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Graphical Abstract

Elemental Sulfur Mediated Cyclization *via* Redox Strategy: Synthesis of Benzothiazoles from *o*-Chloronitrobenzenes and Benzyl Chlorides

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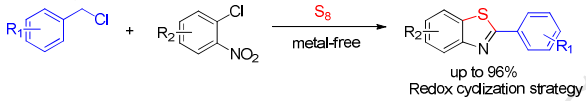

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Elemental Sulfur Mediated Cyclization *via* Redox Strategy: Synthesis of Benzothiazoles from *o*-Chloronitrobenzenes and Benzyl Chlorides

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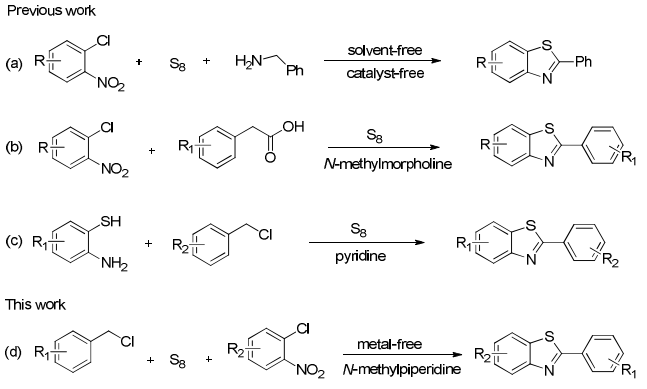
ABSTRACT

A novel metal-free synthesis of 2-substituted benzothiazoles from easily available *o*-chloronitrobenzenes and benzyl chlorides using elemental sulfur as traceless oxidizing agent has been developed. The protocol provides a simple, efficient, and atom-economic way to access to benzothiazoles in moderate to excellent yields. And the approach exhibited good functional group tolerance.

1. Introduction

2-Substituted benzothiazole derivatives represent an important class of heterocyclic compounds which play essential roles as key blocks in the synthesis of a variety of drugs such as antitumoral, antimicrobial, anti-inflammatory and anticonvulsant agents.[1,2] Thus, there are numerous efforts aimed at developing efficient methods for rapid construction of benzothiazoles.

The conventional wisdom approaches for the synthesis of these compounds typically rely on the condensation of 2-aminothiophenols with aldehydes[3] or carboxylic acids[4] under oxidative conditions, the oxidative cross-coupling of benzothiazoles and phenylacetic acids[5] or intramolecular cyclization of 2-haloanilides catalyzed by transition metal[6]. However, these reactions are suffering from difficulties in preparation of starting materials, application of excess added agents, and harsh reaction conditions. To overcome these limitations, it is crucial to make a valid and practical protocol for the construction of C-C and C-S bonds in a direct step- and atom-economical approach.[7] To the best of our knowledge, the strategy for the redox reactions has become a powerful tool to synthesize heterocyclic compounds, as it is highlighted by the direct product formation without an added agent such as oxidant, reductant, acid or base.[8] Recently, our group disclosed a green and novel synthesis of 2-substituted benzothiazoles from 2-chloronitrobenzenes and aliphatic amines via elemental sulfur mediated redox cyclization in the absence of external oxidant or reductant (Scheme 1a).[9a] And meanwhile, Nguyue group also illuminated an analogical methodology.[9b] A decarboxylative redox reaction using *o*-chloronitroarenes, arylacetic acids and elemental sulfur as substrates under solvent- and catalyst-free conditions has been developed by Guntreddi group (Scheme 1b).[10] Thus it can be seen that elemental sulfur which is readily available, nontoxic, and stable under ambient conditions plays a vital role in redox reactions as oxidant and reductant due to its valence states diversity, ranging from -2 to +6.[11] In addition, our lab has reported a metal-free approach to benzothiazoles from benzyl chlorides and 2-mercaptan anilines



Scheme 1. Access to 2-Substituted Benzothiazoles

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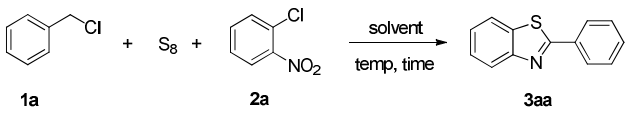
using elemental sulfur as traceless oxidizing angent (Scheme 1c). Furthermore, benzyl chloride derivatives are a family of inexpensive organic intermediates and served as new and potential acyl sources.[12,13]

Herein, we report an elemental sulfur mediated redox condesation from benzyl chlorides and *o*-chloronitrobenzenes for the synthesis of 2-substituted benzothiazoles under metal-free conditions (Scheme 1d).

