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Microwave assisted synthesis and crystal structures of 2-imidazolines and imidazoles

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Abstract—A series of 2-imidazolines and imidazoles has been synthesized using green synthetic methodologies. The preparation of 2-imidazolines was performed by cyclization of nitriles with ethylenediamine. The use of microwave irradiation in solvent-free conditions enabled 2-imidazolines to be obtained in high yields within short reaction times. Aromatization of imidazoles was performed under microwave irradiation in toluene and using Magtrieve™ as the oxidant. The X-ray structures for five of these derivatives are provided. In all cases, the molecules are assembled into chains through N–H···N hydrogen bonds.

1. Introduction

The preparation of 2-substituted imidazolines and imidazoles is of increasing interest because of their applications as disinfectants, pharmaceuticals or as starting materials for these fine chemicals.[1] In supramolecular chemistry these systems have found multiple applications, for example, in the preparation of molecular tectonics through the formation of intermolecular hydrogen bonds,[2] in the formation of a helical assembly through triple hydrogen bonds in tris(oxazoline)-tris(imidazoline) benzene,[3] in the preparation of triple-stranded helices and zig-zag chains by coordination with copper(I),[4] in the synthesis of palladium complexes with pyridine/imidazoline ligands that have been shown to react readily with carbon monoxide,[5] and in the preparation of supramolecular structures by self assembly using π–π stacking and hydrogen bonding interactions.[6]

We became interested in the synthesis of azolyl-substituted imidazolines and imidazoles for possible use in the formation of supramolecular structures by coordination with transition metals or by the formation of intermolecular hydrogen bonds. In this regard, we recently described the synthesis and self-association of azolyl-substituted pyrimidine and 1,3,5-triazine derivatives.[7]

In consequence, we have considered the preparation of pyrazolylimidazolines and imidazoles under green synthetic conditions, using microwave irradiation as the energy source, solvent-free conditions, and green oxidants.

2. Results

2.1. Synthesis of imidazolines 3, 5, and 7

The imidazoline ring was built by cyclization of the appropriate nitrile with ethylenediamine in the presence of sulfur and under solvent-free conditions (Scheme 1).

The preparation of imidazolines has previously been performed by electrophilic diamination of functionalized alkenes,[8] reaction of aziridines with platinum(II) nitriles,[9] and reaction of aromatic nitriles with ethylenediamines by the action of elemental sulfur,[10] copper salts,[11] phosphates or silica.[12]

We consider the reaction with ethylenediamine in the presence of elemental sulfur as the most suitable because of the simplicity of the method and the easy work-up procedure, which makes this method a green synthetic procedure.

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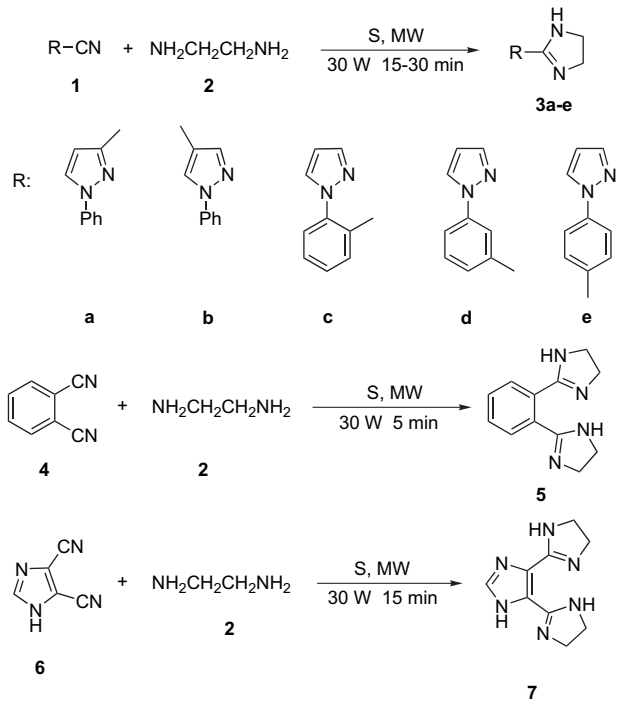


Scheme 1.

Reactions were performed under solvent-free conditions; a mixture of the nitrile, sulfur, and an excess of ethylenediamine was irradiated at 30 W for 3–30 min. Reaction times were optimized for every nitrile considering that in solvent-free conditions absorption of microwave irradiation, and in consequence the temperature reached during the reaction, strongly depends on the polarity of the starting material. The crude product was washed with cold water and, in most cases, the pure product crystallized. Good-to-excellent yields (Table 1) of the corresponding imidazolines were obtained using this approach.

