

Palladium-catalyzed tandem reaction toward 2,5-diarylthiazole derivatives

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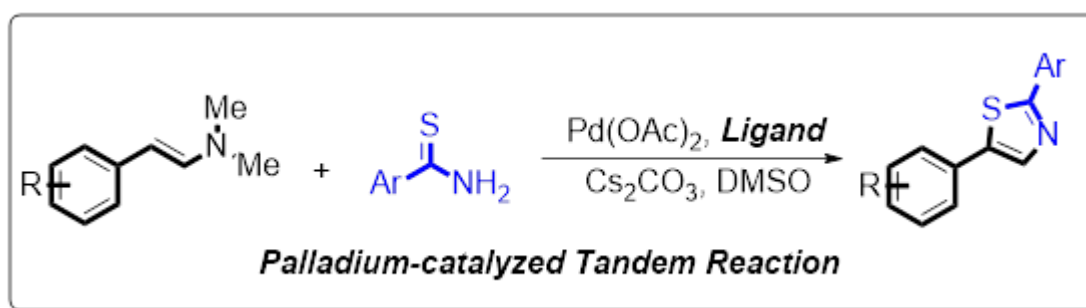
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Abstract

An efficient palladium-catalyzed tandem reaction for the synthesis of 2,5-diarylthiazole derivatives was developed. Notably, from N,N-dimethyl-2-arylethen-1-amines and benzothioamide parent compounds various 2,5-diarylthiazole derivatives were efficiently synthesized under a moderate condition. Finally, a plausible Pd(II)/Pd(IV) reaction mechanism was devised. This new methodology provides an efficient and economical approach for the synthesis of 2,5-diarylthiazole derivatives.



Keywords: Palladium-catalyzed, tandem reaction, C-S bond, benzothioamides, 2,5-diarylthiazole derivatives

Introduction

Thiazoles are an important class of organic compounds with significant application value in various fields rendering them research hotspots.¹⁻⁵ Derivatives containing thiazole rings have diverse structures and exhibit a wide range of biological activities, such as anticancer,⁶ antiviral,^{7,8} insecticidal,⁹ bactericidal,¹⁰ and herbicidal activities.¹¹

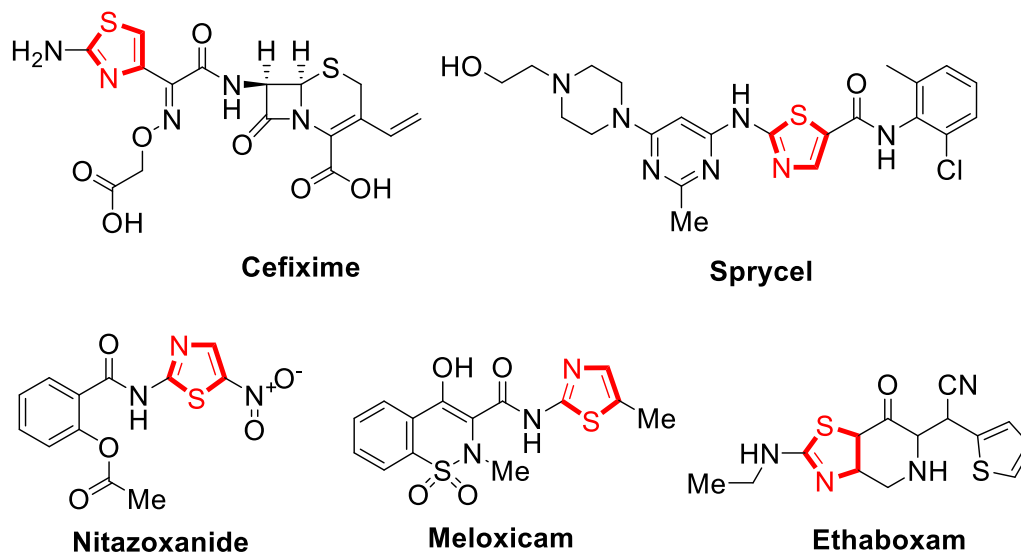


Figure 1. The important clinical drugs of thiazole derivatives.

Researchers have described a large number of thiazole derivatives with excellent bactericidal activity, and have successfully developed multiple commercial products, as shown in Figure 1. These include cefixime,¹² a third-generation cephalosporin antibiotic for oral use, suitable for treating respiratory, urinary, and biliary tract infections caused by sensitive bacteria. Sprycel¹³ is used to treat adult patients with Philadelphia chromosome positive (Ph⁺) chronic myeloid leukemia in the chronic, accelerated, and rapid phases who are resistant or intolerant to imatinib mesylate. Meloxicam,¹⁴ an enol based nonsteroidal anti-inflammatory drug with anti-inflammatory, analgesic, and antipyretic effects. Nitrozoatinide¹⁵ is believed to be related to the enzyme dependent electron transfer reaction that inhibits pyruvate and iron redox protein oxidoreductase, the latter of which is crucial for anaerobic energy metabolism.

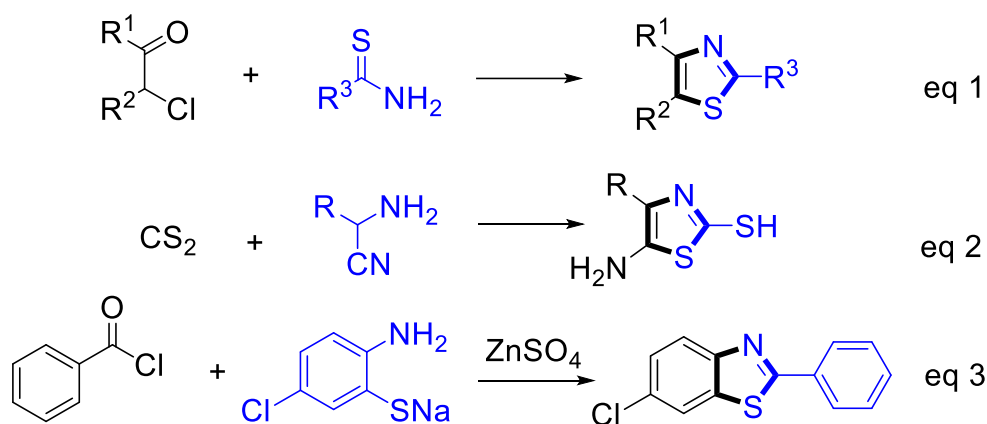


Figure 2. Methods have been proposed for synthesizing thiazole derivatives.

