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Microwave-assisted synthesis of sydnonyl-substituted imidazoles

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Abstract—3-Aryl-4-formylsydnones **1a–d** react with symmetrical 1,2-dicarbonyl compounds, such as benzil (**2a**), 4,4′-dimethoxybenzil (**2b**), 4,4′-difluorobenzil (**2c**), and di-2-thienylethanedione (**2d**), in glacial acetic acid, using ammonium acetate as the ammonia source, to yield 4,5-diaryl-2-sydnonyl-substituted imidazoles **3a–6d** under conventional heating. In a similar treatment, 4,5-diaryl-2-sydnonyl-1-substituted imidazoles **8a–10a** can be prepared by the one-pot condensation of 3-(4-ethoxyphenyl)-4-formylsydnone (**1d**), benzil derivatives, ammonium acetate, and primary amines. However, such reactions, which take 1–3 days at high temperature under classical conditions, are completed successfully within a few minutes under microwave irradiation.

1. Introduction

The importance of imidazoles in biological systems attracted great interest because of their chemical and biochemical characteristics. Even today, research in imidazole chemistry continues unabated. Compounds with an imidazole ring system have numerous pharmacological properties and play important roles in biochemical processes.[1,2] Many substituted imidazoles are known as inhibitors of P38 MAP kinase, fungicides and herbicides, plant growth regulators, and therapeutic agents.[1–4] Several sydnone compounds are also associated with pharmacological activities, including antimicrobial, anti-inflammatory, analgesic and antipyretic properties.[5–10] In view of the continued interest in the development of simpler and more convenient synthetic routes for preparing heterocyclic systems,[11–16] this investigation reports an effective approach for synthesizing some novel 4,5-diaryl-2-sydnonyl-substituted imidazoles **3a–6d** via the one-pot condensation of 3-aryl-4-formylsydnones **1a–d** with symmetrical 1,2-dicarbonyl compounds, including benzil (**2a**), 4,4′-dimethoxybenzil (**2b**), 4,4′-difluorobenzil (**2c**), and di-2-thienylethanedione (**2d**), in glacial acetic acid using ammonium acetate as the ammonia source under conventional heating (Scheme 1). A similar treatment yields 4,5-diaryl-2-sydnonyl-1-substituted imidazoles **8a–10a** by the condensation of 3-(4-ethoxyphenyl)-4-formylsydnone (**1d**), benzil derivatives, ammonium acetate, and primary amines (Scheme 2).

Keywords: Microwave-assisted synthesis; One-pot condensation; Heterocycles; Sydnones; Imidazoles.
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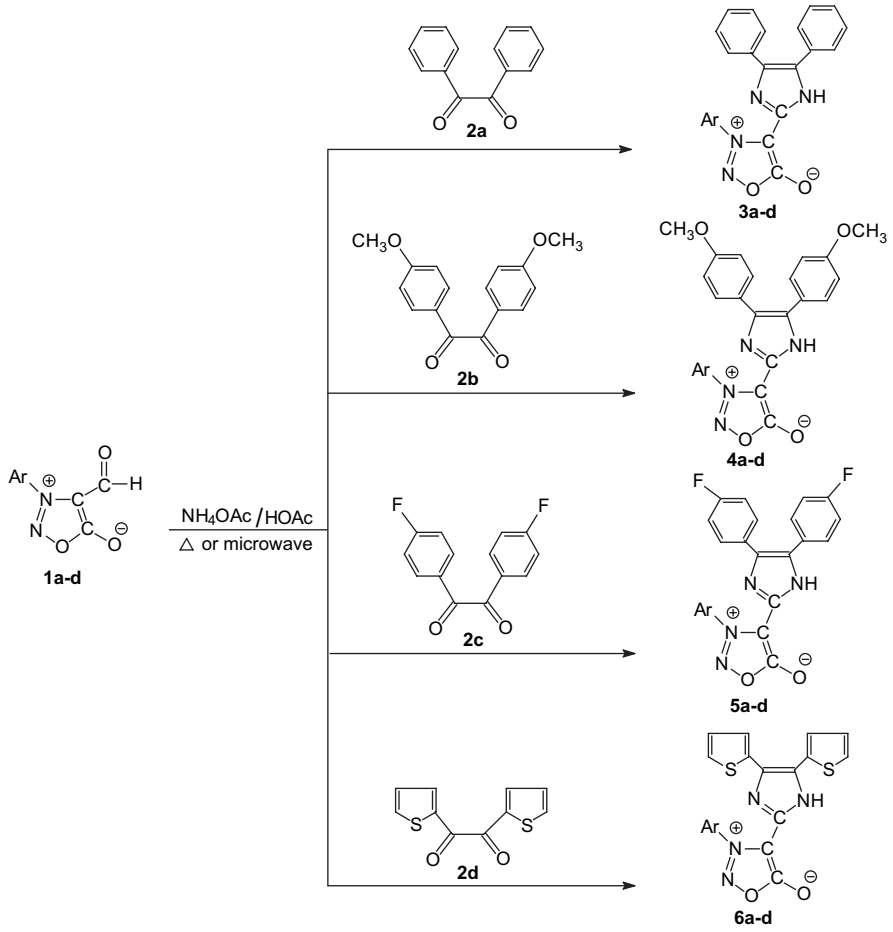
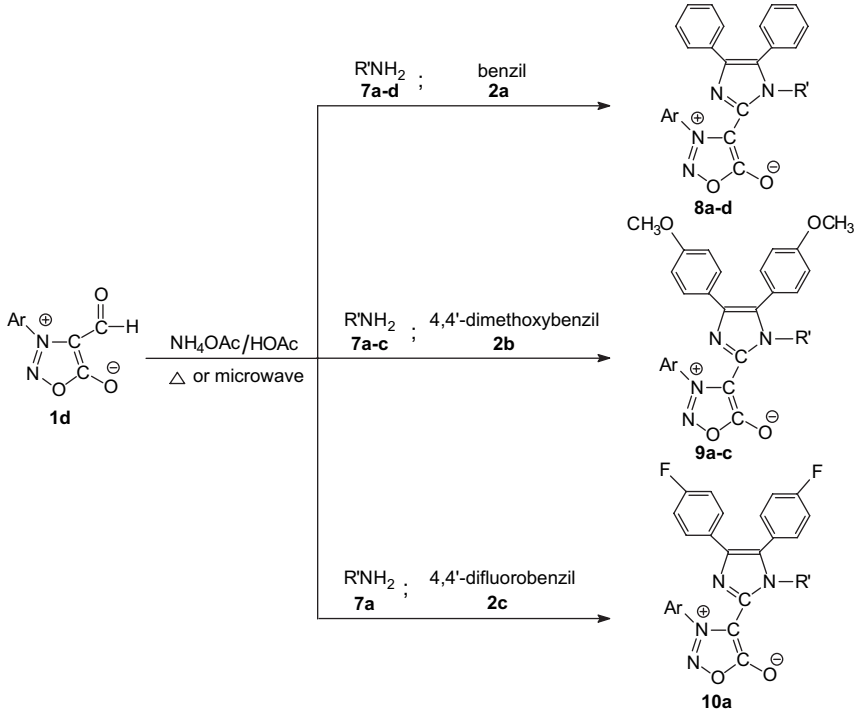
However, the synthetic protocols for sydnonyl-substituted imidazoles require a period of 1–3 days and high temperature under classical conditions. Microwave-assisted organic synthesis is a new and rapidly growing area in synthetic organic chemistry. This synthetic technique is based on the empirical observation that some organic reactions proceed much more quickly and with higher yields under microwave irradiation than under conventional heating. In many cases, reactions that usually require many hours at the reflux temperature under classical conditions can be completed within a few minutes or even seconds in a microwave oven, even at similar reaction temperatures.[17–25] To the best of the authors' knowledge, although microwave-assisted organic syntheses have been well documented, no example of sydnonyl-substituted derivatives synthesized with the microwave irradiation has yet been reported. This work also applies microwave irradiation to the syntheses of diverse sydnonyl-substituted imidazoles rather than classical conditions (Schemes 1 and 2).

2. Results and discussion

Several methods of synthesizing imidazoles have been reported. They include the two-pot syntheses of arylglyoxals, primary amines, carboxylic acids, and isocyanides,[26] the reaction of *N*-(2-oxo)amides with ammonium trifluoroacetate,[27] 1,2-aminoalcohols in the presence of PCl_5,[28] diketones, aldehyde, amine, and ammonium acetate in phosphoric acid,[29] and others.[30–32] However, many of the reported synthetic protocols for imidazoles, which are substituted with the same or different groups on the 4,5-positions, suffer from one or more disadvantages, including



Scheme 1. **1a**: Ar=C_6H_5; **1b**: Ar=*p*-$CH_3C_6H_4$; **1c**: Ar=*p*-$CH_3OC_6H_4$; **1d**: Ar=*p*-$C_2H_5OC_6H_4$.



