Silica-bonded *S*-Sulfonic Acid: A Recyclable Catalyst for the Synthesis of Trisubstituted Imidazoles under Solvent-free Conditions

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Trisubstituted imidazoles have been synthesized in high yields in the presence of silica-bonded *S*-sulfonic acid as a catalyst. The reaction was carried out at 130 ℃ under solvent-free conditions. The reaction work-up is simple and the catalyst is easily separated from the products by filtration.

Keywords silica-bonded *S*-sulfonic acid, trisubstituted imidazole, aldehyde, catalyst, solvent-free

Introduction

The development of heterogeneous catalysts for organic synthesis has become a major area of research. The potential advantages of these materials over homogeneous systems (simplified recovery, reusability and the potential for incorporation in continuous reactors and microreactors) can lead to novel and environmentally benign chemical procedures for academia and industry.[1] From this viewpoint, catalytic reactions lead to valuable processes, since the use of stoichiometric reagents that are often toxic poses inherent limitations from both an economical and an environmental viewpoints and in specific relation to product purification and waste management.[2] Application of solid acids in organic transformation has important roles, because these species have many advantages such as simplicity in handling, decreased reactor and plant corrosion problems, and more environmentally safe disposal.[3-9] It is clear that green chemistry not only requires the use of environmentally benign reagents and solvents, but also the recovery and reuse of the catalyst. One way to overcome the problem of recyclability of the traditional acid catalyst is to chemically anchor the reactive center onto a large surface area inorganic solid carrier to create a new organic-inorganic hybrid catalyst.[4] In these types of solids, the reactive centers are highly mobile similar to homogeneous catalysts and at the same time these species have the advantage of being recyclable in the same fashion as heterogeneous catalysts. In view of this, several types of solid sulfonic acid functionalized silica (both amorphous and ordered) have been synthesized and applied as an alternative to traditional sulfonic acid resins and homogeneous acids in catalyzing chemical transformations.[3-9]

The imidazole moiety is present in wide naturally occurring molecules[10] and pharmaceutically active compounds.[11] Among these, 2,4,5-trisubstituted imidazoles are of great interest because of their chemical and biological activities, making them common structures in numerous synthetic compounds[11] and therapeutic agents.[12] Because of this, numerous classical methods for their synthesis have been reported.[13-15] In these procedures, a 1,2-diketone, an aldehyde and ammonium acetate were condensed in the presence of a strong protic acid (such as H_3PO_4,[16] H_2SO_4,[17] and HOAc[18,19]) or other catalysts in HOAc,[14] under reflux conditions. The products were isolated by neutralization of the reaction mixture. The solvent used for these syntheses has usually been a polar organic solvent, such as ethanol, methanol, acetic acid, DMF or DMSO, with the result that the isolation and recovery procedures are complicated. These processes also generate significant wastes containing the catalysts, which have to be recovered, treated and disposed of in environmentally acceptable ways.

Recently, a few research groups have reported one-pot condensation of α-hydroxy ketone or α-keto-oxime or 1,2-diketone, aldehyde and NH_4OAc on solid supports under microwave irradiation.[20-22] However, in spite of their potential utility, most of these methods not only involve high temperature (180—200 ℃) but also the reactions have been carried out in HOAc. The other methods utilizing ionic liquids,[23,24] silica sulfuric acid,[25] alum,[26] $Zr(acac)_4$,[27] tetrabutylammonium bromide,[28] and polymer-supported zinc chloride[29] have also been described. One important aspect of clean technology is the use of environmentally friendly catalysis typically involving the use of solid acid catalysis. Employing such approaches will lead to minimal

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pollution and waste material, and application of such catalysts to fine chemical manufacturing is likely to be especially important in future.

Results and discussion

Recently, we have reported the preparation of silica-bonded *S*-sulfonic acid (SBSSA) and its application as catalyst to the preparation of acylal,[5] quinoxaline,[6] and coumarin derivatives[7] (Scheme 1).

In our continued interest in the development of a highly expedient methodology for the synthesis of fine chemicals and heterocyclic compounds of biological importance,[30-35] we report here the synthesis of trisubstituted imidazoles in the presence of SBSSA under solvent-free conditions (Scheme 2).

In a primary study, we have chosen the condensation reaction of benzil with benzaldehyde and ammonium acetate as a model reaction in the presence of different catalytic amounts of SBSSA under solvent-free conditions. The results are summarized in Table 1.