At present, many methods have been proposed for synthesizing thiazole derivatives, as shown in Figure 2. The commercialization of 2,5-diarylthiazole derivatives which was developed as the first synthesis based on Hantzsch method¹⁶ (eq 1), Cook-Heilbron method¹⁷ (eq 2), and Herz method¹⁸ (eq 3). The synthesis of thiazole ring is mainly divided into two categories: synthesis and cyclization of the thiazole ring. The synthesis of the thiazole ring usually involves a substitution reaction between thiazole acid or its derivatives and electrophilic reagents to generate the thiazole ring. The cyclization of the thiazole ring involves chemical reactions involving the thiazole ring using amino, carboxyl, and acyl, functional groups.

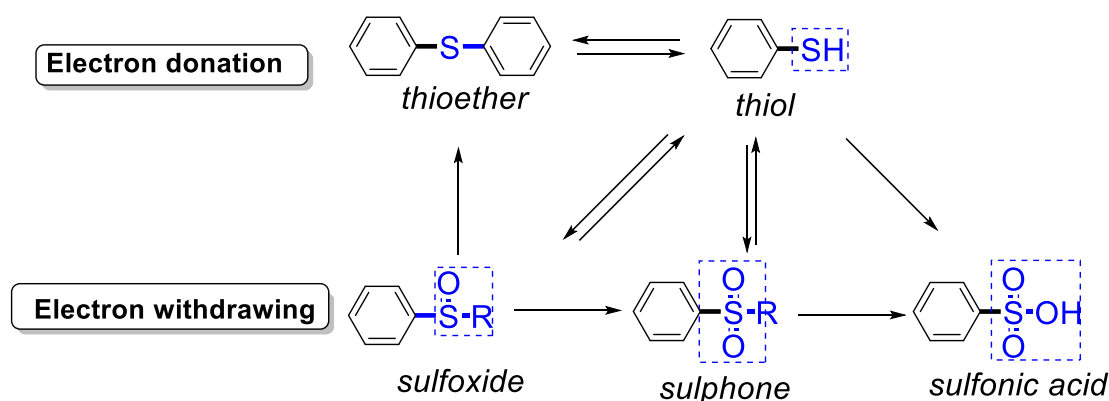


Figure 3. Conversions of sulfur-containing groups.

Due to a larger atomic radius and higher electron density, sulfur has more activation patterns and theoretically allows easier modification, as shown in Figure 3.¹⁹ Developing more efficient strategies of thiolation of C-H bonds is still highly desirable. Considering the need of diversifying synthetic strategies, we focused our interest on the functionalization of sulfur-containing C-H bonds.²⁰⁻²⁵ Herein, we report a palladium-catalyzed tandem reaction aimed at the synthesis of 2,5-diarylthiazole derivatives. In this reaction, from parent compounds N,N-dimethyl-2-arylethen-1-amines and benzothioamides various 2,5-diarylthiazole derivatives were efficiently synthesized under moderate conditions. Finally, a plausible reaction mechanism is proposed.

Results and Discussion

The reaction conditions were screened based on the model reaction involving *N,N*-dimethyl-2-phenylethen-1-aminethiophenol 1a and benzothioamide 2a. Initially, various structurally similar enaminone ligands L1-L9 were investigated, which were proven to efficiently catalyze the C-S coupling reactions shown in Figure 4. The yields observed increased by changing the substituent to -OH (L4-L6). Additionally, other enaminone ligands such as L7, L8 and L9 were produced with lower efficacies. The experimental results indicated that L4 was the optimal ligand for all reactions.

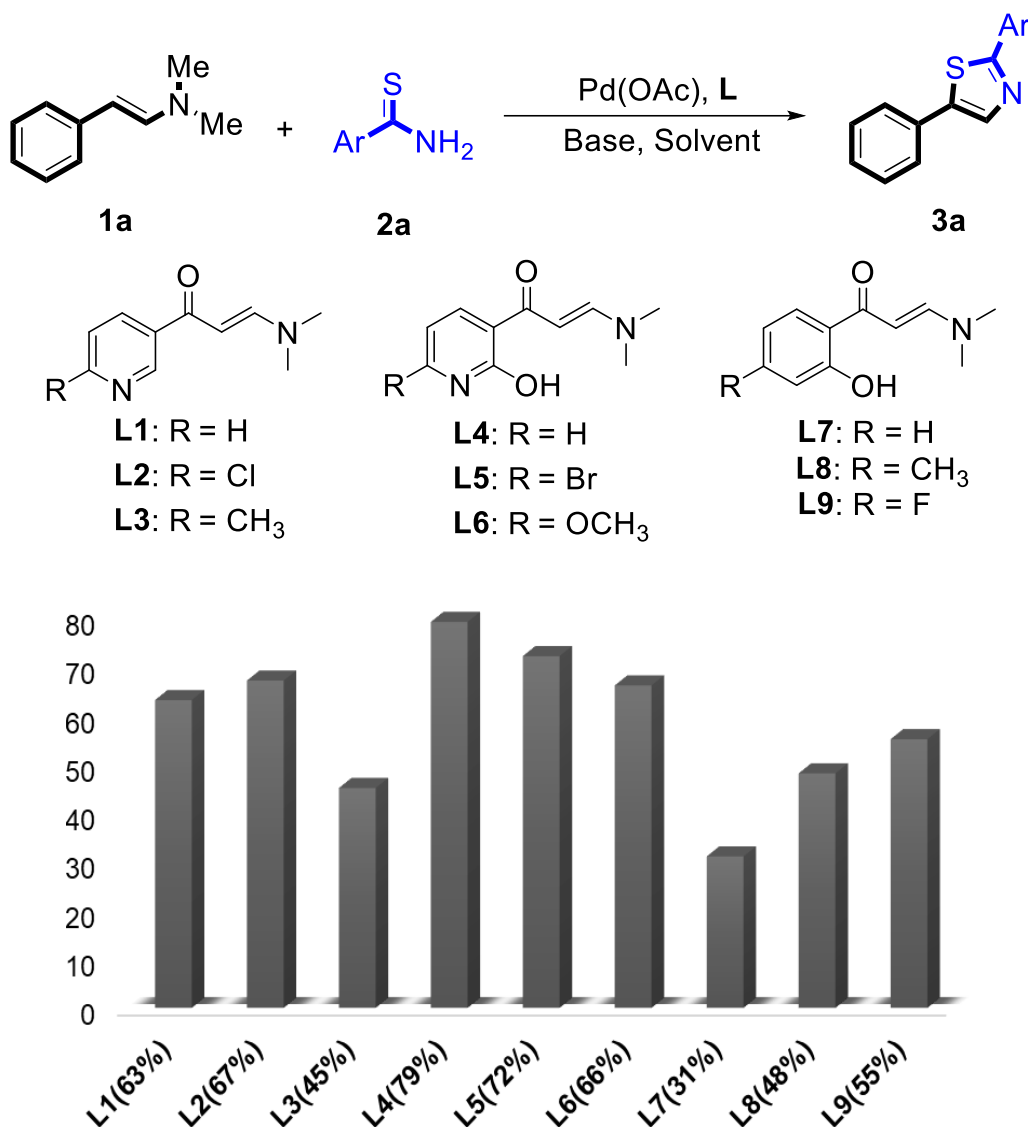


Figure 4. Ligand performances in palladium-catalyzed tandem reaction toward 2,5-diphenylthiazole.