2. Results and discussion

As an exploratory study, benzyl chloride (**1a)** and *o*-chloronitrobenzene (**2a)** were chosen as test substrates in the presence of elemental sulfur (**Table 1**). As we expected, when the reaction was carried out in *N*-methylpiperidine at 120 ℃ for 24 h under nitrogen atmosphere, the desired product **3aa** was obtained in 60% yield (entry 1). The amount of elemental sulfur was an important factor for the yield of the product. And the use of 1.5 equiv elemental sulfur led to a higher yield of **3aa** (entries 2-3). To determine the effect of temperature on this approach, these reactions were checked (entries 4-6),and the reaction yield increased to 80% when the temperature was decreased to 110 ℃ (entry 5). We then investigated the impact of solvent on reaction yield (entries 7-8), and it proved that *N*-methylpiperidine was superior to others. Furthermore, reducing the reaction time to 18 h or prolonging to 36 h resulted in lower yields (entries 9-10).

Table 1. Optimization of the Reaction Conditions[a]



1a **2a** **3aa**

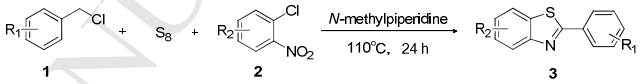
entry	solvent	S (equiv)	temp (℃)	yield[b] (%)
1	*N*-methylpiperidine	1	120	60
2	*N*-methylpiperidine	1.5	120	75
3	*N*-methylpiperidine	2	120	70
4	***N*-methylpiperidine**	**1.5**	**110**	**80**
5	*N*-methylpiperidine	1.5	100	78
6	*N*-methylpiperidine	1.5	90	40
7	pyridine	1.5	110	20
8	Triethylamine	1.5	110	60
9[c]	*N*-methylpiperidine	1.5	110	71
10[d]	*N*-methylpiperidine	1.5	110	72

[a]Reaction conditions: benzyl chloride (1 mmol), *o*-chloronitrobenzene (0.5 mmol) in solvent (1.5 mL) under a nitrogen atmosphere for 24 h at the specified reaction temperature.
[b]Isolated yield.
[c]18 h.
[d]36 h.

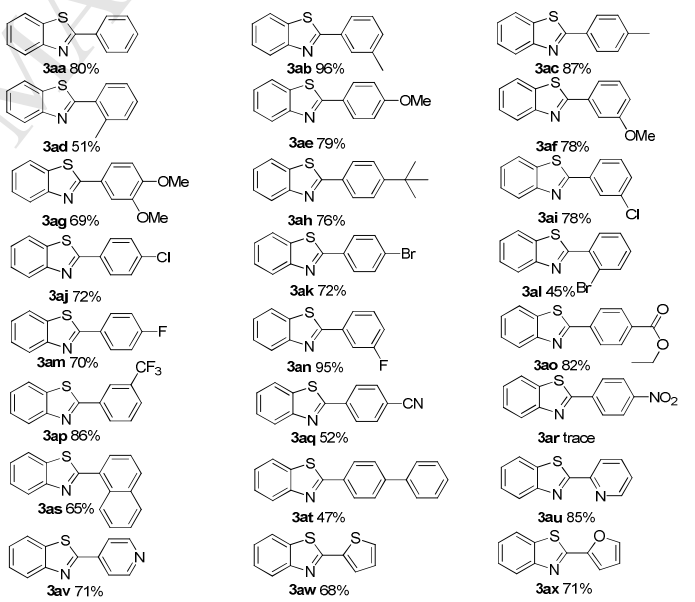
Now the optimal reaction conditions had been identified, the scope of the multicomponent one-pot reaction was investigated (**Table 2**). We first focused on the influence of various benzyl chlorides on the reaction. The reaction with benzyl chlorides bearing electron-donating groups could be smoothly transformed into the desired products (**3ab-3ah**). Furthermore, benzyl chlorides possessing 3, 4-dimethoxy or *p*-*tert*-butyl also provided the corresponding products in good yields (**3ag-3ah**). Additionally, this transformation also showed satisfactory tolerance of halogen groups (**3ai-3an**), which provide useful handles for further transformations through traditional cross-coupling reactions. It is noteworthy that simple methyl or bromine group at the *para*- and *meta*-positions (**3ab, 3ac** and **3ak**) underwent the redox process to afford the expected products in good yields, whereas giving slightly inferior yields when the substituents at *ortho*-position (**3ad, 3al**), probably as a result of steric hindrance. However, we found that the electron-deficient substituents did obviously affect the efficiency on the reaction **(3ao-3ar**). The stronger were the substituents, the lower were the yields. When benzyl chloride linked with nitro group on the benzene ring, no product was obtained (**3ar**). Besides, α-naphthyl and biphenyl group substrates were also compatible to give **3as-3at** in 65% and 47% yields, respectively. Notably, heteroaromatic methyl chlorides also worked well under standard conditions and offered **3au-3ax** in moderate to good yields. On the other hand, we also evaluated readily available substituted *o*-chloronitrobenzenes tolerance in the present reaction conditions subsequently. Much to our satisfaction, the presence of the electron-donating groups such as methyl and methoxyl group promoted the yields of the reaction (**3ba-3da**). Besides, the *o*-chloronitrobenzenes bearing halo-substituted groups were all well-tolerated under the standard reaction conditions and transformed smoothly into expected products in 73%, 72%, 69% and 73% yields, respectively (**3ea-3ha**).