Scheme 2. **1d**: Ar=*p*-$C_2H_5OC_6H_4$; **7a**: R′=*iso*-butyl; **7b**: R′=$C_6H_5CH_2CH_2$; **7c**: R′=$C_6H_5CH_2$; **7d**: R′=$CH_3(CH_2)_5$.

Table 1. Comparison between microwave irradiation (M.W.) and conventional heating (C.H.) in the syntheses of imidazoles **3a–6d**

Starting materials	1,2-Diketones	Products	C.H. reaction time (days)	C.H. yield[a] (%)	M.W. (100 W) reaction time (min)	M.W. (100 W) yield[a] (%)
1a (Ar=C_6H_5)	**2a**	**3a**	1.5	46	30	52
1b (Ar=*p*-$CH_3C_6H_4$)	**2a**	**3b**	1.5	61	30	78
1c (Ar=*p*-$CH_3OC_6H_4$)	**2a**	**3c**	1.5	51	30	69
1d (Ar=*p*-$C_2H_5OC_6H_4$)	**2a**	**3d**	1.5	68	30	76
1a (Ar=C_6H_5)	**2b**	**4a**	2	58	45	70
1b (Ar=*p*-$CH_3C_6H_4$)	**2b**	**4b**	2	77	45	80
1c (Ar=*p*-$CH_3OC_6H_4$)	**2b**	**4c**	2	64	45	74
1d (Ar=*p*-$C_2H_5OC_6H_4$)	**2b**	**4d**	2	67	45	75
1a (Ar=C_6H_5)	**2c**	**5a**	2	59	60	78
1b (Ar=*p*-$CH_3C_6H_4$)	**2c**	**5b**	2	72	60	85
1c (Ar=*p*-$CH_3OC_6H_4$)	**2c**	**5c**	2	60	60	76
1d (Ar=*p*-$C_2H_5OC_6H_4$)	**2c**	**5d**	2	65	60	80
1a (Ar=C_6H_5)	**2d**	**6a**	3	57	90	65
1b (Ar=*p*-$CH_3C_6H_4$)	**2d**	**6b**	3	52	90	62
1c (Ar=*p*-$CH_3OC_6H_4$)	**2d**	**6c**	3	52	90	60
1d (Ar=*p*-$C_2H_5OC_6H_4$)	**2d**	**6d**	3	48	90	58

[a] Recrystallization yield.

multiple steps, harsh reaction conditions, poor yields, a long period, and the use of hazardous and often expensive acid catalysts.

As part of an ongoing development of efficient protocols for the preparation of heterocyclic sydnones, this study reports for the first time, a one-pot condensation of 3-aryl-4-formylsydnones **1a–d**, 1,2-diketones, such as benzil (**2a**), 4,4′-dimethoxybenzil (**2b**), 4,4′-difluorobenzil (**2c**), and di-2-thienylethanedione (**2d**), and ammonium acetate in the presence of acetic acid by classical heating at 90–110 °C for 1–3 days, yielding a diverse array of 4,5-diaryl-2-sydnonyl-substituted imidazoles **3a–6d** (Scheme 1). Similar treatment can also yield 4,5-diaryl-2-sydnonyl-1-substituted imidazoles **8a–10a** by the one-pot condensation of 3-(4-ethoxyphenyl)-4-formylsydnone (**1d**), benzil derivatives **2a–c**, ammonium acetate, and primary amines **7a–d** under classical heating (Scheme 2).

For convenience consideration, only sydnone **1d** was used as starting material in the syntheses of imidazoles **8a–10a**, because of the fact that ^1H and ^{13}C NMR spectra of imidazoles produced from sydnone **1d** with *p*-EtO-C_6H_4 substituent might be easier to judge and read, especially in the case of products substituted with many different groups. Moreover, the reaction processes of compound **1d** with diketones, ammonium acetate, and primary amines displayed that quantity of ammonium acetate and primary amine used strongly influenced the results. Experimental tests showed that ammonium acetate is more reactive than primary amine. When the equivalents of primary amine and ammonium acetate used were the same in the synthesis of compound **8a**, by-product **3d** would be found in trace. Therefore, in the syntheses of imidazoles **8a–10a**, the amount of primary amine used should be more than ammonium acetate to guarantee without by-products **3–5**.

However, the synthetic protocols for all new imidazoles **3a–6d** and **8a–10a** based on conventional heating suffer from a long period and poor yield (Tables 1 and 2). A new synthetic methodology must be developed to solve this problem. In recent years, the application of microwave-assisted reactions in organic synthesis has received considerable attention. Microwave irradiation commonly increases the reaction rates above those obtained by conventional heating and leads to the production of fewer by-products. Materials that are exposed to microwave radiation react differently, depending on their dielectric constants. They may, for example, reflect radiation as does metal, or allow permeation of radiation without being heated up as does glass or plastics. Other substances, such as water, can absorb microwave energy, whereas polar molecules are stimulated to oscillate, and dissolved ions can be moved through the electromagnetic field: both effects cause heating-up of the substance. These properties can be used as a benefit for fast heating-up of aqueous solutions and other polar substances.

Table 2. Comparison between microwave irradiation (M.W.) and conventional heating (C.H.) in the syntheses of imidazoles **8a–10a**

1,2-Diketones	Amines	Products	C.H. reaction time (days)	C.H. yield[a] (%)	M.W. (100 W) reaction time (h)	M.W. (100 W) yield[a] (%)
2a	**7a** (R′=*iso*-butyl)	**8a**	3	34	3	56
2a	**7b** (R′=$C_6H_5CH_2CH_2$)	**8b**	2	25	2	47
2a	**7c** (R′=$C_6H_5CH_2$)	**8c**	2	20	2	46
2a	**7d** (R′=$CH_3(CH_2)_5$)	**8d**	2	22	2	50
2b	**7a** (R′=*iso*-butyl)	**9a**	3	20	3	45
2b	**7b** (R′=$C_6H_5CH_2CH_2$)	**9b**	2	34	2	60
2b	**7c** (R′=$C_6H_5CH_2$)	**9c**	2	26	2	55
2c	**7a** (R′=*iso*-butyl)	**10a**	3	28	3	56

[a] Recrystallization yield.

In contrast to conventional heating in heating blocks or ovens—where heat must initially be transferred to the medium via metal parts, air, or vessels—microwave radiation directly heats the medium, resulting in significant time savings in several fields. Gratifyingly, a microwave-assisted protocol herein produced sydnonyl-substituted imidazoles **3a**–**6d** and **8a**–**10a** in higher yield than obtained using conventional heating, and in less time (Tables 1 and 2).

Primary amine heated up in the air might be oxidized in certain degrees. The sydnone ring itself is sensitive to bases and heat, and primary amine might also make sydnone compounds decompose under C.H. condition. Both effects mentioned above might increase the impurity in the reaction mixture and cause the reaction solution to darken. Unlike the syntheses of imidazoles **3a**–**6d** without primary amines, the desired products **8a**–**10a** could not precipitate out automatically due to the impurity in the solution. Therefore, the work-up procedure is more complicated after the completion of the reaction. Extraction, decolorization, column chromatography, and recrystallization were needed to obtain the desired pure products **8a**–**10a**. The yield is low comparable to that of the reaction without primary amine in conventional heating (Tables 1 and 2). By similar treatment, the microwave-assisted protocol produced imidazoles **8a**–**10a** in less time, less impurities, and in higher yield.

Microwaves are defined as electromagnetic radiation within the frequency range 300 MHz to 300 GHz. The Multiwave 3000, designed by the Anton Paar GmbH company, incorporates two microwave generators (magnetrons), which generate microwaves at a frequency of 2.45 GHz. It includes various rotors for complete closed vessel XF 100 under high pressure and temperature. A hydraulic piston is installed above a reaction vessel in the pressure/temperature sensor head. As soon as the operating pressure exceeds the permissible limit, the microwave energy is continually reduced to prevent rupture of the safety disk. The infrared temperature sensor measures the temperatures at the bottom of the reaction vessels, and protection against overheating is provided for high-boiling mixtures. A Multiwave 3000 oven was employed to perform the one-pot condensation of 3-aryl-4-formylsydnones, benzil derivatives, ammonium acetate, and primary amines to give imidazoles **3a**–**6d** and **8a**–**10a**.