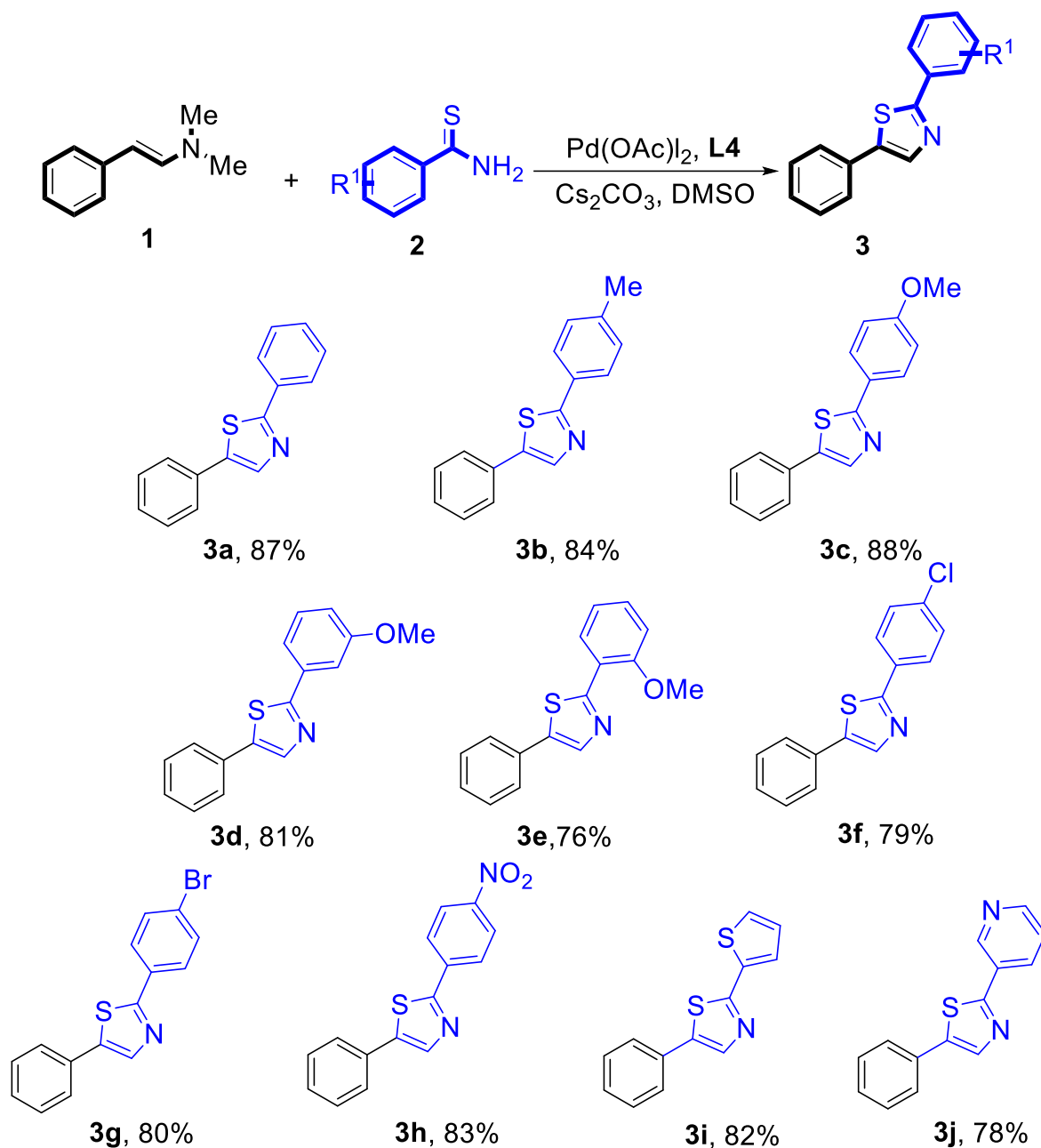
Furthermore, other reaction parameters were optimized, as shown in Table 1. The experimental results demonstrated that the Pd(II) salt had a higher yield than the Pd(0) salt (entries 1-4). By screening different bases for the reaction, Cs₂CO₃ was demonstrated to be more suitable base than others such as Na₂CO₃ and K₂PO₃ (entries 5-7). The results demonstrated that the reaction temperature was as an important parameter; the desired product was formed at a 65% yield at 90°C (entry 8) and at a 77% yield at 100°C (entry 9). Finally, the desired product **3a** was formed at a yield of 83% when the catalyst system **L4** was employed with Pd(OAc)₂ at 100°C (entry 10).

Table 1. Optimization of the model reaction^a

Entry	Copper salt	Base	1a : 2a	3a [%] ^b
1	Pd(NH ₃) ₄ Cl ₂	Cs ₂ CO ₃	1:1	42
2	PdCl ₂	Cs ₂ CO ₃	1:1	79
3	Pd(PPh ₃) ₄	Cs ₂ CO ₃	1:1	nr
4	Pd(OAc) ₂	Cs ₂ CO ₃	1:1	74
5	Pd(OAc) ₂	Cs ₂ CO ₃	1:1	81
6	Pd(OAc) ₂	Na ₂ CO ₃	1:1.2	nr
7	Pd(OAc) ₂	K ₃ PO ₄	1:1.2	41
8	Pd(OAc) ₂	Cs ₂ CO ₃	1:1.2	65 ^[c]
9	Pd(OAc) ₂	Cs ₂ CO ₃	1:1.2	77 ^[d]
10	Pd(OAc) ₂	Cs ₂ CO ₃	1:1.2	83

