NJC

PAPER

View Article Online
View Journal

Cite this: DOI: 10.1039/c5nj00959f

A sequential one-pot approach to 1,2,4,5-tetrasubstituted-2*H*-imidazole synthesis from disubstituted alkynes†

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Received (in Montpellier, France)
17th April 2015,
Accepted 29th June 2015

DOI: 10.1039/c5nj00959f

www.rsc.org/njc

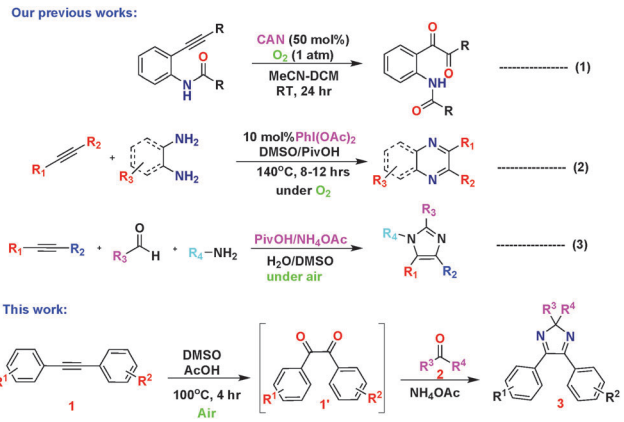
A sequential one-pot approach to the tetrasubstituted 2*H*-imidazole scaffolds has been developed from disubstituted alkynes and structurally diverse ketones. The reaction proceeds *via* a diketo intermediate generated from internal alkynes followed by the addition of ammonium acetate and a suitable ketone, affording a diverse range of 2*H*-imidazoles. Using air-moisture stable reaction conditions and inexpensive reagents, the transformation demonstrates a broad substrate scope and good functional group compatibility.

Introduction

Imidazole derivatives are valuable synthetic targets because of their uses in numerous natural products, pharmaceuticals and materials science.[1] In medicinal chemistry, these compounds are well-known for their anti-cancer, anti-fungal and anti-bacterial activities.[2] Owing to their profound applications in chemistry and biology, much interest has been focused on the synthesis of a diverse range of imidazoles.

Although numerous reports have documented 1*H*-imidazole derivatives, 2*H*-imidazoles have appeared less frequently in the literature.[3] In 1952, Weiss reported the first synthesis of 2,2,4,5-tetrasubstituted-2*H*-imidazoles from benzils *via* condensation.[4] Furthermore, a few other methods were also developed for these compounds.[5] Moreover, the diazaspiro derivatives of 2*H*-imidazole derivatives have proven to be useful precursors in the preparation of racemic-(1*R*,2*R* and 1*S*,2*S*)-transdiphenylethylenediamines, which are useful ligands and chiral auxiliaries for asymmetric synthesis.[6] Thus, the development of simple and efficient approaches to these compounds from commercially available starting materials is desirable.

Recently, our group developed an *ortho* substituted amide-directed oxidation of alkynes using CAN in the presence of oxygen (Scheme 1, eqn (1)).[7a] Furthermore, we extended the concept of oxidizing alkynes followed by reaction with various nucleophiles to generate useful heterocycles such as quinoxalines (Scheme 1, eqn (2))[7b] and 1*H*-imidazoles (eqn (3)).[7c] Based on our previous works and continuous interest in the development of new synthesis methods,[8] herein we report a sequential one-pot approach to the construction of 2*H*-imidazoles from disubstituted alkynes *via* oxidation followed by condensation (Scheme 1, eqn (4)). Moreover, the one-pot strategies have gained significant attention due to their several advantages such as successive reactions in the same reactor, no purification, and savings on cost, time and amounts of reagents and solvents.[9]



Scheme 1 Our previous and present studies.