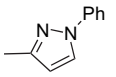
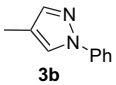
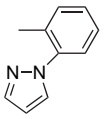
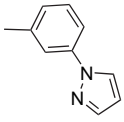
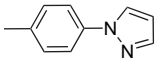
The ^{1}H NMR spectra of compounds **3**, **5**, and **7** contain the characteristic signals of the pyrazole and phenyl rings and two or three broad singlets for the imidazoline protons, one for the NH group, and one or two for the CH_2 groups. A similar situation is also found in the ^{13}C NMR spectra in which the CH_2 carbons are not observed even with a long relaxation time. The presence of broad signals for the CH_2 groups indicates the occurrence of a tautomeric equilibrium in the imidazoline ring. However, the free energy of activation could not be calculated as these signals remain as broad singlets over a broad temperature range (from 223 to 413 K). A similar observation has been previously described for aminopyrazolines.[13]

2.2. Aromatization of imidazolines 3, 5, and 7

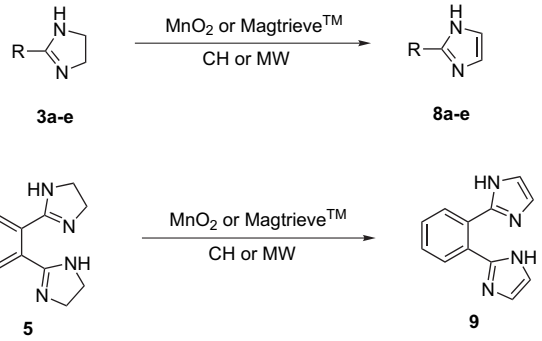
Aromatization of imidazolines to the corresponding imidazoles has been performed by reaction with DMSO,[14] dehydrogenation with Pd/C[14,15] in toluene, by Swern oxidation,[16] and by reaction with trichloroisocyanuric acid[17] in acetonitrile.

We performed the aromatization of imidazolines using Magtrieve™, which is an environmentally friendly oxidant because it can be used under mild conditions, removed magnetically, and recycled (Scheme 2). Magtrieve™ is a chromium dioxide-based reagent that has been used in the oxidation of alcohols[18–20] and thiols,[21] side chain oxidation of arenes,[22] deprotection of acetals,[23] and aromatization of Hantzsch dihydropyridines.[24] Magtrieve™ is polar and can be heated efficiently under microwaves; the material reaches temperatures up to 360 °C within 2 min of irradiation, but is not distributed uniformly and is very difficult to control. When toluene was introduced into the reaction vessel, the temperature of Magtrieve™ reached ca. 140 °C within 2 min and the temperature was more uniformly distributed.[20]

Table 1. Reaction conditions and yields for the preparation of imidazolines **3a–e**, **5**, and **7**

R	Power (W)	*t* (min)	*T* (K)	Yield (%)
 **3a**	30	15	383	74
 **3b**	30	30	383	98
 **3c**	30	30	373	98
 **3d**	30 —	30 30	373 373	82 68[a]
 **3e**	30	15	383	91
 **5**	30 30	5 3	353 353	42 18[b]
 **7**	30 30 30	5 15 25	368 368 368	68 89 95

[a] Conventional heating in an oil bath.
[b] Traces of impurities.



Scheme 2.

Table 2. Aromatization of imidazoline **3b** in toluene solution at reflux (383 K)

Entry	Oxidant	*t* (min)	Power (W)	Yield (%)
1	Magtrieve™	75	120	54
2	Magtrieve™	105	120	64
3	$BaMnO_4$	105	120	21
4	MnO_2	75	120	56
5	MnO_2	105	120	61

As a consequence we decided to study the aromatization of imidazolines **3**, **5**, and **7** using Magtrieve™ under microwave irradiation in toluene solution.

In an effort to show the potential of Magtrieve™ we performed the aromatization of imidazoline **3b** and compared the results with other oxidizing reagents such as MnO_2 and $BaMnO_4$ (Table 2) under microwave irradiation. The results obtained with Magtrieve™ (entries 1 and 2) were comparable to those obtained with MnO_2 (entries 4 and 5) and better than with $BaMnO_4$ (entry 3).

The use of conventional heating with MnO_2 meant that longer reaction times (24–48 h) were required to obtain good results (Table 3).

Under microwave irradiation the reaction times can be shortened to 75–105 min (Table 4) and better yields are obtained in comparison to conventional heating under comparable reaction conditions of temperature and time (see, for example, entries 2 vs 3 and 4 vs 5). Compound **7** with two imidazoline rings did not afford any oxidation product and the starting material was recovered along with the oxidizing agents. This can be a consequence of the acidic imidazole NH interfering with the oxidants. Similarly, compound **5** gave low yield (entry 8) even after increasing the temperature using refluxing xylene as the solvent (entry 9), and only conventional heating in long reaction time gave acceptable results (entry 10).