The operating conditions were set as follows: microwave power: 100 W for each vessel; time for programming to 100 W (ramp): 1 min; pressure limit: 35 bar; rate of change of pressure: 0.5 bar/s; temperature: 90 °C; hold time: 30 min. The experimental results revealed that the reactions proceeded much faster and with higher yields under microwave irradiation than under conventional heating. Tables 1 and 2 present detailed comparative data on microwave irradiation and conventional heating in the syntheses of imidazoles **3a**–**6d** and **8a**–**10a**. Among these new compounds, crystals **8a**, **8b**, **8c**, and **10a** were analytically pure and suitable for X-ray structural analysis. Figures 1–4 present ORTEP drawings of 3-(4-ethoxyphenyl)-4-(1-isobutyl-4,5-diphenyl-1*H*-imidazol-2-yl)sydnone (**8a**), 3-(4-ethoxyphenyl)-4-(1-phenethyl-4,5-diphenyl-1*H*-imidazol-2-yl)sydnone (**8b**), 4-(1-benzyl-4,5-diphenyl-1*H*-imidazol-2-yl)-3-(4-ethoxyphenyl)sydnone (**8c**), and 4-[4,5-bis-(4-fluorophenyl)-

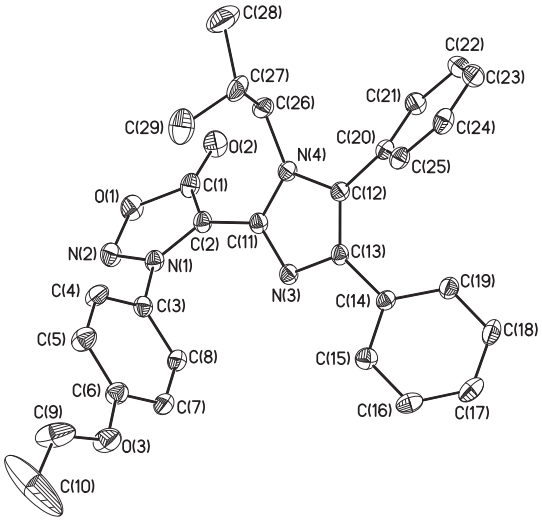


Figure 1. ORTEP drawing of compound **8a**.

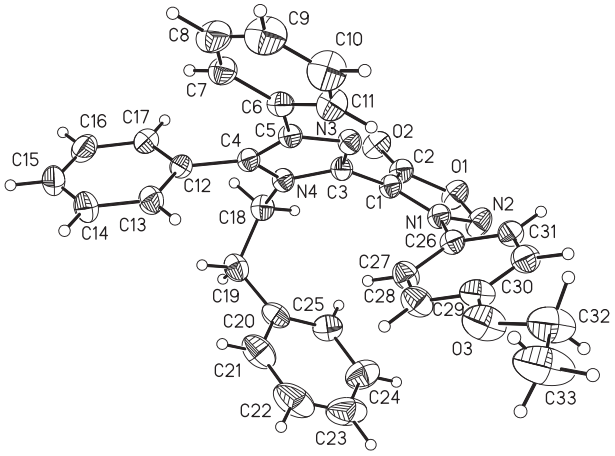


Figure 2. ORTEP drawing of compound **8b**.

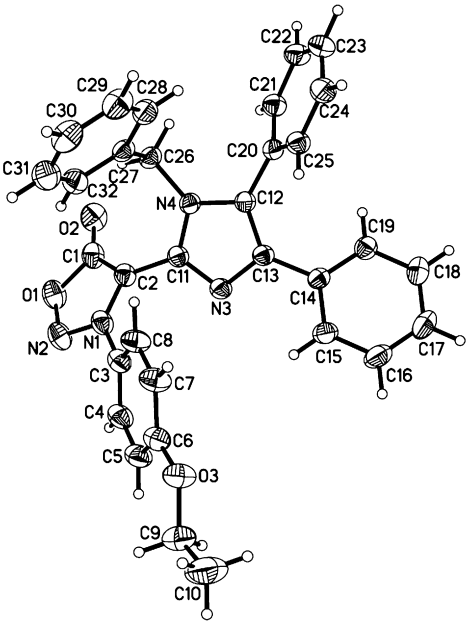


Figure 3. ORTEP drawing of compound **8c**.

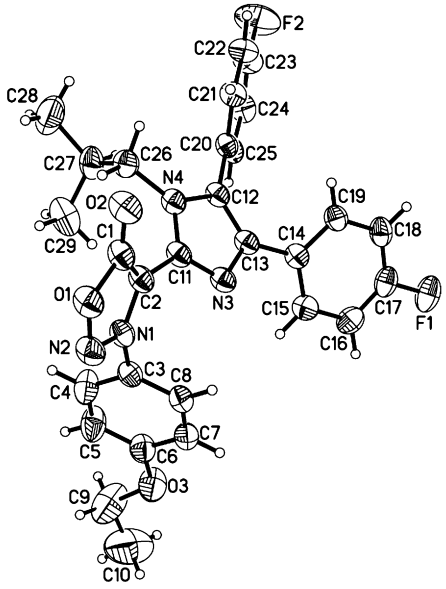


Figure 4. ORTEP drawing of compound **10a**.

1-isobutyl-1*H*-imidazol-2-yl]-3-(4-ethoxyphenyl)sydnone (**10a**). Tables 3 and 4 list all of the crystallographic data of compounds **8a**, **8b**, **8c**, and **10a**.

Table 3. Crystal data of compounds **8a** and **8b**

Compound	**8a**	**8b**
Diffractometer	Bruker Smart Apex CCD	Bruker Smart Apex CCD
Formula	$C_{29}H_{28}N_4O_3$	$C_{33}H_{28}N_4O_3$
Formula weight	480.55	528.59
Crystal system	Triclinic	Triclinic
Space group	*P*-1	*P*-1
a/Å	10.7821(11)	11.6064(11)
b/Å	10.9877(11)	11.6574(11)
c/Å	11.8506(12)	12.9543(12)
α/°	69.541(2)	63.709(2)
β/°	79.685(2)	85.493(2)
γ/°	76.886(2)	66.259(2)
V/Å^3	1273.4(2)	1427.8(2)
Z	2	2
D_{calcd} (g cm^{-3})	1.253	1.230
F_{000}	508	556.00
μ (Mo Kα)/cm^{-1}	0.83	0.80
Crystal size/mm	0.12×0.16×0.51	0.18×0.23×0.25
Temperature (K)	298(2)	298(2)
Refinement method	Full-matrix least-squares on F^2	Full-matrix least-squares on F^2
θ_{range}, °	1.85–28.31	1.77–28.32
Reflections collected	15,300	17,134
Independent reflections	6049 [*R*(int)=0.0449]	6797 [*R*(int)=0.0215]
Final *R* indices [*I*>2.00σ(*I*)]	R_1=0.0978, WR_2=0.2066	R_1=0.0476, WR_2=0.1119
R Indices (all data)	R_1=0.1721, WR_2=0.2435	R_1=0.0789, WR_2=0.1261
GoF	1.079	1.020

Table 4. Crystal data of compounds **8c** and **10a**

Compound	**8c**	**10a**
Diffractometer	Bruker Smart Apex CCD	Bruker Smart Apex CCD
Formula	$C_{32}H_{26}N_4O_3$	$C_{29}H_{26}F_2N_4O_3$
Formula weight	514.57	516.54
Crystal system	Triclinic	Triclinic
Space group	*P*-1	*P*-1
a/Å	9.87880(10)	11.1312(2)
b/Å	11.2436(2)	11.1570(2)
c/Å	12.40500(10)	11.6784(2)
α/°	81.4100(8)	81.0220(11)
β/°	88.2550(9)	70.4990(12)
γ/°	88.7470(7)	78.3820(10)
V/Å^3	1361.57(3)	1332.93(4)
Z	2	2
D_{calcd} (g cm^{-3})	1.255	1.287
F_{000}	540	540
μ (Mo Kα)/cm^{-1}	0.82	0.94
Crystal size/mm	0.20×0.15×0.10	0.20×0.15×0.10
Temperature (K)	295(2)	295(2)
Refinement method	Full-matrix least-squares on F^2	Full-matrix least-squares on F^2
θ_{range}, °	1.66–27.47	1.86–27.46
Reflections collected	10,994	10,850
Independent reflections	6165 [*R*(int)=0.0257]	6030 [*R*(int)=0.0280]
Final *R* indices [*I*>2.00σ(*I*)]	R_1=0.0466, WR_2=0.1191	R_1=0.0702, WR_2=0.1909
R Indices (all data)	R_1=0.0710, WR_2=0.1485	R_1=0.0961, WR_2=0.2224
GoF	1.110	1.050

Microwave irradiation stimulates polar molecules to oscillate, and move in the electromagnetic field. This effect heats the substance. Unlike conventional heating in heating blocks or ovens, in which the heat must first be transferred to the medium via metal parts, air, or vessels, microwave radiation heats the medium directly, significantly reducing the time required in many applications. Nešpûrek and other researchers have characterized sydnone skeleton.[33–35] The general structural formula of sydnones is presented by (A), (B), and (C) in Scheme 3. The ring has a semi-aromatic character; the N(2)–N(3)–C(4)–C(5) portion together with the exocyclic oxygen atom, O(6), are conjugated as in structure (I). Atom O(1) does not participate in the conjugation and retains its 'individuality' more than the other atoms of the mesoionic system (Scheme 3). Therefore, the mesoionic characteristic of the sydnone moiety in the synthesized imidazoles is perhaps to promote heating of the substance by the microwave radiation, and thereby to save reaction time.