Results & discussion

We started our investigation using diphenylacetylene (**1a**) and cyclohexanone (**2a**) as a model substrate; the results are presented in Table 1. First, compounds **1a**, **2b**, ammonium acetate and trifluoroacetic acid (TFA) were added to DMSO at the same time and heated to 100 °C for 8 h; the reaction failed to proceed

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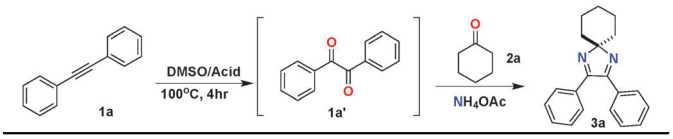
† Electronic supplementary information (ESI) available. CCDC 1404628 (**3c**). For ESI and crystallographic data in CIF or other electronic format see DOI: 10.1039/c5nj00959f

Table 1 Optimization of conditions[a]



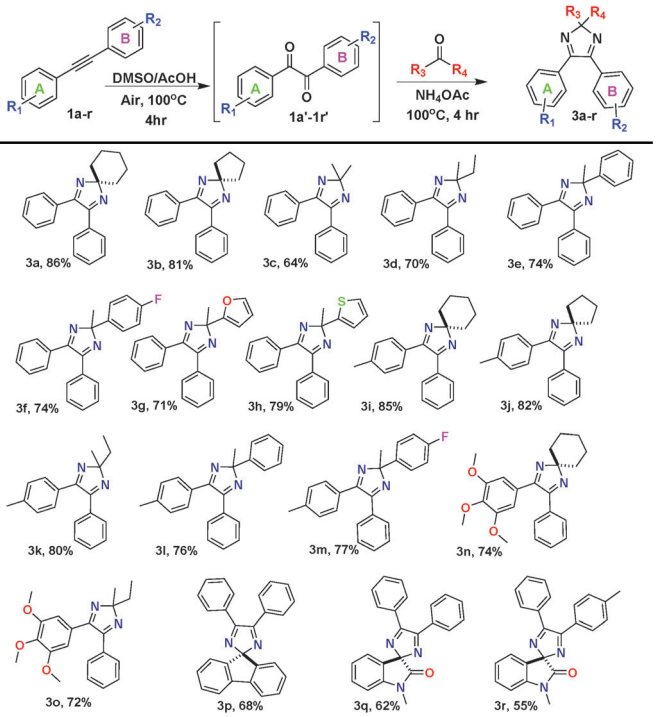
Entry	Acid	Temp. (°C)	Time (h)	Yield[b] (%)
1[c]	TFA	100	8	Traces
2	TFA	100	4 + 4	76
3	TfOH	100	4 + 4	82
4	PivOH	100	4 + 4	75
5	AcOH	100	4 + 4	86
6	MsOH	100	4 + 4	38
7	TsOH	100	4 + 4	40
8	AcOH	120	4 + 4	81
9	AcOH	80	4 + 4	76
10	AcOH	100	4 + 4	60
11[d]	AcOH	100	4 + 4	53
12	—	100	4 + 4	—

[a] Reaction conditions: step I: **1a** (1 mmol), DMSO (4 ml) and acid (4 eq.) heated to 100 °C for 4 hours under air; step II: **2a** (1.3 mmol) and NH_4OAc (4 eq.) heated to 100 °C for 4 hours. [b] Isolated yields. [c] All the reagents were added at one time and heated to 100 °C for 4 hours. [d] NH_4OAC (2 eq.).

(Table 1, entry 1). Instead of adding all the reagents at the same time, we planned the reaction with sequential additions of compound **1a** in acid/DMSO to oxidize into a diketo compound, followed by compound **2a** and ammonium acetate. Accordingly, we attempted a reaction with compound **1a** and TFA in DMSO, and heated it to 100 °C for 4 hours to complete the oxidation (monitored by TLC), followed by the addition of compound **2a** and ammonium acetate at 100 °C for another 4 hours. To our delight, the expected 2*H*-imidazoles were obtained in 76% yield (entry 2). Furthermore, we focused our studies on preparing these scaffolds *via* a sequential one-pot approach. To improve the reaction yield, various acids were screened, and acetic acid provided the best yield among them (entries 3–7). Reducing the equivalent of ammonium acetate affected the reaction yield (entry 11). Deviating from our optimized temperature (100 °C) in either direction decreased the reaction yield (entries 8 and 9). When the reaction was performed in the absence of an acid source, the reaction failed to proceed (entry 12). From this result, we confirm that the acid source was necessary for both the steps. Finally, we concluded entry 5 as an optimized reaction condition.