Table 3. Aromatization of imidazolines **3** with MnO_2 in $CHCl_3$ at reflux under conventional heating

Entry	Imidazoline	*t* (h)	Yield (%)
1	**3a**	24	92
2	**3b**	48	76
3	**3c**	24	93
4	**3d**	24	81
5	**3e**	24	89

Table 4. Aromatization of imidazolines **3** and **5** with Magtrieve™ in toluene at reflux

Entry	Imidazoline	*t* (min)	Power (W)	Yield (%)
1	**3a**	105	120	77
2	**3b**	105	120	64
3	**3b**	105	[a]	16
4	**3c**	75	270	88
5	**3c**	75	[a]	56
6	**3d**	75	270	70
7	**3e**	105	270	77
8	**5**	105	90	26[b]
9	**5**[c]	105	120	20[b]
10	**5**	24 h	[a]	65

[a] Conventional heating.
[b] Yield of compound **9**.
[c] Solvent: xylene.

2.3. Solid-state structure determination

The structures of compounds **3d**, **3e**, **5**, **9**, and **10** were characterized by X-ray crystallography. The crystal structure of compound **5** has been reported previously,[25] but the atomic coordinates were not deposited in the Cambridge Crystallographic Data Centre[26] (CSD refcode IMYLBZ) and so the structure was determined in this work for the sake of comparison.

In all compounds, the supramolecular structure is dominated by one-dimensional chains formed through N–H···N interactions, as illustrated in Figures 1 and 2. Compounds **3d** and **3e** differ in the conformation of the molecule and in the bond distances and angles involving the NH–C=N and C–N=N fragments in the imidazoline and pyrazole rings. In **3e**, the imidazoline ring is almost coplanar with

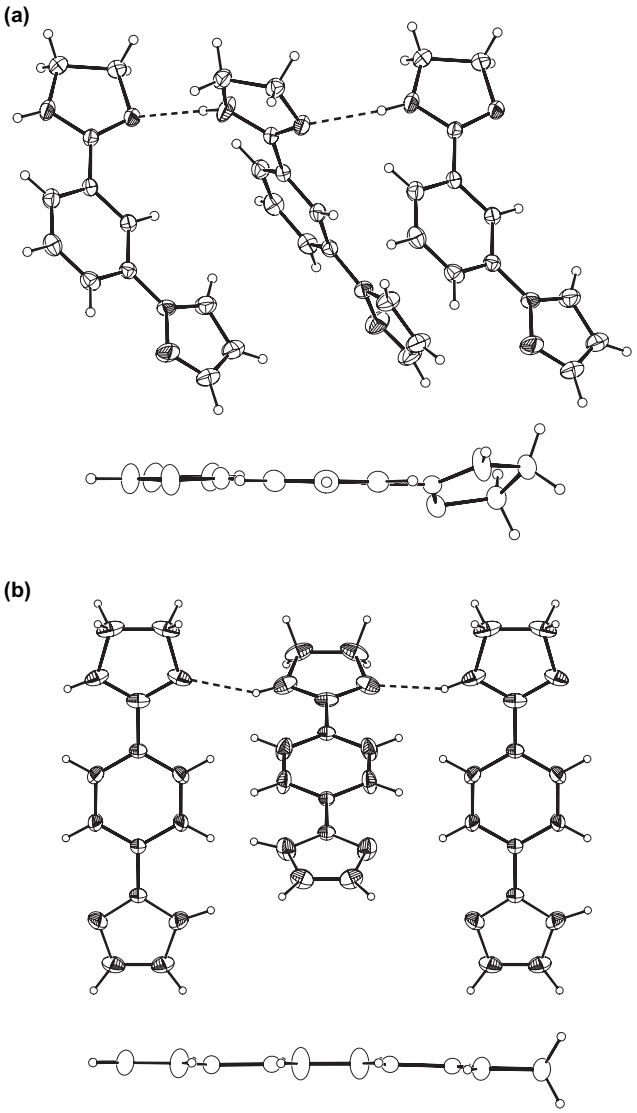


Figure 1. (a) Hydrogen bonding network in **3d** and a perspective view showing the molecular conformation. (b) Same for **3e**. The disorder has been omitted for clarity [N···N intermolecular distances of 2.943(2) and 2.990(6) Å for **3d** and **3e**, respectively].