3. Conclusion

The work focuses on the syntheses of imidazole derivatives, which are substituted with the same aryl groups at the 4,5-positions of imidazole rings. The presented one-pot condensation, including conventional heating and microwave

Scheme 3. The electron density and properties of sydnone ring.

irradiation, simplifies and offers considerable advantages over other methods, such as one-step reaction, elimination of solvents, high yields, and short reaction times. 3-Aryl-4-formylsydnones **1a–d** were used to react with symmetrical 1,2-dicarbonyl compounds, such as benzil (**2a**), 4,4′-dimethoxybenzil (**2b**), 4,4′-difluorobenzil (**2c**), and di-2-thienylethanedione (**2d**), in glacial acetic acid using ammonium acetate as the ammonia source to yield 4,5-diaryl-2-sydnonyl-substituted imidazoles **3a–6d** by conventional heating. Similar treatment yielded 4,5-diaryl-2-sydnonyl-1-substituted imidazoles **8a–10a** by one-pot condensation of 3-(4-ethoxyphenyl)-4-formylsydnone (**1d**), benzil derivatives, ammonium acetate, and primary amines. However, such reactions that required 1–3 days at high temperature under classical conditions were completed successfully in a few minutes using microwave irradiation.

4. Experimental

4.1. General

All melting points were determined on an England Electrothermal Digital Melting Point apparatus and are uncorrected. IR spectra were recorded on a MATTSON/SATELLITE 5000 FT-IR spectrophotometer. Mass spectra were measured on a VG Quattro GC/MS/MS/DS spectrometer. ^{1}H NMR spectra were run on a Bruker AV 400 NMR spectrometer, using TMS as an internal standard. ^{13}C NMR spectra were carried out with complete ^{1}H decoupling and assignments were made through additional DEPT experiments. Elemental analyses were taken with a Heraeus CHN-O-Rapid Analyzer or Elementar Vario EL-III Analyzer. X-ray spectra were performed on a Bruker AXS SMART APEX CCD diffractometer. 3-Aryl-4-formylsydnones (**1a–d**) were prepared from the corresponding 3-arylsydnones according to the literature.[36]

4.2. Syntheses of 3-aryl-4-(4,5-diphenyl-1*H*-imidazol-2-yl)sydnones (3a–d)

4.2.1. Typical procedure for conventional heating. To a solution of benzil (**2a**, 252.2 mg, 1.2 mmol) in glacial acetic acid (4 mL) were added ammonium acetate (231.2 mg, 3.0 mmol) and 3-phenyl-4-formylsydnone (**1a**, 190.2 mg, 1.0 mmol). The mixed solution was heated at 90–100 °C for 24–36 h until the reaction was completed; it was then cooled. The precipitating yellow powder (202.2 mg) was collected by filtration and recrystallized from dichloromethane/ethanol to afford 176.2 mg of 4-(4,5-diphenyl-1*H*-imidazol-2-yl)-3-phenylsydnone (**3a**) as yellow powder in 46% yield.

4.2.2. Typical procedure for microwave irradiation. To a solution of benzil (**2a**, 252.2 mg, 1.2 mmol) in glacial acetic acid (3 mL) were added ammonium acetate (231.2 mg, 3 mmol) and 3-phenyl-4-formylsydnone (**1a**, 190.2 mg, 1.0 mmol). The mixed solution was put into a Teflon vessel, and irradiated in a Microwave 3000 oven. The operating conditions were set as follows: power: 100 W for each vessel; time for programming to 100 W (ramp): 1 min; pressure limit control: 35 bar; pressure rate control: 0.5 bar/s; temperature: 90 °C; hold: 30 min. The progress of the reaction was monitored by TLC using *n*-hexane/EtOAc as eluant and the reaction was run to completion. The reaction mixture was cooled and the precipitating yellow powder (230.2 mg) was collected by filtration and recrystallized from dichloromethane/ethanol to afford 198.5 mg of 4-(4,5-diphenyl-1*H*-imidazol-2-yl)-3-phenylsydnone (**3a**) as yellow powder, yield 52%. The chemical and physical spectral characteristics of these products **3a–d** are given below.

4.2.2.1. 4-(4,5-Diphenyl-1*H*-imidazol-2-yl)-3-phenylsydnone (3a). Yellow powder from CH_2Cl_2/EtOH; mp 205–207 °C; IR (KBr) 3288, 3061, 1741, 1464, 1223 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 6.85–7.50 (m, 10H), 7.63–7.74 (m, 3H), 7.81–7.85 (m, 2H), 12.85 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 101.72, 125.79 (2×C), 126.94 (2×C), 128.36, 128.71, 128.82, 128.94, 129.56, 130.44, 132.00, 132.32, 134.46, 134.62, 137.72, 165.82; FABMS$^+$ *m*/*z* (%): 381 (M^++H, 100), 380 (M^+, 72), 323 (M^+−NO−CO+H, 28), 322 (M^+−NO−CO, 46). Anal. Calcd for $C_{23}H_{16}N_4O_2$: C, 72.62; H, 4.24; N, 14.73. Found: C, 72.58; H, 4.25; N, 14.71.

4.2.2.2. 4-(4,5-Diphenyl-1*H*-imidazol-2-yl)-3-(4-methylphenyl)sydnone (3b). Yellow needles from CH_2Cl_2/EtOAc; mp 218–219 °C; IR (KBr) 3267, 3061, 1739, 1602, 1504, 1463, 1220 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 2.41 (s, 3H), 7.18–7.37 (m, 10H), 7.45 (d, *J*=8.4 Hz, 2H), 7.70 (d, *J*=8.4 Hz, 2H), 12.86 (s, 1H); FABMS$^+$ *m*/*z* (%): 395 (M^++H, 100), 394 (M^+, 68), 337 (M^+−NO−CO+H, 29), 336 (M^+−NO−CO, 57). Anal. Calcd for $C_{24}H_{18}N_4O_2$: C, 73.08; H, 4.60; N, 14.20. Found: C, 72.97; H, 4.62; N, 14.28.

4.2.2.3. 4-(4,5-Diphenyl-1*H*-imidazol-2-yl)-3-(4-methoxyphenyl)sydnone (3c). Yellow needles from CH_2Cl_2/EtOAc; mp 216–217 °C; IR (KBr) 3286, 3055, 2935, 1743, 1606, 1512, 1464, 1258, 1218 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 3.85 (s, 3H), 7.18 (d, *J*=8.9 Hz, 2H), 7.20–7.43 (m, 10H), 7.77 (d, *J*=8.9 Hz, 2H), 12.83 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 56.07, 101.49, 114.67, 127.07, 127.10, 127.23, 127.27, 128.38, 128.47, 128.66, 128.92, 128.97, 130.49, 132.06, 134.57, 137.80, 162.02, 166.05; FABMS$^+$ *m*/*z* (%): 411 (M^++H, 100), 410 (M^+, 68), 353 (M^+−NO−CO+H, 85), 352 (M^+−NO−CO, 47). Anal. Calcd for $C_{24}H_{18}N_4O_3$: C, 70.23; H, 4.42; N, 13.65. Found: C, 70.11; H, 4.45; N, 13.63.

4.2.2.4. 4-(4,5-Diphenyl-1*H*-imidazol-2-yl)-3-(4-ethoxyphenyl)sydnone (3d). Yellow needles from CH_2Cl_2/EtOAc; mp 209–211 °C; IR (KBr) 3285, 3060, 2982, 2933, 1740, 1607, 1511, 1464, 1257, 1220 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 1.35 (t, *J*=6.9 Hz, 3H), 4.13 (q, *J*=6.9 Hz, 2H), 7.15–7.38 (m, 12H), 7.75 (d, *J*=9.2 Hz, 2H), 12.83 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 14.61, 64.07, 101.43, 115.02, 127.00, 127.02, 127.07, 127.19, 128.33, 128.40, 128.63, 128.86, 128.89, 130.46, 132.02, 134.53, 137.72, 161.23, 165.96; FABMS$^+$ *m*/*z* (%): 425 (M^++H, 100), 424 (M^+, 74), 367 (M^+−NO−CO+H, 27), 366 (M^+−NO−CO, 52). Anal. Calcd for $C_{25}H_{20}N_4O_3$: C, 70.74; H, 4.75; N, 13.20. Found: C, 70.59; H, 4.74; N, 13.17.

4.3. Syntheses of 3-aryl-4-[4,5-bis-(4-methoxyphenyl)-1*H*-imidazol-2-yl]sydnones (4a–d)

Compounds **4a–d** were prepared from the starting materials 3-aryl-4-formylsydnones (**1a–d**, 1.0 mmol), 4,4′-dimethoxybenzil (**2b**, 270.3 mg, 1.0 mmol), and ammonium acetate

(231.2 mg, 3.0 mmol) in glacial acetic acid (3 mL) according to the typical procedures of conventional heating and microwave irradiation for **3a**. The chemical and physical spectral characteristics of these products **4a–d** are given below.