Having identified the suitable reaction conditions, the applicability of the range of diversely substituted 2*H*-imidazoles was investigated, as shown in Table 2. First, we examined the scope of various aliphatic and aromatic ketones at R^3 and R^4 positions. Replacement of R^3 and R^4 with cyclic (**3a–b**) and acyclic ketones (**3c–d**) was well tolerated and the desired products were isolated in high yields. The feasibility of aromatic (**3e–f**) and heterocyclic ketones (**3g–h**) was also studied: the reaction proceeded smoothly to give the expected products. Furthermore, the R^1 and R^2 groups in phenyl acetylene were replaced with methyl and trimethoxy groups and corresponding products (**3h–o**) were isolated in good yields. It can be noted that the reaction was suitable for other interesting heterocyclic derivatives such as fluorene (**3p**) and isatins (**3q–r**), and the products were successfully isolated in

Table 2 Substrate scope of the 2*H*-imidazoles[a]



[a] Reaction conditions: step A: **1** (1 mmol), AcOH (4 eq.), DMSO (4 ml) heated to 100 °C for 4 hours; step B: **2** (1.3 mmol) and NH_4OAc (4 eq.) heated to 100 °C for 4 hours.

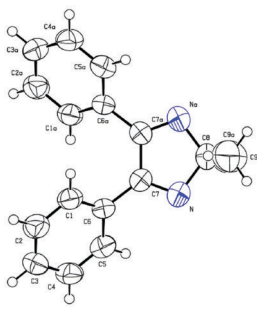
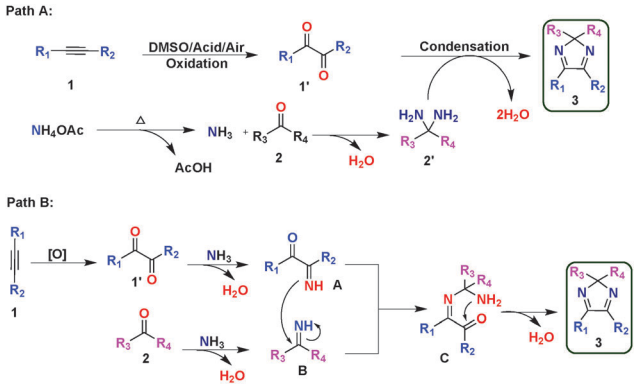


Fig. 1 X-ray structure of compound **3c**.

moderate to good yields. Attempts to replace ketones (**2**) with aldehydes failed. The probable reason could be that the geminal diamine (**2′**) intermediate of aldehydes is more reactive and may not be stable under the reaction conditions. The structure of compound **3c** was unambiguously confirmed by X-ray analysis (Fig. 1).‡

Based on these observations and previous literature,[10,11] we proposed a two reaction mechanism, as shown in Scheme 2 (Path A and B). In Path A, compound **1** oxidized in the presence of DMSO and acid generates the diketo intermediate (**1′**). Moreover, the decomposition of ammonium acetate under the reaction conditions generates ammonia, which subsequently reacts with ketone (**2**), providing the diamine intermediate (**2′**). Finally, the condensation between **1′** and **2′** with the elimination of water gives

‡ CCDC 1404628 (**3c**).



Scheme 2 Proposed reaction mechanism.

the final product **3**. In Path B,[12] the diketo intermediate (**1′**) and ketone are converted into corresponding imines (A & B). The nucleophilic addition of α-imino ketone (A) to imine (B) generates intermediate C. Finally, the intramolecular condensation of intermediate C produces the desired product 3.