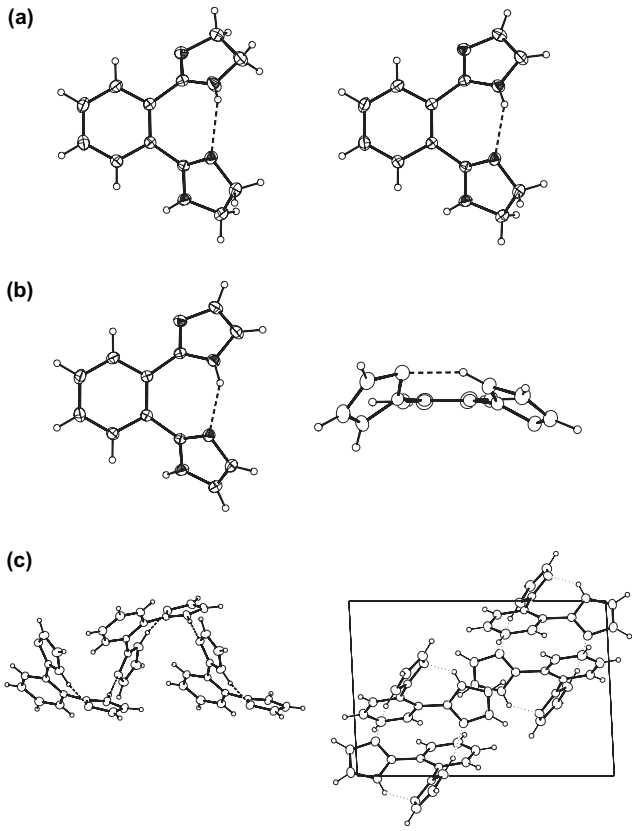


Figure 2. (a) Molecular structures of **5** and **10**. (b) Two views of the molecular structure of **9** showing the disposition of the azoles. (c) 1D structure and crystal packing of **9** along the *b* axis [N···N intra- and intermolecular distances of 2.752(2), 2.935(2); 2.753(2), 2.853(2) and 2.706(2), 2.924(2) Å for **5**, **9**, and **10**, respectively].

the phenyl ring (Fig. 1) and the C═N and N═N bonds are delocalized.

The molecular structure of compounds **5**, **9**, and **10** are shown in Figure 2a, b. The crystal structures of these compounds are isomorphous with one another and so only the supramolecular structure of one compound (**9**) and its crystal packing is illustrated in Figure 2c. In all cases, the analysis reveals a combination of intra- and intermolecular N–H···N hydrogen bonds leading to the formation of helical chains. The main differences between the three compounds concern the conformation of the azoles, imidazoline and/or imidazole, and the type of interactions in which they are involved. The imidazole is, as expected, close to planar, but the imidazoline displays an almost undistorted envelope conformation. In all cases, the azoles are twisted with respect to the phenyl rings, as illustrated in Figure 2b. In compound **10**, where both types of rings are present in the molecular structure, the acidic N–H of the imidazole ring acts as a hydrogen-bond donor to the basic imidazoline N atom in the intramolecular interaction (Fig. 2a) with the shortest N···N distance.

3. Conclusions

The preparation of 2-imidazolines and imidazoles has been performed using green synthetic procedures, i.e., microwave irradiation, solvent-free conditions, and an environmentally friendly oxidant. Microwave irradiation under solvent-free conditions allows the preparation of 2-imidazolines in high yield in a short reaction time. Aromatization of the imidazoles was carried out in solution in order to moderate the absorption of microwave energy by Magtrieve™. Comparison with MnO_2 shows that this oxidant gives similar results under similar conditions but in an environmentally friendly procedure.

The solid-state structures of 2-imidazolines and imidazoles show the formation of one-dimensional chains in compounds with one imidazoline ring (**3d** and **3e**) through intermolecular N–H···N interactions. In compounds with two imidazole or imidazoline rings, a combination of intra- and intermolecular N–H···N interactions leads to the formation of helical chains.

4. Experimental

4.1. General

Melting points were determined using a Gallenkamp melting point apparatus and are uncorrected. NMR spectra were recorded on Varian Unity 300 and 500 spectrometers with TMS as the internal standard. The IR spectra were obtained with a Nicolet-550 FTIR spectrophotometer. The mass spectra were recorded on a VG AutoSpec apparatus using electron impact at 70 eV and Atmospheric pressure Chemical Ionization (ApCI). Flash column chromatography was performed on silica gel 60 (Merck, 230–400 mesh). All compounds gave satisfactory elemental analysis (±0.3%).

Reactions under microwave irradiation were performed in a modified PROLABO MAXIDIGEST MX350. Reactions were performed at the power indicated in Tables 1, 2, and 4. The temperature was measured with an IR pyrometer and controlled using a computer with PACAM MPX-2 software. When the temperature exceeded the programed value, the power was reduced to 10 W.

4.2. General procedure for the synthesis of 4,5-dihydroimidazolylpyrazoles 3 and 7 and bis-4,5-dihydroimidazolylbenzene (5)

A mixture of sulfur (1.95 mmol, 0.062 g), the appropriate nitrile (3.9 mmol), and ethylenediamine (75 mmol, 4.5 g, 5 mL) was introduced into a Pyrex flask and irradiated as described in Table 1. The cold crude mixture was suspended in water and filtered. The solid was washed with water (2×5 mL) to afford the pure imidazoline.