4.3.1. 4-[4,5-Bis-(4-methoxyphenyl)-1*H*-imidazol-2-yl]-3-phenylsydnone (4a). Yellow powder from CH_2Cl_2/EtOH; mp 217–219 °C; IR (KBr) 3300, 3071, 3005, 2936, 2908, 2835, 1740, 1615, 1520, 1491, 1466, 1249, 1220 cm^{-1}; ^1H NMR (DMSO-d_6) δ 3.69 (s, 3H), 3.77 (s, 3H), 6.77 (d, J=7.4 Hz, 2H), 6.96 (d, J=7.4 Hz, 2H), 7.16 (d, J=7.4 Hz, 2H), 7.28 (d, J=7.4 Hz, 2H), 7.64–7.84 (m, 5H), 12.64 (s, 1H); FABMS$^+$ m/z (%): 441 (M^++H, 94), 440 (M^+, 100), 383 (M^+−NO−CO+H, 31), 382 (M^+−NO−CO, 65). Anal. Calcd for $C_{25}H_{20}N_4O_4$: C, 68.17; H, 4.58; N, 12.72. Found: C, 68.23; H, 4.58; N, 12.70.

4.3.2. 4-[4,5-Bis-(4-methoxyphenyl)-1*H*-imidazol-2-yl]-3-(4-methylphenyl)sydnone (4b). Orange needles from CH_2Cl_2/EtOH; mp 219–221 °C; IR (KBr) 3288, 3055, 3003, 2959, 2941, 2837, 1731, 1613, 1521, 1495, 1467, 1247, 1217 cm^{-1}; ^1H NMR (DMSO-d_6) δ 2.42 (s, 3H), 3.70 (s, 3H), 3.76 (s, 3H), 6.80 (d, J=8.1 Hz, 2H), 6.96 (d, J=8.1 Hz, 2H), 7.20 (d, J=8.1 Hz, 2H), 7.28 (d, J=8.1 Hz, 2H), 7.45 (d, J=8.4 Hz, 2H), 7.69 (d, J=8.4 Hz, 2H), 12.64 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 21.14, 55.25, 55.41, 101.61, 113.91, 114.35, 122.81, 125.39, 127.18, 127.95, 128.24, 129.89, 129.99, 131.13, 132.16, 137.22, 142.61, 158.35, 159.22, 166.05; FABMS$^+$ m/z (%): 455 (M^++H, 100), 454 (M^+, 98), 397 (M^+−NO−CO+H, 31), 396 (M^+−NO−CO, 61). Anal. Calcd for $C_{26}H_{22}N_4O_4$: C, 68.71; H, 4.88; N, 12.33. Found: C, 68.64; H, 4.89; N, 12.31.

4.3.3. 4-[4,5-Bis-(4-methoxyphenyl)-1*H*-imidazol-2-yl]-3-(4-methoxyphenyl)sydnone (4c). Orange needles from CH_2Cl_2/EtOH; mp 192–193 °C; IR (KBr) 3275, 3077, 3004, 2938, 2835, 1725, 1611, 1513, 1495, 1463, 1251, 1217 cm^{-1}; ^1H NMR (DMSO-d_6) δ 3.70 (s, 3H), 3.77 (s, 3H), 3.84 (s, 3H), 6.80 (d, J=8.0 Hz, 2H), 6.97 (d, J=8.0 Hz, 2H), 7.17 (d, J=8.8 Hz, 2H), 7.23 (d, J=8.4 Hz, 2H), 7.30 (d, J=8.4 Hz, 2H), 7.76 (d, J=8.8 Hz, 2H), 12.63 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 55.22, 55.38, 56.04, 101.60, 113.88, 114.32, 114.60, 122.84, 127.18, 127.20, 127.26, 127.89, 128.21, 129.90, 131.27, 137.18, 158.33, 159.20, 161.96, 166.05; FABMS$^+$ m/z (%): 471 (M^++H, 91), 470 (M^+, 100), 413 (M^+−NO−CO+H, 30), 412 (M^+−NO−CO, 63). Anal. Calcd for $C_{26}H_{22}N_4O_5$: C, 66.38; H, 4.71; N, 11.91. Found: C, 66.24; H, 4.70; N, 11.80.

4.3.4. 4-[4,5-Bis-(4-methoxyphenyl)-1*H*-imidazol-2-yl]-3-(4-ethoxyphenyl)sydnone (4d). Orange needles from CH_2Cl_2/EtOH; mp 200–202 °C; IR (KBr) 3285, 3076, 2979, 2934, 2831, 1729, 1611, 1512, 1495, 1465, 1249, 1216 cm^{-1}; ^1H NMR (DMSO-d_6) δ 1.35 (t, J=7.0 Hz, 3H), 3.70 (s, 3H), 3.77 (s, 3H), 4.12 (q, J=7.0 Hz, 2H), 6.80 (d, J=8.0 Hz, 2H), 6.97 (d, J=8.0 Hz, 2H), 7.15 (d, J=8.8 Hz, 2H), 7.24 (d, J=8.4 Hz, 2H), 7.30 (d, J=8.4 Hz, 2H), 7.74 (d, J=8.8 Hz, 2H), 12.61 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 14.58, 55.18, 55.35, 64.03, 101.54, 113.82, 114.27, 114.94, 122.80, 127.06, 127.13, 127.18, 127.83, 128.14, 129.86, 131.22, 137.11, 158.27, 159.16, 161.17, 165.97; FABMS$^+$ m/z (%): 485 (M^++H, 95), 484 (M^+, 100), 427 (M^+−NO−CO+H, 33), 426 (M^+−NO−CO, 70). Anal. Calcd for $C_{27}H_{24}N_4O_5$: C, 66.93; H, 4.99; N, 11.56. Found: C, 66.96; H, 4.99; N, 11.56.

4.4. Syntheses of 3-aryl-4-[4,5-bis-(4-fluorophenyl)-1*H*-imidazol-2-yl]sydnones (5a–d)

Compounds **5a–d** were prepared from the starting materials 3-aryl-4-formylsydnones (**1a–d**, 1.00 mmol), 4,4′-difluorobenzil (**2c**, 251.2 mg, 1.02 mmol), and ammonium acetate (231.2 mg, 3.0 mmol) in glacial acetic acid (3 mL) according to the typical procedures of conventional heating and microwave irradiation for **3a**. The chemical and physical spectral characteristics of these products **5a–d** are given below.

4.4.1. 4-[4,5-Bis-(4-fluorophenyl)-1*H*-imidazol-2-yl]-3-phenylsydnone (5a). Yellow powder from CH_2Cl_2/EtOH; mp 249–250 °C; IR (KBr) 3275, 1738, 1519, 1491, 1485, 1228, 1158, 835 cm^{-1}; ^1H NMR (DMSO-d_6) δ 7.03–7.40 (m, 8H), 7.65–7.84 (m, 5H), 12.91 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 101.65, 115.35 (d, $^2J_{C-F}$=22 Hz), 115.87 (d, $^2J_{C-F}$=22 Hz), 125.84, 126.71 (d, $^4J_{C-F}$=4 Hz), 127.77, 128.68 (d, $^3J_{C-F}$=8 Hz), 129.53, 130.77 (d, $^4J_{C-F}$=4 Hz), 131.05 (d, $^3J_{C-F}$=8 Hz), 132.07, 132.31, 134.63, 136.79, 161.31 (d, $^1J_{C-F}$=244 Hz), 162.08 (d, $^1J_{C-F}$=244 Hz), 165.73; FABMS$^+$ m/z (%): 417 (M^++H, 100), 416 (M^+, 76), 359 (M^+−NO−CO+H, 30), 358 (M^+−NO−CO, 61). Anal. Calcd for $C_{23}H_{14}N_4O_2F_2$: C, 66.35; H, 3.39; N, 13.46. Found: C, 66.11; H, 3.53; N, 13.30.

4.4.2. 4-[4,5-Bis-(4-fluorophenyl)-1*H*-imidazol-2-yl]-3-(4-methylphenyl)sydnone (5b). Yellow powder from CH_2Cl_2/EtOH; mp 269–270 °C; IR (KBr) 3261, 1738, 1518, 1493, 1463, 1224, 1160, 835, 814 cm^{-1}; ^1H NMR (DMSO-d_6) δ 2.43 (s, 3H), 7.05–7.69 (m, 10H), 7.70 (d, J=8.4 Hz, 2H), 12.91 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 21.10, 101.38, 115.39 (d, $^2J_{C-F}$=22 Hz), 115.91 (d, $^2J_{C-F}$= 22 Hz), 125.44, 126.71 (d, $^4J_{C-F}$=3 Hz), 127.78, 128.80 (d, $^3J_{C-F}$=9 Hz), 129.93, 130.81 (d, $^4J_{C-F}$=3 Hz), 130.96 (d, $^3J_{C-F}$=9 Hz), 131.97, 132.14, 136.84, 142.57, 161.34 (d, $^1J_{C-F}$=244 Hz), 162.67 (d, $^1J_{C-F}$=244 Hz), 165.85; FABMS$^+$ m/z (%): 431 (M^++H, 100), 430 (M^+, 65), 373 (M^+−NO−CO+H, 36), 372 (M^+−NO−CO, 68). Anal. Calcd for $C_{24}H_{16}N_4O_2F_2$: C, 66.97; H, 3.75; N, 13.02. Found: C, 66.95; H, 3.84; N, 12.85.