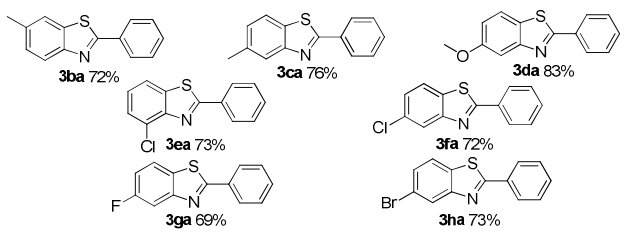
To gain insights into the reaction mechanism, control experi-

Table 2. Reaction Scope and Versatility[a]



1 **2** **3**

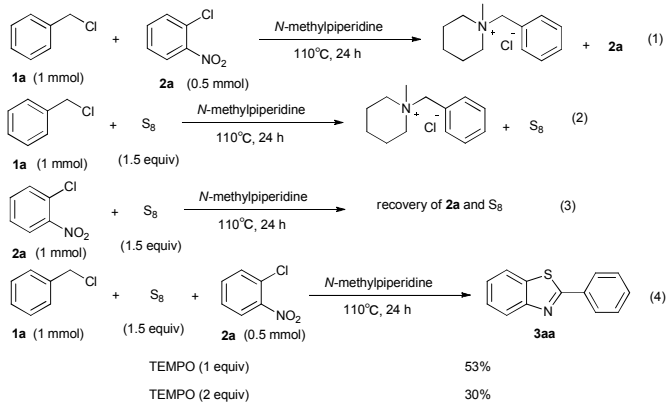




[a]Reaction conditions: **1** (1 mmol), **2** (0.5 mmol), and elemental sulfur (1.5 mmol) in *N*-methylmorpholine (1.5 mL) under a nitrogen atmosphere at 110 ℃ for 24 h. All reported yields are isolated yields.

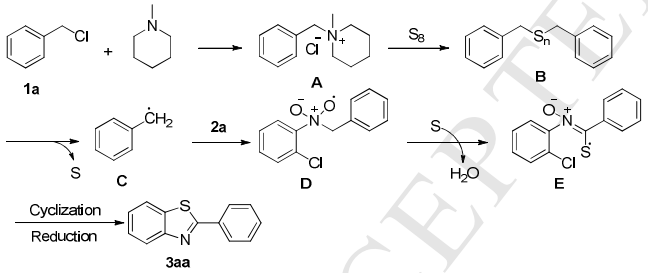
ments were performed under standard conditions as highlighted in Scheme 3. First, each couple of starting materials was heated together at 110 ℃ for 24 h in *N*-methyilpiperidine (Scheme 2,

eqs 1-3): Treatment of benzyl choride **1a** with *N*-methylpiperidine was transformed into 1-benzyl-1-methylpiperidine chloride; In contrast, reaction of sulfur with **2a** did not work and all starting materials were recovered unchanged. Notably, when 1 equiv or 2 equiv radical trapping reagent TEMPO was added to the reaction mixture, the expected product **3aa** was obtained in 53% and 30% yields, respectively, which was lower than that under standard conditions. Thus it indicated that a radical pathway might be involved (Scheme 2, eq 4).