As indicated in Table 1, the best results have been obtained at 130 ℃ with a catalytic amount of 0.002 g (0.068 mol%) of SBSSA, aldehyde (1 mmol), 1,2-diketone (1 mmol), and ammonium acetate (6 mmol) under solvent-free conditions. The yield of reaction with increasing amount of SBSSA or temperature is not considerably increased. It is important to note that in the absence of catalyst the reaction yield is decreased to 35% even at 180 ℃ after 1 h (Table 1, Entry 3).

A wide range of aromatic aldehydes were employed and all imidazoles were obtained in high to excellent yields, and a general method was observed that tolerates both electron-withdrawing and electron-donating constituents. Another important aspect is that various functionalities such as thioether, halide, *etc*., survived under the present reaction conditions. To evaluate the generality of this method, we also concentrated our study on different benzils (Table 2, Entries 9—17). The results illustrate the high ability of this method for the synthesis of 2,4,5-triarylimidazoles with different groups.

Table 1 Model condensation of benzaldehyde with benzil and ammonium acetate in the presence of different amounts of SBSSA under heating and solvent-free conditions[a]

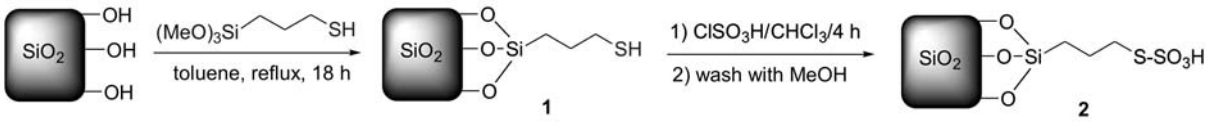
Entry	Amount of catalyst/g	Time/min	Temperature/℃	Yield[b]/%
1	—	60	130	15
2	—	60	150	20
3	—	60	180	35
4	0.2	60	80	20
5	0.1	60	100	50
6	0.2	60	130	80
7	0.1	60	130	92
8	0.05	45	130	92
9	0.03	40	130	93
10	0.01	30	130	93
11	0.005	30	130	93
12	0.002	30	130	95
13	0.1	60	150	95

[a] The molar ratio of aromatic aldehyde : 1,2-diketone : NH_4OAc used was 1 : 1 : 6 respectively. [b] Isolated yield.

Encouraged by this achievement, we extended the reaction to condensation of benzoin and NH_4OAc with a range of aromatic aldehydes under similar conditions (Scheme 3), furnishing the respective corresponding imidazoles in good to excellent yields (Table 3).

The possibility of recycling the catalyst was examined using the reaction of benzil, 4-methylbenzaldehyde and ammonium acetate under optimized conditions. Upon completion, the reaction mixture was filtered and the solid was washed with ethanol, and recycled catalyst was saved for the next reaction. The recycled catalyst could be reused three times without any further treatment. No observation of any appreciable loss in the catalytic activity of SBSSA was observed (Table 2, Entry 2).

Scheme 1 Preparation of silica bonded *S*-sulfonic acid



Scheme 2 SBSSA catalyzed synthesis of trisubstituted imidazoles at 130 ℃ under solvent-free conditions