4.4.3. 4-[4,5-Bis-(4-fluorophenyl)-1*H*-imidazol-2-yl]-3-(4-methoxyphenyl)sydnone (5c). Yellow powder from CH_2Cl_2/EtOH; mp 257–259 °C; IR (KBr) 3281, 1739, 1607, 1512, 1493, 1463, 1262, 1222, 1159, 834 cm^{-1}; ^1H NMR (DMSO-d_6) δ 3.85 (s, 3H), 7.02–7.41 (m, 10H), 7.76 (d, J=9.0 Hz, 2H), 12.91 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 56.01, 101.34, 114.54, 115.36 (d, $^2J_{C-F}$=22 Hz), 115.88 (d, $^2J_{C-F}$=22 Hz), 126.71 (d, $^4J_{C-F}$=3 Hz), 127.16, 127.21, 127.73, 128.77 (d, $^3J_{C-F}$=8 Hz), 130.81 (d, $^4J_{C-F}$=3 Hz), 130.95 (d, $^3J_{C-F}$=8 Hz), 132.07, 136.79, 161.32 (d, $^1J_{C-F}$= 245 Hz), 161.94, 162.05 (d, $^1J_{C-F}$=245 Hz), 165.86; FABMS$^+$ m/z (%): 447 (M^++H, 100), 446 (M^+, 78), 389 (M^+−NO−CO+H, 38), 388 (M^+−NO−CO, 70). Anal. Calcd for $C_{24}H_{16}N_4O_3F_2$: C, 64.57; H, 3.60; N, 12.55. Found: C, 64.45; H, 3.61; N, 12.52.

4.4.4. 4-[4,5-Bis-(4-fluorophenyl)-1*H*-imidazol-2-yl]-3-(4-ethoxyphenyl)sydnone (5d). Yellow powder from CH_2Cl_2/EtOH; mp 256–257 °C; IR (KBr) 3279, 1736, 1606, 1512, 1494, 1462, 1262, 1223, 1160, 835 cm^{-1}; ^1H NMR (DMSO-d_6) δ 1.35 (t, J=7.0 Hz, 3H), 4.12 (q, J=7.0 Hz, 2H), 7.02–7.44 (m, 10H), 7.74 (d, J=9.0 Hz, 2H), 12.86 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 14.60, 64.04, 101.35, 114.94, 115.37 (d, $^2J_{C-F}$=21 Hz), 115.89 (d, $^2J_{C-F}$=21 Hz), 126.73 (d, $^4J_{C-F}$=3 Hz), 127.05, 127.22, 127.73, 128.78 (d, $^3J_{C-F}$=8 Hz), 130.84 (d, $^4J_{C-F}$=3 Hz), 130.97 (d, $^3J_{C-F}$=8 Hz), 132.10, 136.79, 161.33 (d, $^1J_{C-F}$=244 Hz), 161.20, 162.06 (d, $^1J_{C-F}$=244 Hz), 165.87; FABMS$^+$ m/z (%): 461 (M^++H, 100), 460 (M^+, 77), 403 (M^+−NO−CO+H, 35), 402 (M^+−NO−CO, 70). Anal. Calcd for $C_{25}H_{18}N_4O_3F_2$: C, 65.22; H, 3.94; N, 12.17. Found: C, 65.01; H, 4.00; N, 12.12.

4.5. Syntheses of 3-aryl-4-(4,5-di-2-thienyl-1*H*-imidazol-2-yl)sydnones (6a–d)

Compounds **6a–d** were prepared from the starting materials 3-aryl-4-formylsydnones (**1a–d**, 1.0 mmol), di-2-thienylethanedione (**2d**, 222.3 mg, 1.0 mmol), and ammonium acetate (231.2 mg, 3 mmol) in glacial acetic acid (3 mL) according to the typical procedures of conventional heating and microwave irradiation for **3a**. The chemical and physical spectral characteristics of these products **6a–d** are given below.

4.5.1. 4-(4,5-Di-2-thienyl-1*H*-imidazol-2-yl)-3-phenylsydnone (6a). Golden yellow powder from CH_2Cl_2/EtOH; mp 185–187 °C; IR (KBr) 3287, 1745, 1465, 1272, 1234, 952, 684 cm^{-1}; ^1H NMR (DMSO-d_6) δ 6.91–6.96 (m, 2H), 7.17 (t, J=4.0 Hz, 1H), 7.33–7.35 (m, 2H), 7.63–7.83 (m, 6H), 13.02 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 101.24, 121.27, 123.61, 125.43, 125.78, 127.44, 127.75, 127.98, 128.99, 129.49, 129.94, 132.32, 134.23, 134.47, 136.77, 136.87, 165.63; FABMS$^+$ m/z (%): 393 (M^++H, 100), 392 (M^+, 82), 335 (M^+−NO−CO+H, 39), 334 (M^+−NO−CO, 62). Anal. Calcd for $C_{19}H_{12}N_4O_2S_2$: C, 58.15; H, 3.08; N, 14.28; S, 16.34. Found: C, 58.20; H, 3.14; N, 14.02; S, 16.18.

4.5.2. 4-(4,5-Di-2-thienyl-1*H*-imidazol-2-yl)-3-(4-methylphenyl)sydnone (6b). Yellow needles from CH_2Cl_2/EtOAc; mp 209–210 °C; IR (KBr) 3275, 1730, 1597, 1511, 1238, 1220, 1200, 951, 815, 685 cm^{-1}; ^1H NMR (DMSO-d_6) δ 2.41 (s, 3H), 6.94 (dd, J=4.8, 2.8 Hz, 1H), 7.00 (d, J=2.8 Hz, 1H), 7.17 (dd, J=4.8, 2.8 Hz, 1H), 7.33 (d, J=2.8 Hz, 1H), 7.37 (d, J=4.8 Hz, 1H), 7.44 (d, J=8.4 Hz, 2H), 7.64–7.71 (m, 3H), 13.03 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 21.11, 100.97, 121.45, 123.77, 125.41, 125.53, 127.49, 127.78, 127.95, 128.89, 129.91, 129.98, 132.00, 132.22, 134.20, 136.79, 142.56, 165.77; FABMS$^+$ m/z (%): 407 (M^++H, 100), 406 (M^+, 87), 349 (M^+−NO−CO+H, 34), 348 (M^+−NO−CO, 59). Anal. Calcd for $C_{20}H_{14}N_4O_2S_2$: C, 59.10; H, 3.47; N, 13.78; S, 15.78. Found: C, 59.18; H, 3.45; N, 13.66; S, 15.79.

4.5.3. 4-(4,5-Di-2-thienyl-1*H*-imidazol-2-yl)-3-(4-methoxyphenyl)sydnone (6c). Yellow needles from CH_2Cl_2/EtOH; mp 229–231 °C; IR (KBr) 3282, 1733, 1511, 1256, 1236, 1225, 1172, 831, 687 cm^{-1}; ^1H NMR (DMSO-d_6) δ 3.84 (s, 3H), 6.95 (dd, J=4.8, 2.4 Hz, 1H), 7.02 (d, J=2.4 Hz, 1H), 7.15–7.18 (m, 3H), 7.33 (d, J=2.4 Hz, 1H), 7.37 (d, J=4.8 Hz, 1H), 7.68 (d, J=4.8 Hz, 1H), 7.74 (d, J=9.2 Hz, 2H), 13.00 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 56.02, 100.99, 114.58, 121.38, 123.74, 125.51, 127.10, 127.20, 127.51, 127.79, 127.97, 128.92, 130.01, 132.35, 134.21, 136.83, 161.96, 165.80; FABMS$^+$ m/z (%): 423 (M^++H, 100), 422 (M^+, 84), 365 (M^+−NO−CO+H, 35), 364 (M^+−NO−CO, 51). Anal. Calcd for $C_{20}H_{14}N_4O_3S_2$: C, 56.86; H, 3.34; N, 13.26; S, 15.18. Found: C, 56.56; H, 3.36; N, 13.00; S, 15.05.