Scheme 2. Control experiments

On the basis of these above experiments and previous literatures,[9,10,12,13] a plausible mechanism is proposed in Scheme 3. At first, benzyl chloride **1a** undergoes *N*-methylpiperidine to produce 1-benzyl-methylpiperidinium chloride **A**. After that, in the presence of elemental sulfur, **A** is oxidized to form polysulfide **B** and the radical intermediate **C** is generated by the sulfur extrusion, which reacts with the nitro group of **2a** to yield **D** subsequently. Then by the means of sulfuration of the methylene, the intermediate **D** can be converted into **E**, which eventually undergoes a cascade reaction of cyclization and reduction to afford the desired product **3aa**.



Scheme 3. Plausible Mechanism

3. Conclusion

In summary, we have developed a novel and facile approach that elemental sulfur mediated direct construction of 2-substituted benzothiazoles from readily available *o*-chloronitrobenzenes and benzyl chlorides in the absence of transition metal. This approach afforded 2-substituted benzothiazoles in satisfactory yields with good substrate tolerance. The reaction makes the process attractive and practical, which is free from the use of metal or external oxidant. Further investigations of the mechanism and applications are presently underway.

4. Experimental section

4.1. General information

All solvents were obtained from commercial sources and used without further purification. All experiments were conducted with a sealed pressure vessel. NMR spectra were recorded with a 300 MHz or 500 MHz spectrometer for ^{1}H NMR on a Bruker Avance 300 spectrometer with TMS as the internal standard and $CDCl_3$ as solvent, and 75 MHz for ^{13}C NMR spectroscopy on a Bruker Avance 300 spectrometer with TMS as the internal standard using $CDCl_3$ solution. Flash column chromatography was performed over silica gel (200-300 mesh). All substrates are known compounds and prepared according to the literature.

4.2. General experimental procedures

A mixture of *o*-chloronitrobenzene (0.5 mmol), benzyl chloride (1.0 mmol), elemental sulfur (1.5 mmol) and *N*-methylpiperidine (1.5 mL) was placed in a sealed pressure vessel (25 mL) containing a magnetic stirring bar. The The tube was purged with nitrogen three times, and then capped and stirred in a preheated oil bath at 110 °C for 24 h. After the mixture was cooled to room temperature, concentrated in vacuum and purified by silica gel column chromatography by using petroleum ether and ethyl acetate (PE:EA=1:500) as eluent.

*4.2.1. 2-Phenylbenzo[d]thiazole (**3aa, CAS: 883-93-2**)*[14]. Llight yellow solid (85 mg, 80%); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.09-8.11 (m, 3H), 7.90 (d, J = 7.8 Hz, 1H), 7.48-7.52 (m, 4H), 7.38 (t, J = 7.5 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.0, 154.1, 135.1, 133.6, 130.9, 129.0, 127.5, 126.2, 125.1, 123.2, 121.6.

*4.2.2. 2-(m-Tolyl)benzo[d]thiazole (**3ab, CAS: 1211-32-1**)*[5a]. Light yellow solid (103 mg , 96%); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.10 (d, J = 8.4 Hz, 1H), 7.96 (s, 1H), 7.87-7.90 (m, 2H), 7.49 (t, J = 7.5 Hz, 1H), 7.38 (t, J = 7.5 Hz, 2H), 7.30 (d, J = 7.5 Hz, 1H), 2.46 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.2, 154.1, 138.8, 135.0, 133.5, 131.7, 128.8, 127.9, 126.2, 125.0, 124.8, 123.1, 121.5, 21.3.

*4.2.3. 2-(p-Tolyl)benzo[d]thiazole (**3ac, CAS: 16112-21-3**)*[14]. Light yellow solid (94 mg, 87%); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.04 (d, J = 8.1 Hz, 1H), 7.96 (d, J = 8.1 Hz, 2H), 7.85 (d, J = 8.1 Hz, 1H), 7.45 (t, J = 7.8 Hz, 1H), 7.33 (t, J = 7.5 Hz, 1H), 7.26 (d, J = 7.5 Hz, 2H), 2.39 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.1, 154.2, 141.3, 134.9, 131.0, 129.6, 127.4, 126.1, 125.0, 123.0, 121.5, 21.4.