4.2.1. 3-(4,5-Dihydro-1*H*-imidazol-2-yl)-1-phenylpyrazole (3a). From 3-cyano-1-phenylpyrazole **1a** (3.99 mmol, 0.66 g). The mixture was irradiated for 15 min at 30 W. The ethylenediamine was removed in vacuo and the crude mixture was suspended in water and filtered. The solid was washed with water (2×5 mL) to yield 0.67 g (74%). Mp 128–129 °C. IR (KBr) 3450, 3220, 1600, 1521 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.50 (br s, 2H), 4.00 (br s, 2H), 5.47 (br s, 1H), 6.98 (d, *J* 2.7, 1H), 7.32 (t, *J* 7.6, 1H), 7.47 (dd, *J* 7.8, 7.6, 2H), 7.70 (d, *J* 7.8, 2H), 7.92 (d, *J* 2.7, 1H); ^{13}C NMR ($CDCl_3$) δ 107.53, 119.35, 127.02, 128.23,

129.50, 139.76, 145.01, 159.65; MS (ApCI/MeOH) 213.1 (M+H).

4.2.2. 4-(4,5-Dihydro-1*H*-imidazol-2-yl)-1-phenylpyrazole (3b). From 4-cyano-1-phenylpyrazole **1b** (3.99 mmol, 0.66 g). The mixture was irradiated for 30 min at 30 W. Yield 0.814 g (98%). Mp 187–188 °C. IR (KBr) 3444 (ν N–H), 3155, 1630, 1560 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.76 (br s, 4H), 7.33 (t, *J* 7.3, 1H), 7.47 (dd, *J* 7.7, 7.3, 2H), 7.69 (dd, *J* 7.7, 2H), 7.98 (s, 1H), 8.36 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 115.52, 119.28, 126.59, 127.18, 129.57, 139.54, 139.66, 158.52; MS (ApCI/MeOH) 213.1 (M+H).

4.2.3. 1-[2-(4,5-Dihydro-1*H*-imidazol-2-yl)phenyl]pyrazole (3c). From 2-(pyrazol-1-yl)benzonitrile **1c** (3.9 mmol, 0.66 g). The mixture was irradiated for 30 min at 30 W. After cooling, the crude mixture was suspended in water and extracted with CH_2Cl_2 (3×10 mL). The organic solution was dried over anhydrous magnesium sulfate, filtered and the solvent removed in vacuo to give the pure imidazoline. Yield 0.811 g (98%). Mp 102–104 °C. IR (KBr) 3100 (ν N–H), 1590, 1510 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.59 (s, 4H), 4.5 (br s, 1H), 6.44 (dd, *J* 2.4, 1.6, 1H), 7.41–7.43 (m, 2H), 7.51 (td, *J* 8.5, 2.0, 1H), 7.69 (d, *J* 2.4, 1H), 7.71 (d, *J* 1.6, 1H), 7.83 (dd, *J* 9.3, 2.0, 1H); ^{13}C NMR ($CDCl_3$) δ 50.21, 107.05, 126.23, 127.44, 128.45, 130.54, 130.65, 131.44, 138.46, 140.93, 163.51; MS (ApCI/MeOH) 213.1 (M+H).

4.2.4. 1-[3-(4,5-Dihydro-1*H*-imidazol-2-yl)phenyl]pyrazole (3d). From 3-(pyrazol-1-yl)benzonitrile **1d** (3.9 mmol, 0.66 g). The mixture was irradiated for 30 min at 30 W. Yield 0.67 g (82%). Mp 127–128 °C. IR (KBr) 3440 (ν N–H), 1580, 1520 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.5 (br s, 2H), 4.01 (br s, 2H), 4.89 (br s, 1H), 6.48 (dd, *J* 2.4, 1.5, 1H), 7.49 (t, *J* 7.8, 1H), 7.98 (d, *J* 7.8, 1H), 7.73 (d, *J* 1.5), 7.84 (dt, *J* 7.9, 1H), 8.00 (d, *J* 2.4, 1H), 8.10 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 42.0, 56.0, 107.92, 117.38, 121.24, 124.76, 126.85, 129.66, 131.88, 140.31, 141.31, 163.98; MS (ApCI/MeOH) 213.1 (M+H).

4.2.5. 1-[4-(4,5-Dihydro-1*H*-imidazol-2-yl)phenyl]pyrazole (3e). From 4-(pyrazol-1-yl)benzonitrile **1e** (3.9 mmol, 0.66 g). The mixture was irradiated during 15 min at 30 W. Yield 0.765 g (91%). Mp 230–231 °C. IR (KBr) 3140 (ν N–H), 1620, 1530 cm^{-1}; ^1H NMR (DMSO) δ 3.61 (br s, 4H), 6.57 (t, *J* 2.19, 1H), 6.92 (br s, 1H), 7.78 (d, *J* 1.95, 1H), 7.93 and 7.90 (AA′XX′, *J* 8.3, 4H), 8.57 (d, *J* 2.44, 1H); ^{13}C NMR (DMSO) δ 108.19, 117.68, 127.86, 128.25, 128.33, 140.73, 141.35, 162.80; MS (ApCI/MeOH) 213.1 (M+H).