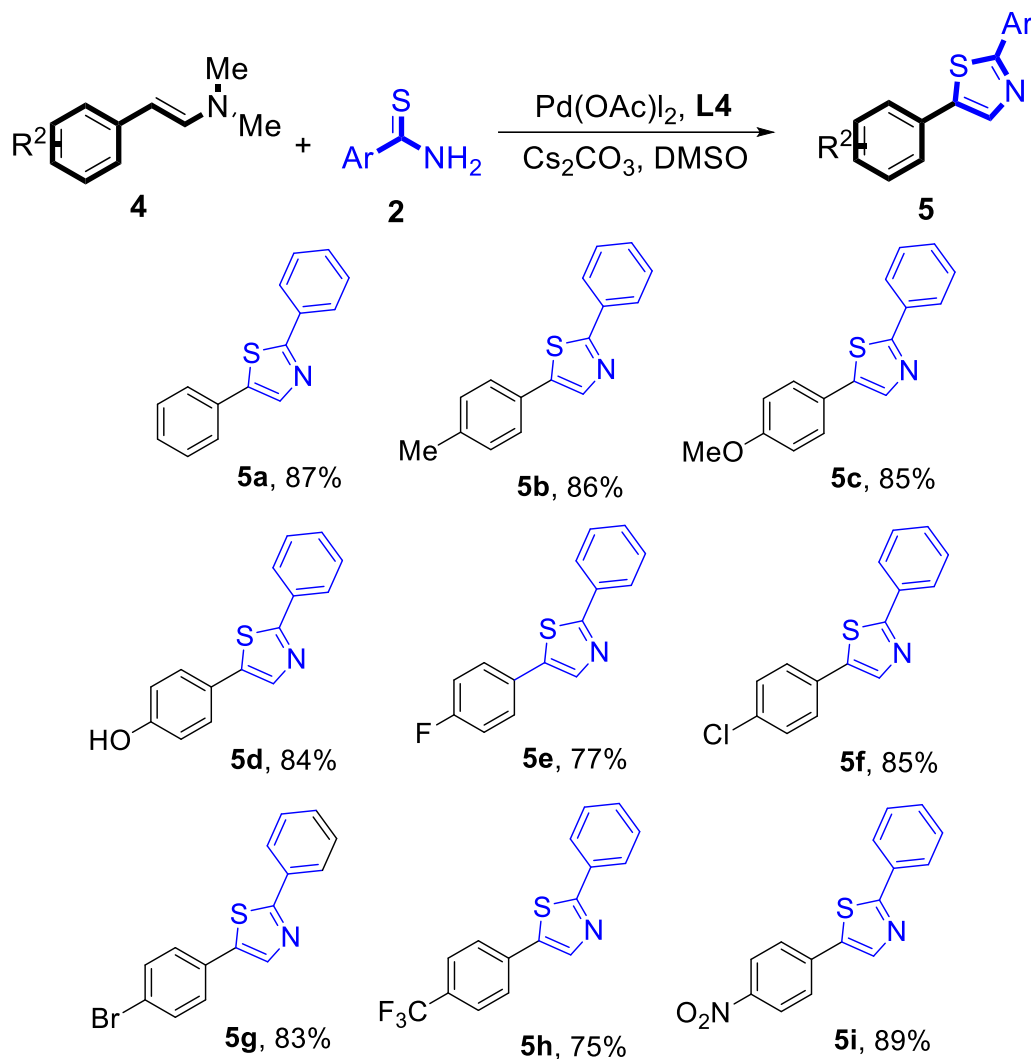
^a Unless otherwise noted, reaction conditions were **1a** (10 mmol), palladium source (10 mol %), **L4** (10 mol %), Cs₂CO₃ (2 equivalents), DMSO (10 mL), 100°C for 24 h. ^b Isolated yield. ^c reaction at 90 °C. ^d reaction at 110 °C.

Once the optimized conditions were determined, the reaction scope was investigated. A wide array of *N,N*-dimethyl-2-arylethen-1-amine **1** and benzothioamide **2** derivatives were produced with good to excellent yields (Table 2). Both the electron-donating and electron-withdrawing *N,N*-dimethyl-2-arylethen-1-amine **1** reacted easily with benzothioamides **2**. *N,N*-dimethyl-2-arylethen-1-amine **1** bearing electron-donating groups showed better activity than those bearing electron-withdrawing groups. Benzothioamides **2** bearing electron-withdrawing groups had better activity than those bearing electron-donating groups.

Table 2. Palladium-catalyzed tandem reactions generating 2,5-diarylthiazole derivatives^{a,b}

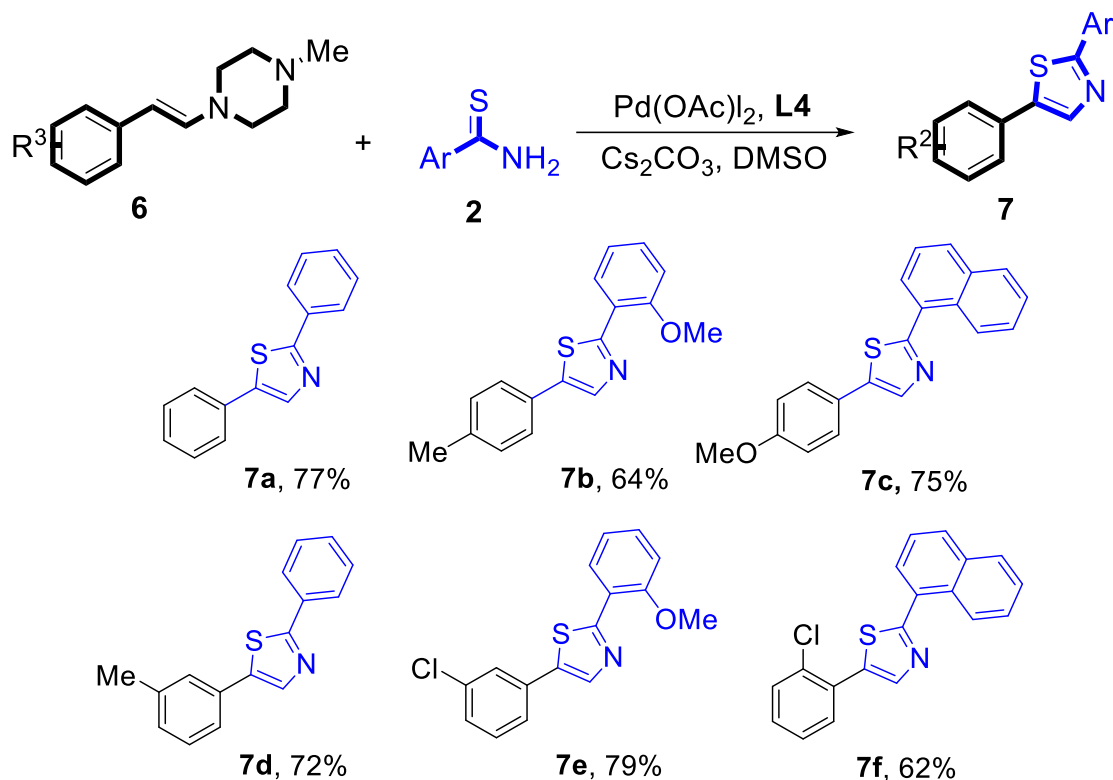
^a Reaction conditions: **1** (10 mmol), **2** (12 mmol), Pd(OAc)₂ (10 mol %), **L4** (10 mol %), Cs₂CO₃ (2 equivalents), DMSO (10 mL), 100°C for 24 h and ^b isolated yields.