*4.2.4. 2-(o-Tolyl)benzo[d]thiazole (**3ad, CAS: 15903-58-9**)*[6a]. Light yellow solid (55 mg, 51%); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.11 (d, J = 7.8 Hz, 1H), 7.94 (d, J = 7.5 Hz, 1H), 7.76 (d, J = 7.5 Hz, 1H), 7.51 (t, J = 8.4 Hz, 1H), 7.25-7.41 (m, 4H), 2.67 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 167.9, 153.8, 137.2, 135.6, 133.1, 131.5, 130.5, 129.9, 126.1, 125.0, 124.8, 123.4, 121.3, 21.3.

*4.2.5. 2-(4-Methoxyphenyl)benzo[d]thiazole (**3ae, CAS: 6265-92-5**)*[14]. Light yellow solid (95 mg, 79%); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.03 (d, J = 6.0 Hz, 3H), 7.86 (d, J = 7.5 Hz, 1H), 7.47 (t, J = 7.5 Hz, 1H), 7.34 (t, J = 6.9 Hz, 1H), 6.99 (d, J = 8.1 Hz, 2H), 3.85 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 167.8, 161.9, 154.2, 134.8, 129.0, 126.4, 126.1, 124.7, 122.8, 121.4, 114.3, 55.4.

*4.2.6. 2-(3-Methoxyphenyl)benzo[d]thiazole **(3af, CAS: 10002-44-5)***[15]. Light yellow solid (94 mg, 78%); ^{1}H NMR (300MHz, $CDCl_3$): δ 8.09 (d, J = 8.1 Hz, 1H), 7.89 (d, J = 8.1 Hz, 1H), 7.64-7.69 (m, 2H), 7.49 (t, J = 8.1 Hz, 1H), 7.36-7.41 (m, 2H), 7.04 (dd, J = 2.4, 8.4 Hz, 1H), 3.91 (s, 3H); ^{13}C NMR (75MHz, $CDCl_3$): δ 167.8, 160.0, 154.1, 135.1, 134.9, 130.0, 126.2, 125.2, 123.2, 121.5, 120.2, 117.3, 112.1, 55.4.

*4.2.7. 2-(3,4-Dimethoxyphenyl)benzo[d]thiazole (**3ag, CAS: 6638-45-5**)*[12]. Light yellow solid (94 mg, 69%); ^{1}H NMR (300

MHz, $CDCl_3$) δ 8.04 (d, J = 4.8 Hz, 1H), 7.87 (d, J = 4.8 Hz, 1H), 7.72 (s, 1H), 7.61 (d, J = 5.1 Hz, 1H), 7.47 (t, J = 4.8 Hz, 1H), 7.35 (t, J = 4.5 Hz, 1H), 6.95 (d, J = 5.1 Hz, 1H), 4.02 (s, 3H), 3.96 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 167.8, 154.1, 151.5, 149.3, 134.8, 126.6, 126.1, 124.8, 122.7, 121.4, 121.1, 111.0, 109.8, 56.0, 55.9.

4.2.8. 2-(4-tert-Butylphenyl)benzo[d]thiazole ***(3ah, CAS: 56048-52-3)***[5a]. Light yellow solid (102 mg, 76%); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.08 (d, J = 8.1 Hz, 1H), 8.04 (d, J = 8.4 Hz, 2H), 7.89 (d, J = 7.8 Hz, 1H), 7.52 (d, J = 8.1 Hz, 2H), 7.48 (d, J = 7.8 Hz, 1H), 7.35-7.40 (m, 1H), 1.38 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 168.1, 154.5, 154.2, 135.0, 130.9, 127.3, 126.2, 125.9, 125.0, 123.1, 121.5, 35.0, 31.2.

4.2.9. 2-(3-Chlorophenyl)benzo[d]thiazole ***(3ai, CAS: 22868-31-1)***[5a]. Light yellow solid (96 mg, 78%); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.07-8.11 (m, 2H), 7.87-7.93 (m, 2H), 7.36-7.52 (m, 4H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 166.2, 154.0, 135.2, 135.10, 135.06, 130.8, 130.2, 127.3, 126.5, 125.6, 125.5, 123.4, 121.6.

4.2.10. 2-(4-Chlorophenyl)benzo[d]thiazole ***(3aj, CAS: 6265-91-4)***[5a]. Light yellow solid (88 mg, 72%); ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.07 (d, J = 8.2 Hz, 1H), 8.04 (d, J = 8.3 Hz, 2H), 7.91 (d, J = 8.0 Hz, 1H), 7.52 (d, J = 7.6 Hz, 1H), 7.48 (d, J = 8.4. Hz, 1H), 7.41 (t, J = 7.5 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 166.5, 154.1, 137.0, 135.0, 132.1, 129.2, 128.7, 126.4, 125.4, 123.3, 121.6.