4.2.6. 1,2-Bis-(4,5-dihydro-1*H*-imidazol-2-yl)benzene (5). From phthalodinitrile **4** (3.9 mmol, 0.511 g). The mixture was irradiated for 5 min at 30 W. Yield 0.362 g (42%). Mp 171–172 °C. IR (KBr) 3090 (ν N–H), 1580, 1490 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.72 (s, 8H), 6.05 (br s, 2H), 7.42 (m, 2H), 7.67 (m, 2H); ^{13}C NMR ($CDCl_3$) δ 51.70, 129.41, 129.72, 130.47, 166.01; EM (ApCI/MeOH) 215.1 (M+H).

4.2.7. 4,5-Bis-(4,5-dihydro-1*H*-imidazol-2-yl)imidazole (7). From 4,5-dicyanoimidazole **6** (3.9 mmol, 0.471 g). The mixture was irradiated for 25 min at 30 W. The crude mixture was suspended in water and filtered. The solid was washed with ethanol (2×5 mL) and diethyl ether (2×5 mL). Yield 0.832 g (96%). Mp >260 °C. IR (KBr) 3120 cm^{-1} (ν N–H); ^1H NMR (D_2O+HCl) δ 3.92 (s, 8H), 7.99 (s, 1H); ^{13}C NMR (D_2O+HCl) δ 123.36, 142.37, 158.07; MS (ESI/MeOH+0.1% TFA) 206.1 (M+H) and 205.1 (M).

4.3. General procedure for the synthesis of imidazolylpyrazoles 8 and bisimidazolylbenzene (9)

Method A. Aromatization under conventional heating

(A1) *Manganese(IV) oxide*. In a round-bottomed flask fitted with a reflux condenser, imidazoline **3** (1.16 mmol), active manganese(IV) oxide (0.976 g, 0.011 mmol), and chloroform (5 g, 6 mL) were introduced and the mixture was heated under reflux for 24 h (Table 3). The solution was filtered through a Whatman paper and the solvent evaporated in vacuo. The product was purified by column chromatography on silica gel using ethanol as the eluent.

(A2) *Magtrieve*™. In a round-bottomed flask fitted with a reflux condenser, imidazoline **3** or **5** (0.707 mmol), Magtrieve™ (0.750 g, 8.9 mmol), and toluene (6 mL) were introduced and the mixture was heated under reflux for 24 h (Table 4). The work-up was performed as for method A1.

Method B. Aromatization under microwave irradiation

(B1) *Manganese(IV) oxide*. A mixture of imidazoline **3b** (0.707 mmol), active manganese(IV) oxide (0.75 g, 8.6 mmol), and toluene (6 mL) was introduced into a Pyrex flask fitted with a reflux condenser and irradiated under the conditions indicated in Table 2. The work-up was performed as for method A1.

(B2) *Barium manganate*. A mixture of imidazoline **3b** (0.707 mmol), barium manganate (0.75 g, 2.9 mmol), and toluene (6 mL) was introduced into a Pyrex flask fitted with a reflux condenser and irradiated under the conditions indicated in Table 2. The work-up was performed as for method A1.

(B3) *Oxidation with Magtrieve*™. A mixture of imidazoline **3** or **5** (0.707 mmol), Magtrieve™ (0.75 g, 8.9 mmol), and toluene (6 mL) was introduced into a Pyrex flask fitted with a reflux condenser and irradiated under the conditions indicated in Tables 2 and 4. The work-up was performed as for method A1.

4.3.1. 3-(1*H*-Imidazol-2-yl)-1-phenylpyrazole (8a). *Method B3*. From **3a** (0.150 g, 0.7 mmol). The mixture was irradiated for 105 min at 90 W and the temperature reached 100 °C. The product was purified by column chromatography using hexane/ethyl acetate 1:1, gradient ethyl acetate, as the eluent. Yield 0.082 g (57%). Mp 160–161 °C. IR (KBr) 3060 (ν N–H), 1600, 1520 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.02 (d, *J* 2.4, 1H), 7.11 (s, 2H), 7.22 (t, *J* 7.3, 1H), 7.36 (dd, *J* 8.3, 7.3, 2H), 7.61 (d, *J* 8.3, 2H), 7.84 (d, *J* 2.44, 1H); ^{13}C NMR ($CDCl_3$) δ 105.99, 118.99, 122.73, 126.54, 128.21, 129.31, 139.62, 141.49, 145.25; MS (ApCI/MeOH) 211.1 (M+H).