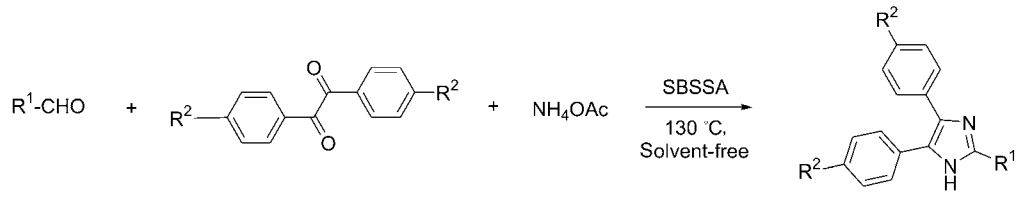


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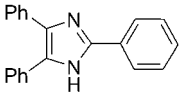
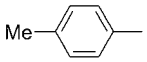
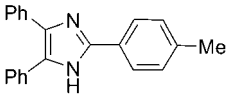
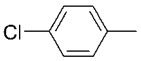
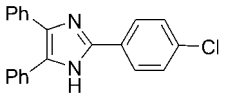
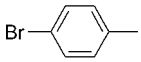
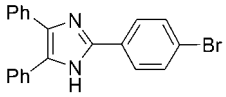
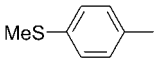
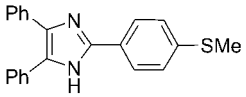
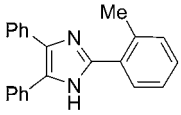
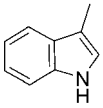
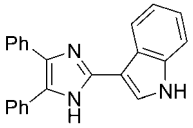
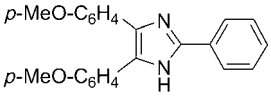
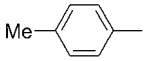
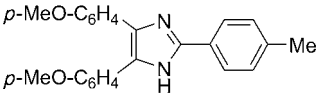
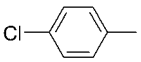
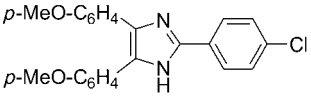
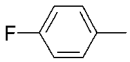
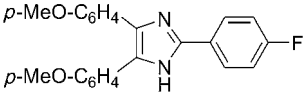
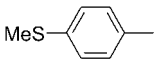
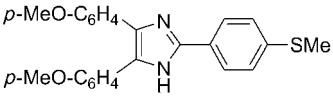
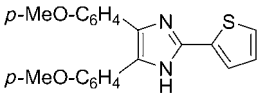
Table 2 Synthesis of trisubstituted imidazole derivatives catalyzed by SBSSA at 130 ℃ under solvent-free conditions[a]

Entry	R^1	R^2	Product	Time/min	Yield[b]/%
1		H		30	95
2		H		25, 25, 30, 30[c]	88, 86, 84, 84[c]
3		H		30	90
4		H		30	89
5		H		30	90
6		H		30	89
7		H		85	92
8		MeO		80	90
9		MeO		60	92
10		MeO		90	94
11		MeO		80	89
12		MeO		120	90
13		MeO		90	89

Continued

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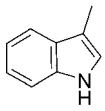
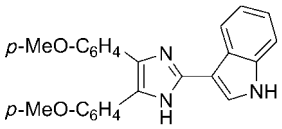
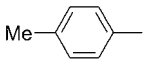
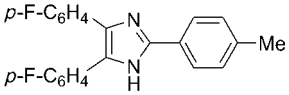
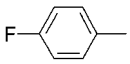
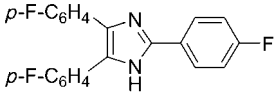
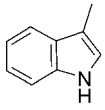
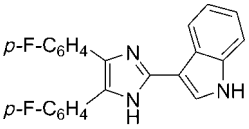
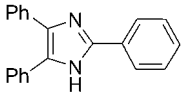
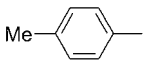
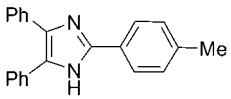
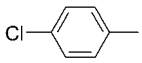
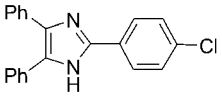
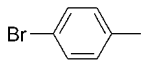
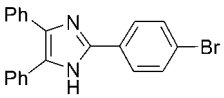
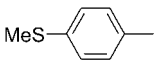
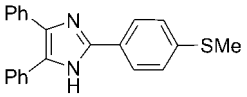
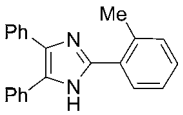
14		MeO		70	95
15		F		90	92
16		F		90	88
17		F		80	91

[a] The molar ratios of 1,2-diketone∶aldehyde∶ammonium acetate used were 1∶1∶6 in the presence of 0.002 (g) of SBSSA. [b] Isolated yield. [c] The reaction was accomplished in the presence of reused SBSSA as catalyst.

Table 3 Synthesis of trisubstituted imidazole via the reaction of α-hydroxy ketone, aldehydes and ammonium acetate catalyzed by SBSSA at 130 ℃ under solvent-free conditions[a]

Entry	R^1	R^2	Product	Time/min	Yield[b]/%
1		H		80	95
2		H		70	88
3		H		90	90
4		H		90	89
5		H		80	90
6		H		80	89

[a] The molar ratios of α-hydroxy ketone∶aldehyde∶ammonium acetate used were 1∶1∶6 in the presence of 0.002 (g) of SBSSA. [b] Isolated yield.