Conclusion

In summary, a simple and convenient sequential one-pot approach to tetrasubstituted 1*H*-imidazoles was successfully synthesized. The course of the reaction proceeded through the internal alkynes being oxidized into diketo intermediates (**1′**), which were captured with various ketones (**2**) and ammonium acetate, giving the desired products. In particular, when cyclic ketones such as cyclohexanone, isatins, and fluorenes were used, the reactions provide interesting spirocyclic imidazole products. Additional features of the study consist of a one-pot approach, commercially available starting materials, inexpensive reagents, operational simplicity and moderate to high reaction yields. These advantages make this methodology a new alternative approach for this rare class of 2*H*-imidazole derivatives and further biological studies of the synthesized compounds are underway in our laboratory.

Experimental

Materials and methods

All chemicals were purchased as best grade commercially available and were used without further purification. All solvents were purchased as HPLC grade and were used without any purification or distillation. Analytical thin layer chromatography was performed on an aluminium plate coated with silica gel (Merck). Gravity column chromatography was performed using 100–200 mesh silica gel, and mixtures of hexane-ethyl acetate were used for elution. Visualization was accomplished using ultraviolet light (254 nm) and chemical staining with acidic potassium permanganate solution, ninhydrin and iodine. Melting points were determined using "Mel-Temp" melting point apparatus and were uncorrected. Proton nuclear magnetic resonance (^{1}H NMR) and carbon nuclear magnetic resonance (^{13}C NMR) spectra were obtained using a Varian (400 MHz) spectrometer. High resolution mass spectra (HRMS) were obtained on a Micromass Q-TOF spectrometer using EI (electron impact, 70 eV).

General experimental procedure for compound 1a

An oven dried round-bottom flask was charged with compound **1a** (1 mmol) and acetic acid (4 equiv.) in DMSO (4 ml) and was heated to 100 °C in air atmosphere for 4 hours. After the diketo intermediate (**1a′**) was formed (monitored by TLC), the reaction mixture was cooled to room temperature. Then, compound **2a** (1.3 mmol) and ammonium acetate (4 eq.) were added and the mixture was heated to 100 °C for another four hours. After the reaction was completed (monitored by TLC), the reaction mass was poured into water and extracted with EtOAc. The combined organic layer was washed with brine solution and dried and evaporated to remove the solvent. The crude residue was passed through flash column chromatography to afford the title compound as a white solid (**3a**, 86%).

2,3-Diphenyl-1,4-diazaspiro[4.5]deca-1,3-diene (3a). Yield: 86%; white solid; m.p.: 104 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51–7.48 (m, 4H), 7.45–7.41 (m, 2H), 7.37–7.33 (m, 4H), 1.99–1.93 (m, 4H), 1.83–1.80 (m, 4H), 1.76–1.70 (m, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 164.0, 133.0, 129.9, 128.8, 128.2, 114.4, 104.0, 34.6, 25.6, 24.0. HRMS-ESI (*m*/*z*): calcd for $C_{20}H_{20}N_2$ $[M + 1]^+$: 288.1626, found 289.1698.

2,3-Diphenyl-1,4-diazaspiro[4.4]nona-1,3-diene (3b). Yield: 81%; purple solid; m.p. 101 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52–7.49 (m, 4H), 7.44–7.40 (m, 2H), 7.36–7.32 (m, 4H), 2.22–2.13 (m, 8H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 163.8, 132.6, 129.9, 128.7, 128.2, 111.4, 35.3, 26.1. HRMS-ESI (*m*/*z*): calcd for $C_{19}H_{18}N_2$ $[M + 1]^+$: 274.1470, found 275.1540.

2,2-Dimethyl-4,5-diphenyl-2*H*-imidazole (3c). Yield: 64%; purple solid; m.p. 74 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52–7.49 (m, 4H), 7.46–7.41 (m, 2H), 7.37–7.33 (m, 4H), 1.66 (s, 6H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 164.1, 132.5, 130.1, 128.7, 128.2, 101.5, 24.0. HRMS-ESI (*m*/*z*): calcd for $C_{17}H_{16}N_2$ $[M + 1]^+$: 248.1313, found 249.1387.