4.3.2. 4-(1*H*-Imidazol-2-yl)-1-phenylpyrazole (8b). *Method B3*. From **3b** (0.150 g, 0.7 mmol). The mixture

was irradiated for 105 min at 120 W and the temperature reached 105 °C. The product was purified by column chromatography using ethyl acetate as the eluent. Yield 0.107 g (64%). Mp 209–211 °C. IR (KBr) 3100 (ν N–H), 1600, 1500 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.12 (s, 2H), 7.28 (t, *J* 7.8, 1H), 7.41 (dd, *J* 7.8, 7.3, 2H), 7.61 (d, *J* 7.3, 2H), 8.03 (s, 1H), 8.37 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 115.49, 119.06, 122.04, 124.68, 126.96, 129.52, 138.23, 139.52, 140.49; MS (ApCI/MeOH) 211.1 (M+H).

4.3.3. 1-[2-(1*H*-Imidazol-2-yl)phenyl]pyrazole (8c). *Method B3*. From **3c** (0.150 g, 0.7 mmol). The mixture was irradiated for 75 min at 270 W and the temperature reached 95 °C. The product was purified by column chromatography using hexane/ethyl acetate 1:1, gradient ethyl acetate, as the eluent. Yield 0.128 g (88%). Mp 139.4–140.1 °C. IR (KBr) 3400 (ν N–H), 1390, 1100 cm^{-1}; ^1H NMR ($CDCl_3$) δ 6.48 (dd, *J* 2.6, 1.8, 1H), 7.04 (s, 2H), 7.31 (dd, *J* 7.7, 1.5, 1H), 7.43 (td, *J* 7.7, 1.5, 1H), 7.55 (td, *J* 7.7, 1.3, 1H), 7.58 (d, *J* 2.6, 1H); 7.85 (d, *J* 1.8, 1H); 8.27 (dd, *J* 7.7, 1.3, 1H); ^{13}C NMR ($CDCl_3$) δ 107.50, 127.55, 127.74, 128.93, 129.54, 130.56, 132.97, 136.75, 141.33, 143.62; MS (ApCI/MeOH) 212.1 (M+H).

4.3.4. 1-[3-(1*H*-Imidazol-2-yl)phenyl]pyrazole (8d). *Method B3*. From **3d** (0.150 g, 0.7 mmol). The mixture was irradiated for 75 min at 270 W and the temperature reached 95 °C. The product was purified by column chromatography using hexane/ethyl acetate 1:1, gradient ethyl acetate, as the eluent. Yield 0.104 g (70%). Mp 154–155 °C. IR (KBr) ν_{max} 3400 (ν N–H), 1590, 1525 cm^{-1}; ^1H NMR ($CDCl_3$) δ 6.42 (dd, *J* 2.4, 1.9, 1H), 7.17 (s, 2H), 7.40 (t, *J* 7.8, 1H), 7.64 (dd, *J* 7.8, 1.9, 1H), 7.70 (d, *J* 1.9, 1H), 7.76 (d, *J* 7.8, 1H), 7.83 (d, *J* 2.4, 1H), 8.14 (t, *J* 1.9, 1H), 11.30 (br s, 1H); ^{13}C NMR ($CDCl_3$) δ 107.83, 115.78, 119.07, 123.22, 126.2, 130.05, 131.56, 140.52, 141.19, 146.05; MS (ApCI/MeOH) 211.2 (M+H).

4.3.5. 1-[4-(1*H*-Imidazol-2-yl)phenyl]pyrazole (8e). *Method B3*. From **3e** (0.150 g, 0.7 mmol). The mixture was irradiated for 105 min at 270 W and the temperature reached 100 °C. The product was purified by column chromatography using ethyl acetate as the eluent. Yield 0.115 g (77%). Mp 260 °C (decomp.). IR (KBr) 3400 (ν N–H), 1620, 1525 cm^{-1}; ^1H NMR (DMSO) δ 6.56 (dd, *J* 2.4, 1.5, 1H), 7.04 and 7.26 (br s, 2H), 7.77 (d, *J* 1.5, 1H), 7.92 (d, *J* 8.8, 2H), 8.04 (d, *J* 8.8, 2H), 8.54 (d, *J* 2.4, 1H), 12.56 (s, 1H); ^{13}C NMR (DMSO) δ 107.97, 117.78, 118.47, 125.79, 127.66, 128.65, 129.06, 139.02, 141.07, 144.88; MS (ApCI/MeOH) 211.1 (M+H).