4.2.11. 2-(4-Bromophenyl)benzo[d]thiazole ***(3ak, CAS: 19654-19-4)***[12]. Light yellow solid (104 mg, 72%); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.06 (d, J = 7.5 Hz, 1H), 7.86-7.94 (m, 3H), 7.60 (d, J = 7.5 Hz, 2H), 7.47-7.51 (m, 1H), 7.38-7.41 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 166.6, 154.0, 135.0, 132.5, 132.1, 128.8, 126.4, 125.4, 123.3, 121.6.

4.2.12. 2-(2-Bromophenyl)benzo[d]thiazole ***(3al, CAS: 22901-00-4)***[12]. Light yellow solid (65 mg, 45%); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.14 (d, J = 7.8 Hz, 1H), 8.00 (dd, J = 1.5, 7.8 Hz, 1H), 7.95 (d, J = 8.1 Hz, 1H), 7.75 (d, J = 7.8 Hz, 1H), 7.51-7.56 (m, 1H), 7.42-7.56 (m, 2H), 7.31-7.36 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 165.5, 152.7, 136.1, 134.5, 134.0, 132.1, 131.2, 127.5, 126.2, 125.4, 123.6, 122.1, 121.4.

4.2.13. 2-(4-Fluorophenyl)benzo[d]thiazole ***(3am, CAS: 1629-26-1)***[14]. Light yellow solid (80 mg, 70%); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.05-8.10 (m, 3H), 7.88 (d, J = 8.1 Hz, 1H), 7.49 (t, J = 7.8 Hz, 1H), 7.38 (t, J = 7.2 Hz, 1H), 7.17 (t, J = 8.4 Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 166.6, 164.4 (d, J = 250.3 Hz), 154.0, 135.0, 130.0 (d, J = 3.2 Hz), 129.5 (d, J = 8.6 Hz), 126.4, 125.2, 123.2, 121.6, 116.1 (d, J = 22.0 Hz); ^{19}F NMR (282 MHz, $CDCl_3$) δ -107.85 (s).

4.2.14. 2-(3-Fluorophenyl)benzo[d]thiazole ***(3an, CAS: 1629-07-8)***[12]. Light yellow solid (109 mg, 95%); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.09 (d, J = 8.1 Hz, 1H), 7.83-7.91 (m, 3H), 7.37-7.53 (m, 3H), 7.15-7.21 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 164.7, 161.4, 154.0, 135.7 (d, J = 8.0 Hz), 135.1, 130.5 (d, J = 8.1 Hz), 126.5, 125.5, 123.4, 123.3 (d, J = 3.0 Hz), 121.6, 117.7 (d, J = 21.2 Hz), 114.3 (d, J = 23.3 Hz); ^{19}F NMR (282 MHz, $CDCl_3$) δ -110.91 (s).

4.2.15. Ethyl 4-(benzo[d]thiazol-2-yl)benzoate ***(3ao, CAS: 1030513-24-6)***[12]. Light yellow solid (116 mg, 82%); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.16 (s, 4H), 8.11 (d, J = 4.8 Hz, 1H), 7.93 (d, J = 4.8 Hz, 1H), 7.52 (t, J = 4.8 Hz, 1H), 7.42 (t, J = 4.5 Hz, 1H), 4.42 (q, J = 4.5 Hz, 2H), 1.43 (t, J = 4.2 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 166.5, 165.8, 154.1, 137.3, 135.2, 132.3, 130.1, 127.3, 126.5, 125.6, 123.5, 121.6, 61.2, 14.3.

4.2.16. 2-(3-(Trifluoromethyl)phenyl)benzo[d]thiazole ***(3ap, CAS: 133389-19-2)***[2e]. Light yellow solid (120 mg, 86%); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.39 (s, 1H), 8.26 (d, J = 7.7 Hz, 1H), 8.11 (d, J = 8.1 Hz, 1H), 7.94 (d, J = 7.9 Hz, 1H), 7.75 (d, J = 7.7 Hz, 1H), 7.63 (t, J = 7.8 Hz, 1H), 7.53 (t, J = 7.6 Hz, 1H), 7.43 (t, J = 7.5 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.1, 154.0, 135.1, 134.5, 131.8, 130.7, 129.6, 127.3 (d, J = 3.5 Hz), 126.6, 125.7, 124.9, 124.3 (d, J = 3.7 Hz), 123.6, 121.7; ^{19}F NMR (282 MHz, $CDCl_3$) δ -61.67 (s).