2-Ethyl-2-methyl-4,5-diphenyl-2*H*-imidazole (3d). Yield: 70%; brown solid; m.p. 98 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51–7.48 (m, 4H), 7.42–7.38 (m, 2H), 7.34–7.30 (m, 4H), 2.20 (q, J = 7.2 Hz, 2H), 1.64 (s, 3H), 0.76 (t, J = 7.2 Hz, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 164.5, 132.5, 129.9, 128.6, 128.1, 103.7, 30.7, 22.63, 8.05. HRMS-ESI (*m*/*z*): calcd for $C_{17}H_{16}N_2$ $[M + 1]^+$: 262.1470, found 263.1542.

2-Methyl-2,4,5-triphenyl-2*H*-imidazole (3e). Yield: 74%; brown sticky oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.86–7.83 (m, 2H), 7.58–7.56 (m, 4H), 4.49–7.44 (m, 2H), 7.40–7.36 (m, 6H), 7.33–7.26 (m, 1H), 1.96 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 164.5, 140.6, 132.2, 128.9, 128.27, 128.24, 127.5, 127.1, 27.5. HRMS-ESI (*m*/*z*): calcd for $C_{22}H_{18}N_2$ $[M + 1]^+$: 310.1470, found 311.1540.

2-(4-Fluorophenyl)-2-methyl-4,5-diphenyl-2*H*-imidazole (3f). Yield: 74%; pale-yellow solid; m.p. 108 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.80–7.76 (m, 2H), 7.56–7.53 (m, 4H), 7.49–7.44 (m, 2H), 7.39–7.36 (m, 4H), 7.07–7.02 (m, 2H), 1.90 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 164.7, 163.4, 160.9, 132.3, 130.4,

128.9, 128.9, 128.8, 128.3, 115.1, 114.9, 104.5, 27.6. HRMS-ESI (*m*/*z*): calcd for $C_{22}H_{17}FN_2$ $[M + 1]^+$: 328.1376, found 329.1445.

2-(Furan-2-yl)-2-methyl-4,5-diphenyl-2*H*-imidazole (3g). Yield: 71%; orange solid; m.p. 81 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56–7.54 (m, 4H), 7.48–7.44 (m, 2H), 7.40–7.35 (m, 4H), 7.33–7.322 (dd, J = 7.6, 1.2 Hz, 1H), 7.24–7.23 (dd, J = 5.2, 1.2 Hz, 1H), 7.01 (dd, J = 5.2, 3.6 Hz, 1H), 2.02 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 165.1, 141.6, 132.1, 130.4, 129.0, 128.9, 128.2, 126.6, 125.0, 124.6, 103.0, 27.5. HRMS-ESI (*m*/*z*): calcd for $C_{20}H_{16}FN_2O$ $[M + 1]^+$: 300.1263, found 301.1278.

2-Methyl-4,5-diphenyl-2-(thiophen-2-yl)-2*H*-imidazole (3h). Yield: 79%; orange solid; m.p. 89 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.58–7.55 (m, 3H), 7.49–7.44 (m, 2H), 7.41–7.37 (m, 4H), 6.37–6.32 (m, 1H), 1.99 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 166.1, 150.6, 142.6, 132.0, 130.5, 129.0, 128.2, 110.1, 106.4, 101.2, 23.0. HRMS-ESI (*m*/*z*): calcd for $C_{20}H_{16}N_2S$ $[M + 1]^+$: 316.1034, found 303.1853.

2-Phenyl-3-(*p*-tolyl)-1,4-diazaspiro[4.5]deca-1,3-diene (3i). Yield: 85%; sticky yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52–7.48 (m, 2H), 7.44–7.32 (m, 5H), 7.14 (d, J = 7.6 Hz, 2H), 2.36 (s, 3H), 1.98–1.92 (m, 4H), 1.81–1.80 (m, 4H), 1.75–1.70 (m, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 164.1, 163.8, 140.0, 133.1, 129.9, 129.8, 128.8, 128.7, 128.1, 16, 128.12, 103.7, 34.5, 25.5, 23.9, 21.3. HRMS-ESI (*m*/*z*): calcd for $C_{21}H_{22}N_2$ $[M + 1]^+$: 302.1783, found 303.1853.