4.5.4. 4-(4,5-Di-2-thienyl-1*H*-imidazol-2-yl)-3-(4-ethoxyphenyl)sydnone (6d). Yellow powder from CH_2Cl_2/EtOH; mp 227–229 °C; IR (KBr) 3290, 1731, 1510, 1258, 1238, 1225, 1174, 955, 826, 680 cm^{-1}; ^1H NMR (DMSO-d_6) δ 1.34 (t, J=7.0 Hz, 3H), 4.12 (q, J=7.0 Hz, 2H), 6.92–7.03 (m, 2H), 7.13–7.20 (m, 3H), 7.31–7.37 (m, 2H), 7.68 (d, J=4.4 Hz, 1H), 7.72 (d, J=9.0 Hz, 2H), 12.99 (s, 1H); ^{13}C NMR (DMSO-d_6) δ 14.62, 64.04, 100.95, 114.95, 121.37, 123.73, 125.50, 126.92, 127.18, 127.50, 127.78, 127.95, 128.91, 130.01, 132.35, 134.19, 136.83, 161.22, 165.80; FABMS$^+$ m/z (%): 437 (M^++H, 100), 436 (M^+, 84). Anal. Calcd for $C_{21}H_{16}N_4O_3S_2$: C, 57.78; H, 3.69; N, 12.83; S, 14.70. Found: C, 57.51; H, 3.73; N, 12.66; S, 14.64.

4.6. Syntheses of 3-aryl-4-(1-substituted-4,5-diaryl-1*H*-imidazol-2-yl)sydnones (8a–10a)

4.6.1. Typical procedure for conventional heating. To a solution of benzil (**2a**, 252.3 mg, 1.2 mmol) in glacial acetic acid (4 mL) were added ammonium acetate (100.6 mg, 1.3 mmol), isobutyl amine (**7a**, 124.7 mg, 1.7 mmol), and 3-(4-ethoxyphenyl)-4-formylsydnone (**1d**, 234.2 mg, 1.0 mmol). The mixed solution was heated at 65–90 °C for about 3 days until the reaction was completed. The resulting solution was dropped into 100 mL of ice-cold water and sodium bicarbonate was slowly added to remove the acid. Ethyl acetate/*n*-hexane (1:1, 250 mL) was used to extract the organic product. The organic layer was combined and washed with distilled water (30 mL). The organic phase was then dried over Na_2SO_4 and decolorized with charcoal. The yellow solid (212.2 mg) obtained after evaporation of the solvent was purified on a silica gel column chromatography with ethyl acetate/*n*-hexane (1:4) as the eluant, to yield a yellow solid (186.2 mg). The solid was then recrystallized from dichloromethane/ethanol to give 165.2 mg of 3-(4-ethoxyphenyl)-4-(1-isobutyl-4,5-diphenyl-1*H*-imidazol-2-yl)sydnone (**8a**) as yellow crystals in 34% yield.

4.6.2. Typical procedure for microwave irradiation. To a solution of benzil (**2a**, 252.2 mg, 1.2 mmol) in glacial acetic acid (3 mL), ammonium acetate (100.6 mg, 1.3 mmol), isobutyl amine (**7a**, 124.7 mg, 1.7 mmol), and 3-(4-ethoxyphenyl)-4-formylsydnone (**1d**, 234.2 mg, 1.0 mmol) were added. The mixed solution was put into a Teflon vessel and irradiated in a Microwave 3000 oven. The operation condition was set as follows: power: 100 W for each vessel; time for programming to 100 W (ramp): 1 min; pressure limit control: 35 bar; pressure rate control: 0.5 bar/sec; temperature: 70 °C; hold: 1 h. The progress of the reaction was monitored by TLC using *n*-hexane/EtOAc as eluant and the reaction was run to completion. The resulting solution was dropped into 100 mL of ice-cold water and sodium

bicarbonate was slowly added to remove the acid. Ethyl acetate/*n*-hexane (1:1, 250 mL) was used to extract the organic product. The organic layer was combined and washed with distilled water (30 mL). The organic phase was then dried over Na_2SO_4 and decolorized with charcoal. The yellow solid (345.2 mg) obtained after evaporation of the solvent was purified on a silica gel column chromatography with ethyl acetate/*n*-hexane (1:4) as eluant to afford yellow solid (286.5 mg). The solid was then recrystallized from dichloromethane/ethanol to give 269.8 mg of 3-(4-ethoxyphenyl)-4-(1-isobutyl-4,5-diphenyl-1*H*-imidazol-2-yl)sydnone (**8a**) as yellow crystals, yield 56%. The chemical and physical spectral characteristics of these products **8a**–**10a** are given below.

4.6.2.1. 3-(4-Ethoxyphenyl)-4-(1-isobutyl-4,5-diphenyl-1*H*-imidazol-2-yl)sydnone (8a). Yellow crystals from CH_2Cl_2/EtOH; mp 172–174 °C; IR (KBr) 3057, 2967, 2931, 2905, 2873, 1767, 1606, 1509, 1464, 1256 cm^{-1}; ^1H NMR (DMSO-d_6) δ 0.50 (d, J=6.8 Hz, 6H), 1.34 (t, J=6.8 Hz, 3H), 1.50 (m, 1H), 3.73 (d, J=8.0 Hz, 2H), 4.12 (q, J=6.8 Hz, 2H), 7.11–7.20 (m, 7H), 7.31–7.39 (m, 2H), 7.49–7.51 (m, 3H), 7.74 (d, J=8.8 Hz, 2H); ^{13}C NMR (DMSO-d_6) δ 14.58, 19.36, 28.34, 51.57, 64.07, 100.83, 115.12, 126.26, 126.77, 126.90, 127.03, 128.29, 129.32, 129.44, 130.12, 130.70, 130.94, 132.32, 133.93, 138.38, 161.27, 165.73; FABMS$^+$ *m/z* (%): 481 (M^++H, 100), 480 (M^+, 53), 423 (M^+−NO−CO+H, 39), 422 (M^+−NO−CO, 93). Anal. Calcd for $C_{29}H_{28}N_4O_3$: C, 72.48; H, 5.87; N, 11.66. Found: C, 72.24; H, 5.77; N, 11.83. X-ray analytical data are listed in Table 3. Further details have been deposited at the Cambridge Crystallographic Data Center and allocated the deposition number CCDC 630274.

4.6.2.2. 3-(4-Ethoxyphenyl)-4-(1-phenethyl-4,5-diphenyl-1*H*-imidazol-2-yl)sydnone (8b). Yellow crystals from EtOAc/EtOH; mp 171–172 °C; IR (KBr) 3056, 3023, 2980, 1737, 1605, 1510, 1440, 1259, 699 cm^{-1}; ^1H NMR (DMSO-d_6) δ 1.32 (t, J=6.8 Hz, 3H), 2.67 (t, J=7.6 Hz, 2H), 4.10 (q, J=6.8 Hz, 2H), 4.19 (t, J=7.6 Hz, 2H), 6.80–6.84 (m, 2H), 7.08–7.20 (m, 10H), 7.34–7.37 (m, 2H), 7.50–7.54 (m, 5H); ^{13}C NMR (DMSO-d_6) δ 14.56, 36.00, 46.06, 64.03, 100.59, 115.00, 126.09, 126.73, 126.80, 126.85, 127.01, 128.27, 128.60, 128.65, 129.44, 129.46, 130.06, 130.66, 130.87, 131.87, 133.93, 137.69, 138.36, 161.14, 165.97; FABMS$^+$ *m/z* (%): 529 (M^++H, 100), 528 (M^+, 45), 471 (M^+−NO−CO+H, 32), 470 (M^+−NO−CO, 71). Anal. Calcd for $C_{33}H_{28}N_4O_3$: C, 74.98; H, 5.34; N, 10.60. Found: C, 74.98; H, 5.40; N, 10.61. X-ray analytical data are listed in Table 3. Further details have been deposited at the Cambridge Crystallographic Data Center and allocated the deposition number CCDC 630275.

4.6.2.3. 4-(1-Benzyl-4,5-diphenyl-1*H*-imidazol-2-yl)-3-(4-ethoxyphenyl)sydnone (8c). Yellow needles from CH_2Cl_2/EtOAc; mp 185–186 °C; IR (KBr) 3061, 2967, 2935, 2892, 1758, 1604, 1510, 1439, 1255, 702 cm^{-1}; ^1H NMR (DMSO-d_6) δ 1.33 (t, J=7.2 Hz, 3H), 4.11 (q, J=7.2 Hz, 2H), 5.09 (s, 2H), 6.72–6.74 (m, 2H), 7.10 (d, J=9.0 Hz, 2H), 7.12–7.32 (m, 10H), 7.35 (d, J=9.0 Hz, 2H), 7.44–7.46 (m, 3H); ^{13}C NMR (DMSO-d_6) δ 14.56, 47.70, 64.05, 100.73, 115.03, 126.17, 126.40, 126.49, 126.75, 126.88, 127.78, 128.33, 128.77, 129.38, 129.42, 129.56, 130.86, 131.36, 132.18, 133.79, 136.68, 138.39, 161.25, 165.76; FABMS$^+$ *m/z* (%): 515 (M^++H, 100), 514 (M^+, 31), 457 (M^+−NO−CO+H, 65), 456 (M^+−NO−CO, 86). Anal. Calcd for $C_{32}H_{26}N_4O_3$: C, 74.69; H, 5.09; N, 10.89. Found: C, 74.71; H, 5.16; N, 10.90. X-ray analytical data are listed in Table 4. Further details have been deposited at the Cambridge Crystallographic Data Center and allocated the deposition number CCDC 630276.