Conclusion

In conclusion, heterogeneous conditions, easy and clean work-up and high yields make this method practical for multi-component reactions. We believe that the present methodology could be an important addition to the existing methodologies.

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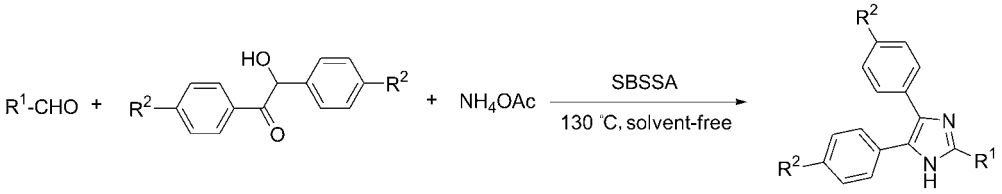
Scheme 3 Preparation of trisubstituted imidazoles using aromatic aldehyde, α-hydroxy ketone and ammonium acetate



Experimental

General

Chemicals were purchased from Merck, Fluka and Aldrich chemical companies. IR spectra were run on a Perkin Elmer FT-IR Spectrum BX instrument. ^{1}H and ^{13}C NMR spectra were run on a Bruker Ultrashield 400 (400 MHz) spectrometer, or a Bruker Avance 500 (500 MHz) spectrometer. Melting points were recorded on a Melting Point SMP1 apparatus in open capillary tubes and are uncorrected. With TLC using silica gel SILG/UV 254 plates the progress of reaction was followed. Most of the products are known and characterized by comparison of their spectral (IR, ^{1}H NMR), TLC and physical data with those reported in the literature.[19,24-29,36-38]

General procedure for the synthesis of trisubstituted imidazole derivatives

To a mixture of aromatic aldehyde (1 mmol), 1,2-diketone (1 mmol) and ammonium acetate (6 mmol) was added silica-bonded *S*-sulfonic acid (0.002 g) and the resulting mixture was heated at 130 ℃. The solid materials residue was then washed with acetone and the solvent was evaporated to give the crude product. For further purification it was crystallized from 9∶1 (*V*∶*V*) acetone-water mixture to afford pure product.

Spectral data

2,4,5-Triphenylimidazole (Table 2, Entry 1): m.p. 271—273 ℃ (Lit.[26] 272—273 ℃); ^{1}H NMR ($CDCl_3$/DMSO-d_6, 500 MHz) δ: 7.13—7.14 (m, 2H), 7.20 (t, J=7.2 Hz, 5H), 7.27—7.30 (m, 2H), 7.46 (d, J=7.0 Hz, 4H), 7.98 (d, J=7.7 Hz, 2H), 12.00 (brs, 1H); ^{13}C NMR ($CDCl_3$/DMSO-d_6, 125 MHz) δ: 125.95, 127.34, 128.48, 128.64, 128.82, 130.95, 146.64.

4,5-Diphenyl-2-(4-tolyl)imidazole (Table 2, Entry 2): m.p. 236—238 ℃ (Lit.[11] 232—235 ℃); ^{1}H NMR ($CDCl_3$/DMSO-d_6, 500 MHz) δ: 2.03 (s, 3H), 6.86—6.91 (m, 4H), 6.96 (t, J=7.2 Hz, 4H), 7.21 (d, J=7.4 Hz, 4H), 7.64 (d, J=8.1 Hz, 2H), 11.89 (brs, 1H); ^{13}C NMR ($CDCl_3$/DMSO-d_6, 125 MHz) δ: 21.44, 125.66, 127.13, 128.07, 128.22, 128.44, 129.33, 138.03, 146.52.

2-(4-Chlorophenyl)-4,5-diphenylimidazole (Table 2, Entry 3): m.p. 263—265 ℃ (Lit.[36] 266—268 ℃); ^{1}H NMR ($CDCl_3$/DMSO-d_6, 500 MHz) δ: 6.89—6.95 (m, 6H), 7.01 (d, J=8.5 Hz, 2H), 7.19 (d, J=7.1 Hz, 4H), 7.72 (d, J=8.5 Hz, 2H), 12.00 (brs, 1H); ^{13}C NMR ($CDCl_3$/DMSO-d_6, 125 MHz) δ: 127.03, 128.16, 128.47, 128.73, 129.45, 133.65, 145.21.