2-Phenyl-3-(*p*-tolyl)-1,4-diazaspiro[4.4]nona-1,3-diene (3j). Yield: 82%; orange sticky oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52–7.49 (m, 2H), 7.45–7.33 (m, 5H), 7.15 (d, J = 8.0 Hz, 2H), 2.37 (s, 3H), 2.19–2.14 (m, 8H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 164.0, 163.8, 140.2, 132.9, 129.9, 129.7, 129.1, 128.9, 128.8, 128.2, 128.2, 111.3, 35.4, 29.6, 26.2, 21.4. HRMS-ESI (*m*/*z*): calcd for $C_{20}H_{20}N_2$ $[M + 1]^+$: 288.1626, found 289.1696.

2-Ethyl-2-methyl-4-phenyl-5-(*p*-tolyl)-2*H*-imidazole (3k). Yield: 80%; sticky orange oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51–7.49 (m, 2H), 7.45–7.32 (m, 5H), 7.15–7.13 (dd, J = 8.4, 0.4 Hz, 2H), 2.36 (s, 3H), 2.18 (q, J = 7.2 Hz, 2H), 1.64 (s, 3H), 0.757 (t, J = 7.6 Hz, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 164.8, 164.5, 140.2, 132.7, 129.9, 129.6, 128.8, 128.7, 128.1, 103.6, 30.8, 22.7, 21.3, 8.0. HRMS-ESI (*m*/*z*): calcd for $C_{19}H_{20}N_2$ $[M + 1]^+$: 276.1626, found 277.1696.

2-Methyl-2,4-diphenyl-5-(*p*-tolyl)-2*H*-imidazole (3l). Yield: 76%; sticky orange oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85–7.82 (m, 2H), 7.59–7.56 (m, 2H), 7.48–7.44 (m, 3H), 7.40–7.35 (m, 4H), 7.32–7.28 (m, 1H), 7.18 (d, J = 8.0 Hz, 2H), 2.40 (s, 3H), 1.95 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 164.7, 164.4, 140.7, 140.4, 132.6, 130.2, 130.1, 129.5, 128.9, 128.27, 128.24, 128.20, 127.5, 127.4, 127.1, 104.8, 27.5, 21.4. HRMS-ESI (*m*/*z*): calcd for $C_{23}H_{20}N_2$ $[M + 1]^+$: 324.1626, found 325.1696.

2-(4-Fluorophenyl)-2-methyl-4-phenyl-5-(*p*-tolyl)-2*H*-imidazole (3m). Yield: 77%; white solid; m.p. 116 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81–7.77 (m, 2H), 7.57–7.54 (m, 2H), 7.48–7.36 (m, 5H), 7.18 (d, J = 8.0 Hz, 2H), 7.07–7.02 (m, 2H), 2.39 (s, 3H), 1.90 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 164.8, 164.5, 140.6, 136.5 (J_F = 4.6 Hz), 132.5. 130.3, 129.4, 128.9, 128.9, 128.8, 128.7, 128.3, 128.2, 115.1, 114.9, 104.3, 27.6, 21.4. HRMS-ESI (*m*/*z*): calcd for $C_{23}H_{19}FN_2$ $[M + 1]^+$: 342.1532, found 343.1602.

2-Phenyl-3-(3,4,5-trimethoxyphenyl)-1,4-diazaspiro[4.5]deca-1,3-diene (3n). Yield: 74%; pale-yellow solid; m.p. 173 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53–7.51 (m, 2H), 7.43–7.37 (m, 3H), 6.74 (s, 2H), 3.86 (s, 3H), 3.68 (s, 3H), 1.96–1.92 (m, 4H), 1.90–1.84 (m, 2H), 1.77–1.67 (m, 4H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 164.3, 163.5, 153.1, 139.8, 133.7, 130.0, 129.1, 128.4, 128.1, 106.5, 104.1, 61.1, 56.1, 34.9, 25.8, 24.3. HRMS-ESI (*m*/*z*): calcd for $C_{23}H_{26}N_2O_3$ $[M + 1]^+$: 378.1943, found 379.2013.