Next, we turned our attention to other *N,N*-dimethyl-2-arylethen-1-amines **4** and benzothioamide **2** (Table 3). Of note, *N,N*-dimethyl-2-arylethen-1-amines **4** worked well in this reaction. The corresponding products were isolated in 75–89% yield. Nitro and trifluoromethyl substituted reactants also reacted well and retained in corresponding products **5** achieve in good yields (entries **5h** and **5i**).

Table 3. Palladium-catalyzed tandem reaction for the synthesis of 2,5-diarylthiazole derivatives^{a,b}

^a Reaction conditions: **4** (10 mmol), **2** (12 mmol), Pd(OAc)₂ (10 mol %), **L4** (10 mol %), Cs₂CO₃ (2 equiv), DMSO (10 mL), 100°C for 24 h and ^b Isolated yields.

Of note, 1-methyl-4-styrylpiperazines **6** and benzothioamides **2** also reacted smoothly using this method (Table 4). The corresponding products were isolated with yields of 62-79%. Naphthyl-substituted reactants **7c** and **7f** generated corresponding products with medium yields.

Table 4. Palladium-catalyzed tandem reaction generating 2,5-diarylthiazole derivatives^{a,b}

^a Reaction conditions: **6** (10 mmol), **2** (12 mmol), Pd(OAc)₂ (10 mol %), **L4** (10 mol %), Cs₂CO₃ (2 equiv), DMSO (10 mL), 100°C for 24 h and ^b isolated yields.

Based on the above results, a reaction mechanism was proposed (Figure 5). After the coordination of Pd(OAc)₂ with **L4**, a corresponding intermediate **8** was generated.¹⁰ Next, the intermediate **9** was formed from intermediate **8** with *N,N*-dimethyl-2-arylethen-1-amine **1** by an oxidative addition step. Next, intermediate **9** reacted with benzothioamide **2** to produce intermediate **10** via a transamina step. Finally, intermediate **10** furnished the desired products **3** and concomitantly generated intermediate **8** which re-entered the catalytic cycle by heterocyclization and a reductive elimination step.

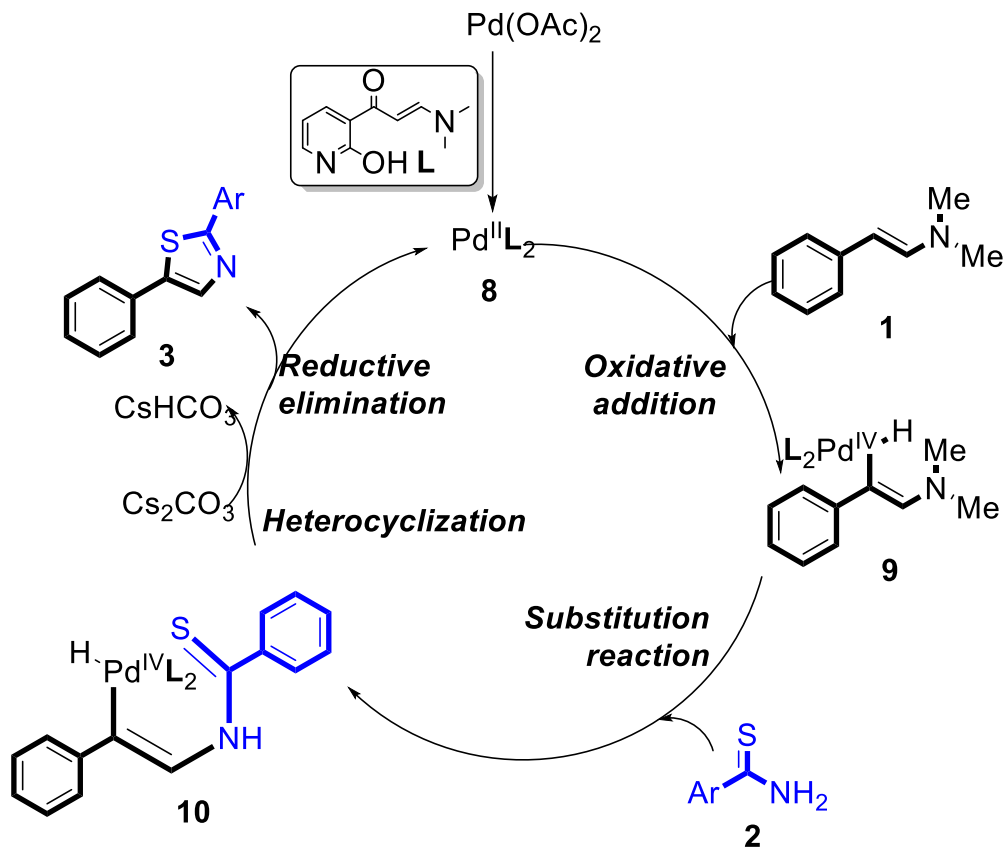


Figure 5. The proposed reaction mechanism.

Conclusions

An efficient palladium-catalyzed tandem reaction producing 2,5-diarylthiazole derivatives was developed. Notably, from reaction of N,N -dimethyl-2-arylethen-1-amines and benzothioamides various 2,5-diarylthiazole derivatives were efficiently synthesized. The process also uses moderate conditions. Finally, a plausible $\text{Pd}(\text{II})/\text{Pd}(\text{IV})$ reaction mechanism was proposed. This new methodology provides an efficient and economical approach toward 2,5-diarylthiazole derivatives.

Experimental Section

General. All reagents used in the experiments were obtained from commercial sources and used without further purification. Solvents for chromatography were technical grade and distilled prior to use. Solvent mixtures were prepared as volume/volume solutions. Chemical yields refer to pure isolated substances. Catalysts were purchased as analytical reagent grade. Thin layer chromatography employed glass 0.25 mm silica gel plates with F-254 indicator, visualized by irradiation with UV light. The NMR spectra were recorded by Bruker AVANCE III-400 spectrometry at 400 MHz and 100 MHz for ^1H and ^{13}C NMR in CDCl_3 , respectively. The chemical shifts are referenced to signals at 7.26 and 77.0 ppm, respectively, and chloroform is solvent with TMS as the internal standard. The NMR spectra were reported in delta (δ) units, parts per million (ppm) downfield from the internal

standard and coupling constants were reported in Hertz (Hz). Multiplicities were indicated as s (singlet), d (doublet), t (triplet), q (quartet), and m (multiplet). The mass spectra were performed on a Bruker Esquire 3000plus mass spectrometer equipped with ESI interface and ion trap analyzer. The ESI HR-MS were tested on Bruker 7-tesla FT-ICR MS equipped with an electrospray source.

