.3, 129.2, 128.8, 127.2, 126.7, 125.8, 124.9, 122.8, 122.6, 112.5, 111.1, 109.8, 79.4 (N-C-S), 69.1 (N-C), 57.9 (C), 51.2 (CH), 19.9 ( $\text{CH}_3$ ), 19.7 ( $\text{CH}_3$ ); IR (neat)  $\nu$  3066, 3037, 2934, 2231, 2205, 1738, 1671, 1593, 1582, 1469, 1448, 1303, 1219, 1179, 1135, 1031, 824, 747, 686  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{27}\text{H}_{22}\text{N}_3\text{OS}$  436.1478; found 436.1472.

*1-Benzoyl-2-(naphthalen-2-yl)-1,2-dihydrobenzo[d]pyrrolo[2,1-b]thiazole-3,3(3aH)-dicarbonitrile (7af)*: Eluent: petroleum ether/DCM = 1:2, white solid (41.6 mg, 91% yield);  $R_f$  = 0.36 (petroleum ether/EtOAc = 6:1); m.p. 125.1–126.4 °C;  $^1\text{H NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.79–7.76 (m, 2H, Ar-H), 7.72–7.68 (m, 1H, Ar-H), 7.55–7.51 (m, 1H, Ar-H), 7.39–7.35 (m, 2H, Ar-H), 7.35–7.30 (m, 3H, Ar-H), 7.30–7.22 (m, 2H, Ar-H), 7.21–7.13 (m, 2H, Ar-H), 7.00 (td,  $J$  = 7.7, 1.2 Hz, 1H, Ar-H), 6.88 (td,  $J$  = 7.6, 1.1 Hz, 1H, Ar-H), 6.46 (d,  $J$  = 7.9 Hz, 1H, Ar-H), 6.01 (s, 1H, N-CH-S), 5.42 (d,  $J$  = 9.0 Hz, 1H, N-CH), 5.20 (d,  $J$  = 8.9 Hz, 1H, CH);  $^{13}\text{C NMR}$  (101 MHz,  $\text{CDCl}_3$ )  $\delta$  196.2 (C=O), 145.9, 136.1, 135.0, 134.6, 131.2, 130.8, 129.2, 129.1, 128.8, 128.7, 127.9, 126.8, 124.9, 123.1, 122.9, 112.0, 111.2, 109.7, 79.9 (N-C-S), 70.5 (N-C), 51.8 (C), 49.8 (CH); IR (neat)  $\nu$  3072, 2919, 2850, 2207, 1732, 1675, 1589, 1579, 1466, 1444, 1293, 1250, 1216, 1201, 1181, 1032, 855, 746, 703, 687  $\text{cm}^{-1}$ ; HRMS (ESI)  $m/z$ :  $[\text{M} + \text{H}]^+$  calcd for  $\text{C}_{29}\text{H}_{20}\text{N}_3\text{OS}$  458.1322; found 458.1330.

#### 4. Conclusions

In summary, we developed an efficient strategy for the [3 + 2] cycloaddition reactions of heteroaromatic *N*-ylides with different electron-deficient olefins for the diverse synthesis of fused polyheterocyclic compounds under mild reaction conditions. With the *N*-phenacylbenzothiazolium bromides as the heteroaromatic *N*-ylides precursors, the heteroaromatic *N*-ylides can smoothly react with maleimides to give fused polycyclic

octahydropyrrolo[3,4-*c*]pyrroles in moderate to excellent isolated yields (52–99%). Moreover, this [3 + 2] cycloaddition concept could also be extended to 3-trifluoroethylidene oxindoles and benzylidenemalononitriles as electron-deficient olefins, affording a series of structurally diverse functionalized polyheterocyclic compounds in good to excellent yields (70–97%). Further studies about exploring benzothiazolium salts to synthesize other new structurally unique *N,S*-polyheterocycle compounds are currently underway in our laboratory.

**Supplementary Materials:** The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/molecules28114410/s1>, X-ray data for products **3aa**; copies of  $^1\text{H}$ ,  $^{13}\text{C}$  NMR spectra. References [69–71] are cited in the supplementary materials.

**Author Contributions:** Conceptualization, Z.-H.W. and W.-C.Y.; methodology, Z.-H.W., T.Z. and L.-W.S.; investigation, X.Y., Y.-P.Z., Y.Y. and J.-Q.Z.; writing—original draft preparation, Z.-H.W. and W.-C.Y.; writing—review and editing, W.-C.Y.; supervision, Z.-H.W. and W.-C.Y. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the Natural Science Foundation of China (nos. 22171029, 21901024, 21871252, and 22271027) and the Sichuan Science and Technology Program (nos. 2023NS-FSC1080 and 2021YFS0315).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** All the required data are reported in the manuscript and Supplementary Materials.

**Acknowledgments:** This work was performed using the equipment of Chengdu University.

**Conflicts of Interest:** The authors declare no conflict of interest.

**Sample Availability:** Samples of the compounds are available from the authors.

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