2-(4-Bromophenyl)-4,5-diphenylimidazole (Table 2, Entry 4): m.p. 262—264 ℃ (Lit.[26] 252—254 ℃); ^{1}H NMR ($CDCl_3$/DMSO-d_6, 500 MHz) δ: 7.12—7.19 (m, 6H), 7.39 (d, J=8.5 Hz, 2H), 7.43 (d, J=7.1 Hz, 4H), 7.87 (d, J=8.5 Hz, 2H), 12.12 (brs, 1H); ^{13}C NMR ($CDCl_3$/DMSO-d_6, 125 MHz) δ: 122.27, 127.50, 128.42, 128.66, 130.00, 131.87, 145.57.

2-(4-Methylthiophenyl)-4,5-diphenylimidazole (Table 2, Entry 5): m.p. 244—246 ℃ (Lit.[26] 242—244 ℃); ^{1}H NMR ($CDCl_3$/DMSO-d_6, 500 MHz) δ: 2.31 (s, 3H), 7.00—7.12 (m, 8H), 7.33—7.39 (m, 4H), 7.83 (d, J = 8.5 Hz, 2H), 11.90 (brs, 1H); ^{13}C NMR ($CDCl_3$/DMSO-d_6, 125 MHz) δ: 15.76, 126.23, 126.44, 127.75, 128.57, 138.74, 146.19.

4,5-Diphenyl-2-(2-tolyl)imidazole (Table 2, Entry 6): m.p. 204—206 ℃ (Lit.[26] 198—202 ℃); ^{1}H NMR ($CDCl_3$/DMSO-d_6, 500 MHz) δ: 2.61 (s, 3H), 7.20—7.24 (m, 5H), 7.25—7.30 (m, 5H), 7.56 (m, 3H), 7.63 (d, J = 7.6 Hz, 1H), 11.40 (brs, 1H); ^{13}C NMR ($CDCl_3$/DMSO-d_6, 125 MHz) δ: 21.47, 126.01, 127.33, 128.36, 128.72, 128.78, 129.60, 130.92, 131.35, 137.35, 147.04.

2-(3-Indolyl)-4,5-diphenylimidazole (Table 2, Entry 7): m.p. 302—305 ℃; ^{1}H NMR (DMSO-d_6, 400 MHz) δ: 7.05—7.16 (m, 3H), 7.23—7.28 (m, 3H), 7.37 (d, J=7.8 Hz, 3H), 7.44 (d, J=7.3 Hz, 2H), 7.56 (d, J =7.1 Hz, 2H), 7.93 (d, J=2.5 Hz, 1H), 8.40 (d, J=8.6 Hz, 1H), 11.29 (s, 1H), 12.20 (brs, 1H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ: 106.79, 111.58, 119.68, 121.48, 121.84, 123.74, 125.06, 126.84, 128.15, 128.67, 136.24, 143.69, 145.27, 171.66; IR (neat) v: 3412.71, 3055.71, 1621.86, 1598.56, 1491.27, 1451.65, 1336.66, 1208.91, 1182.28, 1049.08, 940.61, 854.56, 761.99, 749.63, 696.11 cm^{-1}. Anal. calcd for $C_{23}H_{17}N_3$: C 82.36, H 5.11, N 12.53; found C 82.17, H 5.17, H 12.29.

4,5-Di(4-anisyl)-2-phenylimidazole (Table 2, Entry 8): m.p. 110—112 ℃ (Lit.[37] 202—203 ℃); ^{1}H NMR (DMSO-d_6, 400 MHz) δ: 3.77 (s, 6H), 6.95 (d, J=8.1 Hz, 4H), 7.35 (t, J=7.3 Hz, 1H), 7.44—7.48 (m, 6H), 8.07 (d, J=7.3 Hz, 2H), 12.54 (brs, 1H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ: 55.07, 113.84, 125.02, 127.98, 128.62, 128.93, 130.49, 144.78, 158.30, 172.02.