General procedures for preparation of products 3 and 5. A mixture of N,N-dimethyl-2-arylethen-1-amines **1** or **4** (10 mmol), and benzothioamides **2** (12 mmol), Pd(OAc)₂ (10 mol %) and Cs₂CO₃ (2 equiv, 20 mmol), in DMSO (15 mL) was stirred under an N₂ atmosphere. After the reaction mixture was stirred at 100°C for 24 h, it was allowed to cool to ambient temperature. Next, the mixture was quenched with saturated salt water (20 mL), and the solution was extracted with ethyl acetate (3×20 mL). The organic layers were combined and dried by sodium sulfate and concentrated in a vacuum. The pure product 2,5-diarylthiazole derivatives **3** or **5** (76-89% yield) was obtained by flash column chromatography on silica gel.

2,5-diphenylthiazole (3a). Pale yellow solid, 2.38 g, isolated yield: 87%, m.p. 116-118 °C. ¹H NMR (CDCl₃, 400 MHz): δ 8.1 (q, 2H, *J* = 4.0 Hz), 7.7 (d, 2H, *J* = 7.6 Hz), 7.4 (m, 6H), 7.3 (t, 1H, *J* = 7.4 Hz); ¹³C NMR (CDCl₃, 100 MHz): δ 161, 151, 130, 129, 129, 128, 28, 127, 126, 124, 123; HRMS(ESI): *m/z* calcd for C₁₅H₁₁NNaS (M+Na)⁺: 260.0510, found: 260.0508.

5-phenyl-2-(p-tolyl)thiazole (3b). Pale yellow solid, 2.22 g, isolated yield: 84%, m.p. 117-119 °C. ¹H NMR (CDCl₃, 400 MHz): δ 8.0 (d, 2H, *J* = 8.0 Hz), 7.7 (d, 2H, *J* = 7.6 Hz), 7.4 (t, 3H, *J* = 7.0 Hz), 7.3 (d, 1H, *J* = 7.6 Hz), 7.3 (d, 2H, *J* = 8.0 Hz), 2.41 (s, 3H); ¹³C NMR (CDCl₃, 100 MHz): δ 161, 151, 140, 129, 128, 128, 128, 126, 124, 124, 123, 21; HRMS(ESI): *m/z* calcd for C₁₆H₁₃NNaS (M+Na)⁺: 274.0666, found: 274.0664.

2-(4-methoxyphenyl)-5-phenylthiazole (3c). Pale yellow solid, 2.35 g, isolated yield: 88%, m.p. 108-109 °C. ¹H NMR (CDCl₃, 400 MHz): δ 7.7 (t, 3H, *J* = 6.6 Hz), 7.6 (s, 1H), 7.4 (m, 5H), 7.00 (q, 1H, *J* = 4.2 Hz), 3.89 (s, 3H); ¹³C NMR (CDCl₃, 100 MHz): δ 161, 159, 151, 129, 128, 128, 128, 128, 124, 123, 118, 116, 111, 55; HRMS(ESI): *m/z* calcd for C₁₆H₁₃NNaOS (M+Na)⁺: 290.0616, found: 290.0614.

2-(3-methoxyphenyl)-5-phenylthiazole (3d). Pale yellow solid, 2.17 g, isolated yield: 81%, m.p. 121-124 °C. ¹H NMR (CDCl₃, 400 MHz): δ 7.7 (t, 2H, *J* = 6.6 Hz), 7.6 (s, 1H), 7.4 (m, 5H), 7.00 (q, 1H, *J* = 8.4 Hz); ¹³C NMR (CDCl₃, 100 MHz): δ 161, 160, 151, 130, 128, 128, 128, 128, 124, 123, 118, 116, 111, 55; HRMS(ESI): *m/z* calcd for C₁₆H₁₃NNaOS (M+Na)⁺: 290.0616, found: 290.0614.

2-(2-methoxyphenyl)-5-phenylthiazole (3e). Pale yellow solid, 2.03 g, isolated yield: 76%, m.p. 127-129 °C. ¹H NMR (CDCl₃, 400 MHz): δ 7.7 (t, 2H, *J* = 6.6 Hz), 7.6 (s, 1H), 7.3 (m, 5H), 7.0 (q, 1H, *J* = 8.4 Hz); ¹³C NMR (CDCl₃, 100 MHz): δ 161, 159, 151, 130, 129, 128, 128, 128, 124, 123, 118, 116, 111, 55; HRMS(ESI): *m/z* calcd for C₁₆H₁₃NNaOS (M+Na)⁺: 290.0616, found: 290.0614.

2-(4-chlorophenyl)-5-phenylthiazole (3f). Pale yellow solid, 2.15 g, isolated yield: 79%, m.p. 123-125 °C. ¹H NMR (CDCl₃, 400 MHz): δ 8.0 (d, 2H, *J* = 8.8 Hz), 7.7 (d, 2H, *J* = 7.6 Hz), 7.4 (m, 5H), 7.3 (t, 1H, *J* = 7.4 Hz); ¹³C NMR (CDCl₃, 100 MHz): δ 160, 151, 136, 129, 128, 128, 127, 127, 125, 124, 123; HRMS(ESI): *m/z* calcd for C₁₅H₁₀ClNNaS (M+Na)⁺: 294.0120, found: 294.0118.

2-(4-bromophenyl)-5-phenylthiazole (3g). Pale yellow solid, 2.53g, isolated yield: 80%, m.p. 120-122 °C. ¹H NMR (CDCl₃, 400 MHz): δ 7.9 (d, 2H, *J* = 8.8 Hz), 7.7 (d, 2H, *J* = 7.6 Hz), 7.6 (d, 2H, *J* = 8.8 Hz), 7.4 (m, 3H), 7.3 (t, 1H, *J* = 7.4 Hz); ¹³C NMR (CDCl₃, 100 MHz): δ 171, 160, 151, 132, 128, 128, 127, 127, 126, 124, 124, 123; HRMS(ESI): *m/z* calcd for C₁₅H₁₀BrNNaS (M+Na)⁺: 337.9615, found: 337.9613.

2-(4-nitrophenyl)-5-phenylthiazole (3h). Pale yellow solid, 2.34 g, isolated yield: 83%, m.p. 208-210 °C. ¹H NMR (CDCl₃, 400 MHz): δ 8.34 (d, 2H, *J* = 9.2 Hz), 8.1 (m, 2H), 7.8 (d, 2H, *J* = 8.8 Hz), 7.6 (s, 1H), 7.5 (t, 3H, *J* = 3.2 Hz); ¹³C NMR (CDCl₃, 100 MHz): δ 162, 149, 147, 133, 131, 129, 126, 126, 126, 124, 124; HRMS(ESI): *m/z* calcd for C₁₄H₅D₅N₂NaOS (M+Na)⁺: 305.0361, found: 305.0359.