4.2.17. 2-(4-Cyanophenyl) benzo[d]thiazole ***(3aq, CAS: 17930-02-8)***[1c]. Light yellow solid (61 mg, 52%); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.15 (d, J = 8.4 Hz, 2H), 8.09 (d, J = 8.2 Hz, 1H), 7.91 (d, J = 7.8 Hz, 1H), 7.73 (d, J = 8.4 Hz, 2H), 7.50-7.55 (m, 1H), 7.40-7.45 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.2, 154.0, 137.4, 135.2, 132.6, 127.8, 126.7, 126.0, 123.7, 121.7, 118.2, 114.0.

4.2.18. 2-(Naphthalen-1-yl)benzo[d]thiazole ***(3as, CAS: 56048-50-1)***[5a]. Light yellow solid (85 mg, 65%); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.94 (d, J = 8.1 Hz, 1H), 8.21 (d, J = 8.4 Hz, 1H), 7.93-8.01 (m, 4H), 7.54-7.65 (m, 4H), 7.46 (t, J = 7.5 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 167.5, 154.1, 135.4, 133.9, 131.0, 130.7, 130.6, 129.3, 128.3, 127.5, 126.4, 126.2, 125.8, 125.2, 124.9, 123.5, 121.3.

4.2.19. 2-([1,1'-Biphenyl]-4-yl)benzo[d]thiazole ***(3at, CAS: 67362-98-5)***[1a]. Light yellow solid (68 mg, 47%); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.11-8.18 (m, 3H), 7.91 (d, J = 4.5 Hz, 1H), 7.66-7.73 (m, 4H), 7.40-7.50 (m, 5H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 167.6, 154.2, 143.7, 140.0, 135.1, 132.5, 128.9, 128.0, 127.6, 127.1, 126.3, 125.1, 123.2, 121.6.

4.2.20. 2-(Pyridin-2-yl)benzo[d]thiazole ***(3au, CAS: 716-80-3)***[1a]. Light yellow solid (90 mg, 85%); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.70 (d, J = 4.8 Hz, 1H), 8.38 (d, J = 7.8 Hz, 1H), 8.10 (d, J = 8.1 Hz, 1H), 7.97 (d, J = 7.8 Hz, 1H), 7.85 (t, J = 7.7 Hz, 1H), 7.51 (t, J = 7.2 Hz, 1H), 7.37-7.44 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 169.3, 154.2, 151.4, 149.5, 136.9, 136.1, 126.2, 125.5, 125.1, 123.5, 121.9, 120.7.

4.2.21. 2-(Pyridin-4-yl)benzo[d]thiazole ***(3av, CAS: 2295-38-7)***[1a]. Light yellow solid (75 mg, 71%); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.78 (d, J = 3.3 Hz, 2H), 8.14 (d, J = 5.1 Hz, 1H), 7.94-7.97 (m, 3H), 7.55 (t, J = 4.8 Hz, 1H), 7.46 (t, J = 4.5 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.0, 153.9, 150.7, 140.4, 135.2, 126.7, 126.1, 123.9, 121.8, 121.1.

4.2.22. 2-(Thiophen-2-yl)benzo[d]thiazole ***(3aw, CAS: 34243-38-4)***[1e]. Light yellow solid (74 mg, 68%); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.04 (d, J = 8.1 Hz, 1H), 7.83 (d, J = 8.1 Hz, 1H), 7.64 (d, J = 3.3 Hz, 1H), 7.44-7.50 (m, 2H), 7.36 (t, J = 7.5 Hz, 1H), 7.12 (t, J = 4.2 Hz, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 161.3, 153.7, 137.3, 134.7, 129.2, 128.5, 128.0, 126.3, 125.1, 122.9, 121.4.

4.2.23. 2-(Furan-2-yl)benzo[d]thiazole ***(3ax, CAS: 1569-98-8)***[1e]. Light yellow solid (72 mg, 71%); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.05 (d, J = 8.1 Hz, 1H), 7.89 (d, J = 7.8 Hz, 1H), 7.61 (s, 1H), 7.49 (t, J = 7.5 Hz, 1H), 7.38 (t, J = 7.5 Hz, 1H), 7.19 (d, J = 3.3 Hz, 1H), 6.60 (s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 157.5, 153.7, 148.7, 144.6, 134.3, 126.4, 125.1, 123.1, 121.5, 112.4, 111.3.