4,5-Di(4-anisyl)-2-(4-tolyl)imidazole (Table 2, Entry 9): m.p. 102—104 ℃ (Lit.[37] 212—215 ℃); ^{1}H NMR (DMSO-d_6, 400 MHz) δ: 2.35 (s, 3H), 3.77 (s, 6H), 6.86—6.99 (m, 4H), 7.27 (d, J=8.1 Hz, 2H), 7.44 (d, J=8.3 Hz, 4H), 7.95 (d, J=8.1 Hz, 2H), 12.43 (brs, 1H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ: 20.87, 55.07,

113.81, 124.99, 127.83, 129.18, 137.36, 144.93, 157.77, 172.01.

4,5-Di(4-anisyl)-2-(4-chlorophenyl)imidazole (Table 2, Entry 10): m.p. 122—124 ℃; ^{1}H NMR (DMSO-d_6, 400 MHz) δ: 3.77 (s, 6H), 6.84—7.01 (m, 4H), 7.38—7.50 (m, 4H), 7.53 (d, J=8.8 Hz, 2H), 8.08 (d, J = 8.8 Hz, 2H), 12.01 (brs, 1H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ: 55.07, 113.75, 113.79, 114.02, 126.64, 128.71, 129.35, 132.44, 143.69, 172.01; IR (neat) v: 2932.21, 2835.92, 1650.62, 1613.37, 1573.65, 1494.35, 1297.54, 1247.29, 1178.54, 1029.62, 831.13, 729.04, 639.69 cm^{-1}. Anal. calcd for $C_{23}H_{19}ClN_2O_2$: C 70.68, H 4.90, N 7.17, Cl 9.07; found C 70.49, H 5.04, N 6.99, Cl 8.89.

4,5-Di(4-anisyl)-2-(4-fluorophenyl)imidazole (Table 2, Entry 11): m.p. 126—129 ℃; ^{1}H NMR (DMSO-d_6, 400 MHz) δ: 3.77 (s, 6H), 6.83—7.04 (m, 4H), 7.30 (t, J=8.8 Hz, 2H), 7.44 (d, J=7.6 Hz, 4H), 8.10 (dd, J=8.8, 5.5 Hz, 2H), 12.53 (brs, 1H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ: 55.04, 113.79, 113.91, 115.47, 127.15, 127.18, 143.98, 160.74, 163.17, 172.02; IR (neat) v: 2933.24, 1650.05, 1614.17, 1551.75, 1509.43, 1498.37, 1242.47, 1171.29, 1030.63, 833.59, 808.11, 729.48, 660.80, 608.77 cm^{-1}. Anal. calcd for $C_{23}H_{19}FN_2O_2$: C 73.78, H 5.11, N 7.48, F 5.07; found C 73.56, H 5.18, N 7.27, F 4.88.

4,5-Di(4-anisyl)-2-(4-methylthiophenyl)imidazole (Table 2, Entry 12): m.p. 112—114 ℃; ^{1}H NMR (DMSO-d_6, 400 MHz) δ: 2.47 (s, 3H), 3.72 (s, 6H), 6.84—6.94 (m, 4H), 7.29 (d, J=8.3 Hz, 2H), 7.39 (d, J=8.6 Hz, 4H), 7.95 (d, J=8.3 Hz, 2H), 12.42 (brs, 1H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ: 21.05, 55.07, 113.84, 113.89, 125.47, 125.83, 127.07, 138.05, 144.49, 172.02; IR (neat) v: 2960.60, 2837.95, 1650.20, 1613.39, 1573.89, 1503.20, 1390.47, 1298.51, 1251.79, 1180.16, 1029.22, 837.93, 724.34, 637.61 cm^{-1}. Anal. calcd for $C_{24}H_{22}N_2O_2S$: C 71.62, H 5.51, N 7.95, S 7.97; found C 71.41, H 5.63, N 6.77, S 7.81.

4,5-Di(4-anisyl)-2-(2-thienyl)imidazole (Table 2, Entry 13): m.p. 137—139 ℃ (Lit.[38] 139.5—140.5 ℃); ^{1}H NMR (DMSO-d_6, 400 MHz) δ: 3.77 (s, 6H), 6.85—7.04 (m, 4H), 7.12—7.14 (m, 1H), 7.42 (d, J=8.6 Hz, 4H), 7.53 (dd, J=5.0, 1.3 Hz, 1H), 7.66 (dd, J=3.5, 1.0 Hz, 1H), 12.61 (brs, 1H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ: 55.07, 113.83, 114.00, 123.83, 125.88, 127.84, 128.16, 129.49, 129.75, 134.20, 140.90, 172.02.