2-Ethyl-2-methyl-4-phenyl-5-(3,4,5-trimethoxyphenyl)-2*H*-imidazole (3o). Yield: 72%; pale-yellow solid; m.p. 172 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53–7.50 (m, 2H), 7.46–7.36 (m, 3H), 6.72 (s, 2H), 3.85 (s, 3H), 3.66 (s, 6H), 2.23–2.14 (m, 2H), 1.64 (s, 3H), 0.77 (t, J = 7.2 Hz, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 164.8, 164.0, 152.8, 139.6, 133.0, 129.9, 128.8, 128.2, 127.4, 106.2, 103.7, 60.8, 55.8, 30.8, 29.6, 22.7, 8.2. HRMS-ESI (*m*/*z*): calcd for $C_{21}H_{24}N_2O_3$ $[M + 1]^+$: 352.1787, found 353.1798.

4′,5′-Diphenylspiro[fluorene-9,2′-imidazole] (3p). Yield: 68%; white solid; m.p. 230 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.80 (d, J = 7.6 Hz, 2H), 7.71–7.68 (m, 4H), 7.53–7.49 (m, 2H), 7.44–7.40 (m, 6H), 7.26–7.21 (m, 2H), 6.89 (d, J = 7.6 Hz, 2H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 168.5, 142.2, 138.7, 132.1, 130.7, 129.6, 129.1, 128.3, 127.8, 123.1, 120.8. HRMS-ESI (*m*/*z*): calcd for $C_{27}H_{18}N_2$ $[M + 1]^+$: 370.1470, found 371.1541.

1′-Methyl-4,5-diphenylspiro[imidazole-2,3′-indolin]-2′-one (3q). Yield: 62%; white solid; m.p. 232 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.58 (d, J = 6.8 Hz, 1H), 7.61–7.56 (m, 3H), 7.46–7.42 (m, 5H), 7.41–7.38 (m, 1H), 7.33–7.31 (m, 1H), 7.25–7.20 (m, 3H), 3.68 (s, 3H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 146.4, 142.6, 136.3, 131.1, 131.0, 130.8, 128.5, 128.2, 128.0, 127.9, 127.5, 125.9, 124.5, 123.8, 30.7. HRMS-ESI (*m*/*z*): calcd for $C_{23}H_{17}N_3O$ $[M + 1]^+$: 351.137, found 352.1441.

1′-Methyl-4-phenyl-5-(*p*-tolyl)spiro[imidazole-2,3′-indolin]-2′-one (3r). Yield: 55%; pale-yellow solid; m.p. 185 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.54–8.52 (dd, J = 7.6, 1.2 Hz, 2H), 7.64–7.47 (m, 6H), 7.39–7.35 (m, 2H), 7.30–7.26 (m, 3H), 7.08 (d, J = 8.0 Hz, 1H), 3.65 (s, 3H), 2.46–2.32 (d, J = 5.6 Hz, 3H). HRMS-ESI (*m*/*z*): calcd for $C_{24}H_{19}N_3O$ $[M + 1]^+$: 365.1528, found 366.1599.

Benzil (1a′). Yield 92%; yellow solid; m.p. 92 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.99–7.96 (m, 4H), 7.68–7.64 (tt, J = 8.0, 1.6 Hz, 2H), 7.54–7.49 (m, 4H). ^{13}C NMR ($CDCl_3$, 100 MHz): δ 194.5, 134.88, 129.8, 129.0.

Acknowledgements

The authors gratefully acknowledge funding from the Ministry of Science and Technology (MOST), Taiwan, and the Centre for Research Resources and Development of Kaohsiung Medical University for 400 MHz NMR analyses.

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