4.6.2.4. 3-(4-Ethoxyphenyl)-4-(1-hexyl-4,5-diphenyl-1*H*-imidazol-2-yl)sydnone (8d). Yellow needles from EtOAc/EtOH; mp 101–103 °C; IR (KBr) 3061, 2978, 2956, 2927, 2858, 1744, 1603, 1510, 1438, 1257 cm^{-1}; ^1H NMR (DMSO-d_6) δ 0.70 (t, J=7.0 Hz, 3H), 0.91–1.02 (m, 6H), 1.27–1.37 (m, 5H), 3.85 (t, J=7.0 Hz, 2H), 4.10 (q, J=7.0 Hz, 2H), 7.09–7.21 (m, 7H), 7.35–7.52 (m, 5H), 7.70 (d, J=8.8 Hz, 2H); ^{13}C NMR (DMSO-d_6) δ 13.88, 14.57, 21.79, 25.46, 29.67, 30.41, 44.53, 64.07, 100.31, 115.22, 126.19, 126.73, 126.94, 127.17, 128.30, 129.37, 129.41, 130.11, 130.75, 131.72, 131.99, 133.99, 138.42, 161.27, 166.01; FABMS$^+$ *m/z* (%): 509 (M^++H, 100), 508 (M^+, 43). Anal. Calcd for $C_{31}H_{32}N_4O_3$: C, 73.21; H, 6.34; N, 11.02. Found: C, 73.15; H, 6.31; N, 11.10.

4.6.2.5. 3-(4-Ethoxyphenyl)-4-[1-isobutyl-4,5-bis-(4-methoxyphenyl)-1*H*-imidazol-2-yl]sydnone (9a). Orange needles from CH_2Cl_2/EtOH; mp 145–146 °C; IR (KBr) 3084, 3009, 2967, 2935, 2904, 2840, 1741, 1604, 1517, 1491, 1442, 1244, 1183, 1030, 848 cm^{-1}; ^1H NMR (DMSO-d_6) δ 0.51 (d, J=6.4 Hz, 6H), 1.34 (t, J=7.0 Hz, 2H), 1.52 (m, 1H), 3.67 (s, 3H), 3.69 (d, J=6.8 Hz, 2H), 3.80 (s, 3H), 4.12 (q, J=7.0 Hz, 2H), 6.74 (d, J=8.8 Hz, 2H), 7.04 (d, J=8.8 Hz, 2H), 7.13 (d, J=8.8 Hz, 2H), 7.17 (d, J=9.2 Hz, 2H), 7.22 (d, J=8.8 Hz, 2H), 7.72 (d, J=9.2 Hz, 2H); ^{13}C NMR (DMSO-d_6) δ 14.60, 19.43, 28.37, 51.45, 55.16, 55.33, 64.08, 101.02, 113.78, 114.84, 115.09, 122.08, 126.71, 126.92, 127.04, 127.40, 129.79, 131.68, 132.14, 138.30, 158.16, 159.68, 161.25, 165.76; FABMS$^+$ *m/z* (%): 541 (M^++H, 85), 540 (M^+, 55), 483 (M^+−NO−CO+H, 46), 482 (M^+−NO−CO, 100). Anal. Calcd for $C_{31}H_{32}N_4O_5$: C, 68.87; H, 5.97; N, 10.36. Found: C, 68.86; H, 5.99; N, 10.32.

4.6.2.6. 4-[4,5-Bis-(4-methoxyphenyl)-1-phenethyl-1*H*-imidazol-2-yl]-3-(4-ethoxyphenyl)sydnone (9b). Yellow crystals from EtOAc/EtOH; mp 154–155 °C; IR (KBr) 3019, 2968, 2947, 1732, 1604, 1511, 1491, 1439, 1249, 1175, 1030, 840 cm^{-1}; ^1H NMR (DMSO-d_6) δ 1.32 (t, J=7.0 Hz, 3H), 2.68 (t, J=7.6 Hz, 2H), 3.66 (s, 3H), 3.83 (s, 3H), 4.10 (q, J=7.0 Hz, 2H), 4.15 (t, J=7.6 Hz, 2H), 6.72 (d, J=8.4 Hz, 2H), 6.84 (d, J=8.0 Hz, 2H), 7.08–7.20 (m, 9H), 7.25 (d, J=8.0 Hz, 2H), 7.50 (d, J=8.8 Hz, 2H); ^{13}C NMR (DMSO-d_6) δ 14.59, 36.05, 45.91, 55.16, 55.42, 64.05, 100.78, 113.77, 114.85, 114.96, 122.00, 126.73, 126.81, 126.86, 127.03, 127.25, 128.62, 128.70, 129.47, 131.29, 132.30, 137.81, 138.35, 158.16, 159.85, 161.13, 165.99; FABMS$^+$ *m/z* (%): 589 (M^++H, 98), 588 (M^+, 70), 531 (M^+−NO−CO+H, 46), 530 (M^+−NO−CO, 100). Anal. Calcd for $C_{35}H_{32}N_4O_5$: C, 71.41; H, 5.48; N, 9.52. Found: C, 71.26; H, 5.55; N, 9.47.

4.6.2.7. 4-[1-Benzyl-4,5-bis-(4-methoxyphenyl)-1*H*-imidazol-2-yl]-3-(4-ethoxyphenyl)sydnone (9c). Yellow crystals from EtOAc/EtOH; mp 192–194 °C; IR (KBr)

3005, 2973, 2938, 2839, 1744, 1605, 1518, 1493, 1440, 1254, 1175, 1035, 845 cm^{-1}; ^1H NMR (DMSO-d_6) δ 1.33 (t, J=7.0 Hz, 3H), 3.67 (s, 3H), 3.77 (s, 3H), 4.10 (q, J=7.0 Hz, 2H), 5.05 (s, 2H), 6.72–6.77 (m, 4H), 7.00 (d, J=8.4 Hz, 2H), 7.08 (d, J=9.2 Hz, 2H), 7.16–7.23 (m, 7H), 7.31 (d, J=9.2 Hz, 2H); ^{13}C NMR (DMSO-d_6) δ 14.60, 47.49, 55.17, 55.36, 64.07, 100.95, 113.84, 114.86, 115.00, 121.52, 126.42, 126.44, 126.57, 126.77, 127.35, 127.78, 128.81, 130.21, 131.59, 132.32, 136.92, 138.33, 158.25, 159.86, 161.24, 165.78; FABMS$^+$ m/z (%): 575 (M^++H, 100), 574 (M^+, 60), 517 (M^+−NO−CO+H, 61), 516 (M^+−NO−CO, 86). Anal. Calcd for $C_{34}H_{30}N_4O_5$: C, 71.07; H, 5.26; N, 9.75. Found: C, 71.17; H, 5.40; N, 9.65.

4.6.2.8. 4-[4,5-Bis-(4-fluorophenyl)-1-isobutyl-1*H*-imidazol-2-yl]-3-(4-ethoxyphenyl)sydnone (10a). Orange needles from CH_2Cl_2/EtOH; mp 183–185 °C; IR (KBr) 3060, 2988, 2958, 2928, 2872, 1754, 1608, 1511, 1258, 1227, 848 cm^{-1}; ^1H NMR (DMSO-d_6) δ 0.52 (d, J=6.4 Hz, 6H), 1.34 (t, J=6.8 Hz, 2H), 1.50 (m, 1H), 3.72 (d, J=8.0 Hz, 2H), 4.12 (q, J=6.8 Hz, 2H), 7.01–7.06 (m, 2H), 7.14–7.20 (m, 4H), 7.31–7.41 (m, 4H), 7.73 (d, J=8.8 Hz, 2H); ^{13}C NMR (DMSO-d_6) δ 14.59, 19.37, 28.39, 51.59, 64.08, 100.69, 115.12, 115.30 (d, $^2J_{C-F}$=22 Hz), 116.64 (d, $^2J_{C-F}$=22 Hz), 126.25 (d, $^4J_{C-F}$=4 Hz), 126.86, 127.04, 128.13 (d, $^3J_{C-F}$=9 Hz), 129.69, 130.34 (d, $^4J_{C-F}$=4 Hz), 132.48, 133.14 (d, $^3J_{C-F}$=9 Hz), 137.79, 161.22 (d, $^1J_{C-F}$=245 Hz), 161.28, 162.58 (d, $^1J_{C-F}$=245 Hz), 165.70; FABMS$^+$ m/z (%): 517 (M^++H, 100), 516 (M^+, 57), 459 (M^+−NO−CO+H, 39), 458 (M^+−NO−CO, 85). Anal. Calcd for $C_{29}H_{26}N_4O_3F_2$: C, 67.43; H, 5.07; N, 10.85. Found: C, 67.50; H, 5.20; N, 10.87. X-ray analytical data are listed in Table 4. Further details have been deposited at the Cambridge Crystallographic Data Center and allocated the deposition number CCDC 630277.

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