4.3.6. 1,2-Bis-(1*H*-imidazol-2-yl)benzene (9) and 1-(1*H*-imidazol-2-yl)-2-(4,5-dihydro-1*H*-imidazol-2-yl)-benzene (10). *Method B3*. From **5** (0.150 g, 0.7 mmol), Magtrieve™ (0.75 g, 0.0089 mol), and toluene (6 mL). The mixture was irradiated for 105 min at 120 W. Product **9** was purified by column chromatography using ethyl acetate with 1% diethylamine as the eluent. Yield 0.029 g (20%). Mp 230 °C. IR (KBr) 3050 (ν N–H), 2600 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.01 (AA′XX′, J_{AX} 7.9, $J_{AA'}$ 7.3, $J_{AX'}$ 1.4, 2H), 7.17 (s, 4H), 7.57 (AA′XX′, J_{AX} 7.9, $J_{AA'}$ 7.3, $J_{AX'}$ 1.4, 2H); ^{13}C NMR ($CDCl_3$) δ 122.45, 126.84, 127.73, 130.15, 146.62; EIMS 210 (M), 156.

The same eluent gave traces of product **10**. Mp 189–190 °C. IR (KBr) ν_{max} 3105 (ν N–H), 2865, 1585 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.86 (s, 4H), 7.15 (s, 2H), 7.32 (ddd, *J* 7.8, 7.3, 1.5, 1H), 7.50 (ddd, *J* 8.0, 7.3, 1.5, 1H), 7.61 (dd, *J* 7.8, 1.5, 1H), 8.4 (dd, *J* 8.0, 1.5, 1H); ^{13}C NMR ($CDCl_3$) δ 49.95, 122.95, 126.95, 127.56, 129.08, 129.82, 130.55, 130.61, 146.62, 166.83; EIMS 212 (M), 211, 182, 156.

4.4. X-ray analysis

Crystals of **3d**, **5**, **9**, and **10** were obtained by crystallization from solutions in ethyl acetate and those of **3e** were obtained from a solution in methanol. The intensity data for all compounds were recorded at room temperature on a Nonius Kappa CCD diffractometer [λ(Mo Kα)=0.7107 Å] driven by DENZO[27] and COLLECT[28] software. Crystals of **5**, **9**, and **10** are isomorphous. All structures were solved by direct methods[29] and refined based on F^2 using SHELXL97,[30] both programs operating under the WinGx program package.[31] All hydrogen atoms were located on difference Fourier maps and were allowed to ride on the respective bonded atoms. Structural illustrations have been drawn with PLATON[32] under WinGx.

3d: $C_{12}H_{12}N_4$, *M*=212.26, monoclinic, space group *P*2/*c*, *a*=20.4378(63), *b*=5.5678(7), *c*=9.6300(13) Å, β=103.320(6)°, *Z*=4, D_c=1.322 g cm^{-3}, final *R*=0.053 and R_w=0.118 for 1693 observed reflections ($I>2\sigma(I)$).

3e: $C_{12}H_{12}N_4$, *M*=212.26, orthorhombic, space group *Pcam*, *a*=15.781(6), *b*=6.372(8), *c*=10.309(9) Å, *Z*=4, D_c=1.360 g cm^{-3}, final *R*=0.080 and R_w=0.223 for 824 observed reflections ($I>2\sigma(I)$). The systematic absences permitted $Pca2_1$ and *Pcam* as possible space groups. The solution of the structure and the refinement in $Pca2_1$ gave similar results as in *Pcam* with missing symmetry strongly indicated.[32]

The molecule almost exhibits C_s symmetry and, in *Pcam*, lies on a crystallographic mirror plane perpendicular to the phenyl ring. Therefore, and due to the lack of symmetry of the azoles, the molecule is disordered over two positions with distinct sites for the –N= atoms and the associated H atoms.

5: $C_{12}H_{14}N_4$, *M*=214.27, monoclinic, space group $P2_1/n$, *a*=9.0190(7), *b*=9.2100(5), *c*=13.1630(16) Å, β=93.575(5)°, *Z*=4, D_c=1.304 g cm^{-3}, final *R*=0.060 and R_w=0.155 for 2155 observed reflections ($I>2\sigma(I)$).

9: $C_{12}H_{10}N_4$, *M*=210.24, monoclinic, space group $P2_1/n$, *a*=8.7990(5), *b*=9.0830(10), *c*=12.9030(10) Å, β=92.762(6)°, *Z*=4, D_c=1.356 g cm^{-3}, final *R*=0.051 and R_w=0.145 for 1868 observed reflections ($I>2\sigma(I)$).

10: $C_{12}H_{12}N_4$, *M*=212.26, monoclinic, space group $P2_1/n$, *a*=8.8890(7), *b*=9.1110(7), *c*=13.0610(7) Å, β=93.558(4)°, *Z*=4, D_c=1.335 g cm^{-3}, final *R*=0.058 and R_w=0.160 for 2063 observed reflections ($I>2\sigma(I)$).

CCDC reference numbers 296364–296368 for compounds **10**, **3d**, **3e**, **5**, and **9**, respectively.

See http://www.rsc.org/suppdata/ … for crystallographic files in .cif format.

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