5-phenyl-2-(thiophen-2-yl)thiazole (3i). Pale yellow solid, 2.00 g, isolated yield: 82%, m.p. 112-114 °C. ¹H NMR (CDCl₃, 400 MHz): δ 7.7 (d, 1H, *J* = 3.6 Hz), 7.7 (d, 2H, *J* = 7.6 Hz), 7.4 (m, 3H), 7.3 (s, 1H), 7.3 (t, 1H, *J* = 7.4 Hz), 7.1 (q, 1H, *J* = 4.4 Hz); ¹³C NMR (CDCl₃, 100 MHz): δ 157, 150, 130, 128, 128, 128, 127, 127, 127, 124, 123; HRMS(ESI): *m/z* calcd for C₁₃H₉NNaS₂ (M+Na)⁺: 266.0074, found: 266.0072.

5-phenyl-2-(pyridin-3-yl)thiazole (3j). Pale yellow solid, 1.86 g, isolated yield: 78%, m.p. 137-139 °C. ¹H NMR (CDCl₃, 400 MHz): δ 9.3 (d, 1H, *J* = 1.2 Hz), 8.6 (d, 1H, *J* = 3.2 Hz), 8.3 (d, 1H, *J* = 8.0 Hz), 7.7 (d, 2H, *J* = 7.6 Hz), 7.3 (m, 5H); ¹³C NMR (CDCl₃, 100 MHz): δ 158, 152, 150, 147, 133, 129, 128, 127, 124, 123, 123; HRMS(ESI): *m/z* calcd for C₁₄H₁₀N₂NaS (M+Na)⁺: 261.0462, found: 261.0460.

2,5-diphenylthiazole (5a). Pale yellow solid, 2.38 g, isolated yield: 87%, m.p. 116-118 °C. ¹H NMR (CDCl₃, 400 MHz): δ 8.1 (q, 2H, *J* = 4.0 Hz), 7.7 (d, 2H, *J* = 7.6 Hz), 7.4 (m, 6H), 7.3 (t, 1H, *J* = 7.4 Hz); ¹³C NMR (CDCl₃, 100 MHz): δ 161, 151, 130, 128, 128, 128, 28, 127, 126, 124, 123; HRMS(ESI): *m/z* calcd for C₁₅H₁₁NNaS (M+Na)⁺: 260.0510, found: 260.0508.

2-phenyl-5-(p-tolyl)thiazole (5b). Pale yellow solid, 2.19 g, isolated yield: 87%, m.p. 129-131 °C. ¹H NMR (CDCl₃, 400 MHz): δ 8.1 (d, 2H, *J* = 8.0 Hz), 7.6 (d, 2H, *J* = 8.0 Hz), 7.4 (m, 3H), 7.3 (s, 1H), 7.2 (d, 2H, *J* = 7.6 Hz), 2.39 (s, 3H); ¹³C NMR (CDCl₃, 100 MHz): δ 160, 151, 138, 130, 129, 128, 127, 126, 125, 124, 122, 21; HRMS(ESI): *m/z* calcd for C₁₆H₁₃NNaS (M+Na)⁺: 274.0666, found: 274.0664.

5-(4-methoxyphenyl)-2-phenylthiazole (5c). Colorless solid, 2.27 g, isolated yield: 85%, m.p. 128-129 °C. ¹H NMR (CDCl₃, 400 MHz): δ 8.1 (d, 2H, *J* = 6.4 Hz), 7.6 (d, 2H, *J* = 8.8 Hz), 7.4 (m, 3H), 7.3 (s, 1H), 6.9 (d, 2H, *J* = 8.8 Hz), 3.8 (s, 3H); ¹³C NMR (CDCl₃, 100 MHz): δ 160, 159, 151, 130, 128, 127, 126, 125, 122, 121, 114, 55; HRMS(ESI): *m/z* calcd for C₁₆H₁₃NNaOS (M+Na)⁺: 290.3358, found: 290.3356.

4-(2-phenylthiazol-5-yl)phenol (5d). Pale yellow solid, 2.13 g, isolated yield: 84%, m.p. 89-91 °C. ¹H NMR (DMSO-*d*, 400 MHz): δ 9.8 (s, 1H), 8.0 (t, 2H, *J* = 6.4 Hz), 7.6 (d, 2H, *J* = 8.8 Hz), 7.5 (s, 1H), 7.4 (m, 3H), 6.8 (d, 2H, *J* = 8.4 Hz); ¹³C NMR (DMSO-*d*, 100 MHz): δ 159, 158, 151, 130, 129, 127, 126, 126, 122, 119, 116; HRMS(ESI): *m/z* calcd for C₁₄H₅D₅N₂NaOS (M+Na)⁺: 276.0459, found: 276.0457.

5-(4-fluorophenyl)-2-phenylthiazole (5e). Pale yellow solid, 1.97g, isolated yield: 77%, m.p. 98-100 °C. ¹H NMR (CDCl₃, 400 MHz): δ 8.0 (q, 2H, *J* = 7.2 Hz), 7.6 (m, 2H), 7.4 (m, 3H), 7.3 (s, 1H), 7.1 (d, 2H, *J* = 8.8 Hz); ¹³C NMR (CDCl₃, 100 MHz): δ 161, 150, 130, 129, 128, 129, 127, 126, 126, 123, 116; HRMS(ESI): *m/z* calcd for C₁₅H₁₀FNNaS (M+Na)⁺: 278.0416, found: 278.0414.

5-(4-chlorophenyl)-2-phenylthiazole (5f). Colorless solid, 2.31 g, isolated yield: 85%, m.p. 110-112 °C. ¹H NMR (CDCl₃, 400 MHz): δ 8.0 (q, 2H, *J* = 3.8 Hz), 7.6 (d, 2H, *J* = 8.4 Hz), 7.4 (m, 3H), 7.4 (d, 2H, *J* = 3.6 Hz), 7.3 (s, 1H); ¹³C NMR (CDCl₃, 100 MHz): δ 161, 150, 134, 130, 129, 128, 127, 126, 126, 125, 123; HRMS(ESI): *m/z* calcd for C₁₅H₁₀ClNNaS (M+Na)⁺: 294.0120, found: 294.0118.