4,5-Di(4-anisyl)-2-(3-indolyl)imidazole (Table 2, Entry 14): m.p. 136—139 ℃; ^{1}H NMR (DMSO-d_6, 400 MHz) δ: 3.77 (s, 6H), 6.96 (d, J=8.1 Hz, 4H), 7.12—7.20 (m, 2H), 7.44—7.51 (m, 5H), 7.97 (d, J=2.52 Hz, 1H), 8.48 (d, J=7.06 Hz, 1H), 11.34 (s, 1H), 12.08 (brs, 1H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ: 55.07, 106.98, 111.55, 113.85, 119.59, 121.51, 121.78, 123.50, 125.06, 128.76, 136.23, 142.98, 158.08, 172.02; IR (neat) v: 2833.79, 1655.93, 1611.97, 1587.00, 1529.82, 1494.24, 1402.85, 1247.10, 1179.05, 1030.05, 837.99, 750.54, 649.00 cm^{-1}. Anal. calcd for $C_{25}H_{21}N_3O_2$: C 73.78, H 5.11, N 7.48, F 5.07; found C 73.59, H 5.19, N 7.27, F 4.90.

4,5-Di(4-fluorophenyl)-2-(4-tolyl)imidazole (Table 2, Entry 15): m.p. 243—245 ℃; ^{1}H NMR (DMSO-d_6, 400 MHz) δ: 2.36 (s, 3H), 7.19—7.27 (m, 4H), 7.29 (d, J=8.1 Hz, 2H), 7.50—7.54 (m, 4H), 7.95 (d, J=8.1 Hz, 2H), 12.66 (brs, 1H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ: 20.89, 125.17, 129.27, 144.29, 145.61, 170.32; IR (neat) v: 3047.66, 1612.10, 1517.42, 1499.79, 1219.84, 1154.86, 1094.16, 970.89, 823.93, 728.59, 658.72, 609.69 cm^{-1}. Anal. calcd for $C_{22}H_{16}F_2N_2$: C 76.29, H 4.66, N 8.09, F 10.97; found C 76.07, H 4.75, N 7.91, F 10.83.

2,4,5-Tri(4-fluorophenyl)imidazole (Table 2, Entry 16): m.p. 162—164 ℃; ^{1}H NMR (DMSO-d_6, 400 MHz) δ: 7.28—7.44 (m, 6H), 7.66—7.72 (m, 4H), 8.15 (dd, J = 8.8, 5.5 Hz, 2H), 12.73 (brs, 1H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ: 115.72, 115.94, 116.09, 116.31, 123.09, 124.50, 128.65, 129.01, 129.82, 158.66, 162.35; IR (neat) v: 1606.13, 1513.02, 1498.80, 1220.23, 1156.08, 1095.86, 965.90, 830.00, 740.76, 659.24 cm^{-1}. Anal. calcd for $C_{21}H_{13}F_3N_2$: C 71.99, H 3.74, N 8.00, F 16.27; found C 71.78, H 3.87, N 7.89, F 16.05.

4,5-Di(4-fluorophenyl)-2-(3-indolyl)imidazole (Table 2, Entry 17): m.p. 303—305 ℃; ^{1}H NMR (DMSO-d_6, 400 MHz) δ: 6.93—7.01 (m, 4H), 7.10—7.14 (m, 2H), 7.26 (d, J=7.82 Hz, 1H), 7.34—7.43 (m, 4H), 7.78 (d, J=2.5 Hz, 1H), 8.27 (d, J=7.3 Hz, 1H), 11.19 (s, 1H), 12.12 (brs, 1H); ^{13}C NMR (DMSO-d_6, 100 MHz) δ: 106.68, 115.20, 119.70, 121.41, 121.85, 123.75, 125.00, 128.63, 130.27, 135.56, 143.69, 163.65, 165.27; IR (neat) v: 3425.31, 3055.92, 1614.17, 1591.07, 1515.87, 1503.57, 1409.97, 1334.10, 1225.69, 1157.76, 1093.83, 936.77, 835.74, 750.20, 741.96, 725.28, 657.93, 608.49 cm^{-1}. Anal. calcd for $C_{23}H_{15}F_2N_3$: C 74.38, H 4.07, N 11.31, F 10.23; found C 74.19, H 4.15, N 11.10, F 10.02.

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