4.2.24. 6-Methyl-2-phenylbenzo[d]thiazole ***(3ba, CAS: 10205-58-0)***[12]. Light yellow solid (81 mg, 72%); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.07-8.10 (m, 2H), 7.97 (d, J = 8.4 Hz, 1H), 7.67 (s, 1H), 7.47-7.49 (m, 3H), 7.30 (dd, J = 1.2, 8.1 Hz, 1H), 2.49 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 166.9, 152.3, 135.3, 133.7, 130.7, 128.9, 127.8, 127.4, 126.2, 122.7, 121.3, 21.5.

*4.2.25. 5-Methyl-2-phenylbenzo[d]thiazole (**3ca, CAS: 107611-15-4**)*[5a]. Light yellow solid (86 mg, 76%); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.09-8.10 (m, 2H), 7.90 (s, 1H), 7.78 (d, J = 8.0 Hz, 1H), 7.49 (d, J = 3.5 Hz, 3H), 7.22 (d, J = 8.1 Hz, 1H), 2.52 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 168.0, 154.5, 136.3, 133.7, 132.0, 130.7, 128.9, 127.4, 126.7, 123.2, 121.0, 21.4.

*4.2.26. 5-Methoxy-2-phenylbenzo[d]thiazole (**3da, CAS: 157328-07-9**)*[5a]. Light yellow solid (100 mg, 83%); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.08 (d, J = 3.5 Hz, 2H), 7.75 (d, J = 9.0 Hz, 1H), 7.58 (s, 1H), 7.49 (s, 3H), 7.05 (d, J = 9.0 Hz, 1H), 3.91 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 169.3, 159.2, 155.4, 133.7, 130.9, 129.0, 127.4, 121.8, 115.5, 105.6, 55.6.

*4.2.27. 7-Chloro-2-phenylbenzo[d]thiazole (**3ea, CAS: 1242289-39-9**)*[9a]. Light yellow solid (90 mg, 73%); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.09 (d, J = 3.6 Hz, 2H), 7.95 (d, J = 7.5 Hz, 1H), 7.34-7.51 (m, 5H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 168.7, 154.7, 135.3, 133.1, 131.3, 129.0, 127.5, 127.2, 126.8, 124. 8, 121.5.

*4.2.28. 5-Chloro-2-phenylbenzo[d]thiazole (**3fa, CAS: 952-16-9**)*[15]. Light yellow solid (88 mg, 72%); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.07-8.09 (m, 3H), 7.81 (d, J = 8.5 Hz, 1H), 7.52 (s, 3H), 7.37 (d, J = 8.5 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 169.9, 155.0, 133.3, 133.2, 132.3, 131.3, 129.0, 127.6, 125.6, 123.0, 122.2.

*4.2.29. 5-Fluoro-2-phenylbenzo[d]thiazole (**3ga, CAS: 1629-93-2**)*[12]. Light yellow solid (79 mg, 69%); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.05-8.08 (m, 2H), 7.73-7.81 (m, 2H), 7.4-7.05 (m, 3H), 7.11-7.18 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 170.5, 163.5, 160.3, 155.04 (d, J = 12.0 Hz), 133.4, 131.2, 130.4, 129.0, 127.5, 122.2 (d, J = 9.8 Hz), 113.8 (d, J = 25.7 Hz), 109.3 (d, J = 23.5 Hz); ^{19}F NMR (282 MHz, $CDCl_3$) δ -114.75 (s).

*4.2.30. 5-Bromo-2-phenylbenzo[d]thiazole (**3ha, CAS: 305372-56-9**)*[9a]. Light yellow solid (75 mg, 73%); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.23 (s, 1H), 8.07-8.12 (m, 2H), 7.76 (d, J = 8.5 Hz, 1H), 7.49-7.51 (m, 4H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 169.6, 155.3, 133.8, 133.2, 131.3, 129.0, 128.2, 127.6, 126.0, 122.5, 119.8.

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Supplementary Material

Supplementary data associated with this article can be found in the online version.

General information, general experimental procedures, characterization data of the products, and copies of the ^{1}H, ^{13}C and ^{19}F NMR spectra (PDF)

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