5-(4-bromophenyl)-2-phenylthiazole (5g). Pale yellow solid, 2.62 g, isolated yield: 83%, m.p. 111-113 °C. ¹H NMR (CDCl₃, 400 MHz): δ 8.0 (q, 2H, *J* = 4.0 Hz), 7.5 (s, 4H), 7.4 (m, 4H); ¹³C NMR (CDCl₃, 100 MHz): δ 161, 150, 132, 130, 128, 127, 127, 126, 125, 124, 123; HRMS(ESI): *m/z* calcd for C₁₅H₁₀BrNNaS (M+Na)⁺: 337.9615, found: 337.9613.

2-phenyl-5-(4-(trifluoromethyl)phenyl)thiazole (5h). Colorless solid, 2.29 g, isolated yield: 75%, m.p. 203-205 °C. ¹H NMR (CDCl₃, 400 MHz): δ 8.1 (q, 2H, *J* = 3.8 Hz), 7.8 (d, 2H, *J* = 8.0 Hz), 7.6 (d, 2H, *J* = 8.0 Hz), 7.5 (s, 1H), 7.4 (q, 3H, *J* = 2.4 Hz); ¹³C NMR (CDCl₃, 100 MHz): δ 162, 149, 131, 131, 130, 129, 128, 127, 126, 126, 125, 124; HRMS(ESI): *m/z* calcd for C₁₆H₁₀F₃NNaS (M+Na)⁺: 328.0384, found: 328.0382.

5-(4-nitrophenyl)-2-phenylthiazole (5i). Pale yellow solid, 2.51 g, isolated yield: 89%, m.p. 132-135 °C. ¹H NMR (CDCl₃, 400 MHz): δ 8.3 (d, 2H, *J* = 9.2 Hz), 8.1 (m, 2H), 7.8 (d, 2H, *J* = 8.8 Hz), 7.6 (s, 1H), 7.5 (d, 3H, *J* = 3.2 Hz); ¹³C NMR (CDCl₃, 100 MHz): δ 162, 149, 147, 133, 131, 129, 126, 126, 126, 124, 124; HRMS(ESI): *m/z* calcd for C₁₅H₁₀N₂NaO₂S (M+Na)⁺: 305.3068, found: 305.3066.

2,5-diphenylthiazole (7a). Pale yellow solid, 2.11 g, isolated yield: 87%, m.p. 118-120 °C. ¹H NMR (CDCl₃, 400 MHz): δ 8.1 (q, 2H, *J* = 4.0 Hz), 7.7 (d, 2H, *J* = 7.6 Hz), 7.4 (m, 6H), 7.3 (t, 1H, *J* = 7.4 Hz); ¹³C NMR (CDCl₃, 100 MHz): δ 161, 151, 130, 128, 128, 128, 28, 127, 126, 124, 123; HRMS(ESI): *m/z* calcd for C₁₅H₁₁NNaS (M+Na)⁺: 260.0510, found: 260.0508.

2-(2-methoxyphenyl)-5-(p-tolyl)thiazole (7b). Pale yellow solid, 1.80 g, isolated yield: 74%, m.p. 117-119°C. ¹H NMR (CDCl₃, 400 MHz): δ 7.7 (t, 2H, *J* = 6.6 Hz), 7.6 (s, 1H), 7.3 (m, 5H), 7.0 (q, 1H, *J* = 8.4 Hz); ¹³C NMR (CDCl₃, 100 MHz): δ 161, 159, 151, 130, 129, 128, 128, 128, 124, 123, 118, 116, 111, 55; HRMS(ESI): *m/z* calcd for C₁₇H₁₅NNaOS (M+Na)⁺: 304.0772, found: 304.0770.

5-(4-methoxyphenyl)-2-(naphthalen-1-yl)thiazole (7c). Pale yellow solid, 2.38 g, isolated yield: 85%, m.p. 109-112°C. ¹H NMR (CDCl₃, 400 MHz): δ 8.6 (s, 1H), 8.1 (d, 1H, *J* = 8.4 Hz), 7.7 (m, 5H), 7.47 (m, 5H), 7.3 (t, 1H, *J* = 7.2 Hz); ¹³C NMR (CDCl₃, 100 MHz): δ 161, 151, 134, 133, 128, 128, 128, 128, 128, 127, 127, 126, 126, 124, 124, 123, 123; HRMS(ESI): *m/z* calcd for C₂₀H₁₅NNaOS (M+Na)⁺: 340.0772, found: 340.0770.

2-phenyl-5-(m-tolyl)thiazole (7d). Pale yellow solid, 1.81 g, isolated yield: 82%, m.p. 119-121°C. ¹H NMR (CDCl₃, 400 MHz): δ 8.1 (d, 2H, *J* = 8.0 Hz), 7.6 (d, 2H, *J* = 8.0 Hz), 7.4 (m, 3H), 7.4 (s, 1H), 7.2 (d, 2H, *J* = 7.6 Hz), 2,3 (s, 3H); ¹³C NMR (CDCl₃, 100 MHz): δ 160, 151, 138, 130, 129, 128, 127, 126, 125, 124, 122, 21; HRMS(ESI): *m/z* calcd for C₁₆H₁₃NNaS (M+Na)⁺: 274.0666, found: 274.0664.

5-(3-chlorophenyl)-2-(2-methoxyphenyl)thiazole (7e). Pale yellow solid, 2.39 g, isolated yield: 89%, 112-114 °C. ¹H NMR (CDCl₃, 400 MHz): δ 8.1 (m, 2H), 7.6 (s, 1H), 7.5 (d, 1H, *J* = 8.0 Hz), 7.4 (m, 4H), 7.3 (t, 1H, *J* = 8.0 Hz), 7.2 (d, 1H, *J* = 8.4 Hz); ¹³C NMR (CDCl₃, 100 MHz): δ 161, 149, 135, 130, 130, 129, 128, 128, 127, 126, 124, 124, 122; HRMS(ESI): *m/z* calcd for C₁₆H₁₂ClNNaOS (M+Na)⁺: 324.0226, found: 324.0224.

5-(2-chlorophenyl)-2-(naphthalen-1-yl)thiazole (7f). Colorless solid, 2.00 g, isolated yield: 72%, 111-112 °C. ¹H NMR (CDCl₃, 400 MHz): δ 8.1 (q, 2H, *J* = 3.8 Hz), 7.7 (s, 1H), 7.5 (d, 1H, *J* = 8.0 Hz), 7.4 (m, 4H), 7.3 (t, 1H, *J* = 8.0 Hz), 7.3 (d, 1H, *J* = 8.4 Hz); ¹³C NMR (CDCl₃, 100 MHz): δ 161, 149, 135, 130, 130, 129, 128, 128, 127, 126, 124, 124, 122; HRMS(ESI): *m/z* calcd for C₁₉H₁₂ClNNaS (M+Na)⁺: 344.0277, found: 344.0275.

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Supplementary Material

Spectroscopic data of synthesized compounds are available in the Supplementary material file associated with this manuscript.

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