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Design, Synthesis, and Evaluation of Unsymmetrical Difluoro-Boron Complexes with Imidazoline as Potential Fungicides

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ABSTRACT: *A series of unsymmetrical difluoroboron(BF_2) complexes with pyridine and imidazoline were synthesized by reaction of new chelating ligands (arylmethyl-imidazolidinylidene)-pyridin-2-ylamine with boron trifluoride diethyl etherate. All the ligands and BF_2 complexes were structurally characterized by IR, HRMS,^{1}H, ^{13}C,^{11}B, and ^{19}F NMR, indicating the bidentate complexation of imidazoline nitrogen and the pyridine nitrogen to the boron center. Evaluation of agricultural bioactivities showed that some of the BF_2 complexes exhibited moderate fungicidal activities, and most of the BF_2 complexes exhibited higher activities than the none-BF_2 complexed substrates.* © 2010 Wiley Periodicals, Inc. Heteroatom Chem 20:418–424, 2009; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/hc.20567

INTRODUCTION

Imino-imidazoline, a unique class of chemicals containing an exocyclic C=N double bond, has drawn great attentions for many years in its biological activities [1–3]. The benzene-substituted derivatives 2-phenyl-imino-imidazolines **1** (Fig. 1) are effective pharmacophores in medicinal chemistry [4–6], and there are reports on **1** and its derivatives for their fungicidal activities [7]. Based on the principles of bioisoteric concept, the replacement of benzene by pyridine in some cases exhibited higher activity and lower toxicity [8–10]. Therefore, bioisosterism pyridyl-imino-imidazoline **2** (Fig. 1) was expected to have higher fungicidal activities than that of **1**. Arylmethyl-pyridyl-imino-imidazoline **3** (Fig. 1) can be easily prepared by introduction of the arylmethyl group into **2**. The introduction of the arylmethyl group could influence the biological activities because of enhancing the flexibility of the molecule [7].

Organoboron complexes have also attracted significant attention for their potential medicinal, biochemical, and agrochemical applications [11–15]. Trivalent boron compounds are well known to be electron deficient and behave as Lewis acid [16]. The intramolecular pyridine nitrogen could serve as electron donor and form stable complex as indicated in structure **4** (Fig. 1), similar complexes were reported before [17]. Recently, more and more difluoro-boron (BF_2) complexes have been synthesized as fluorophores for their excellent fluorescent characteristics [18, 19]. Singh et al reported that the thiosemicarbazone BF_2 complexes exhibited higher antifungal activity than the parent thiosemicarbazone itself [20]. That prompted us to investigate the antifungal activity of BF_2 complex **4**.

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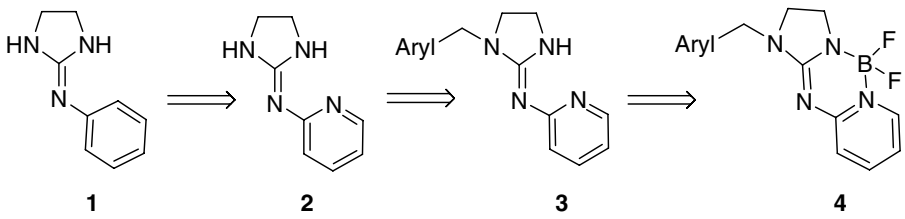


FIGURE 1 Design of the object compound.

RESULTS AND DISCUSSION

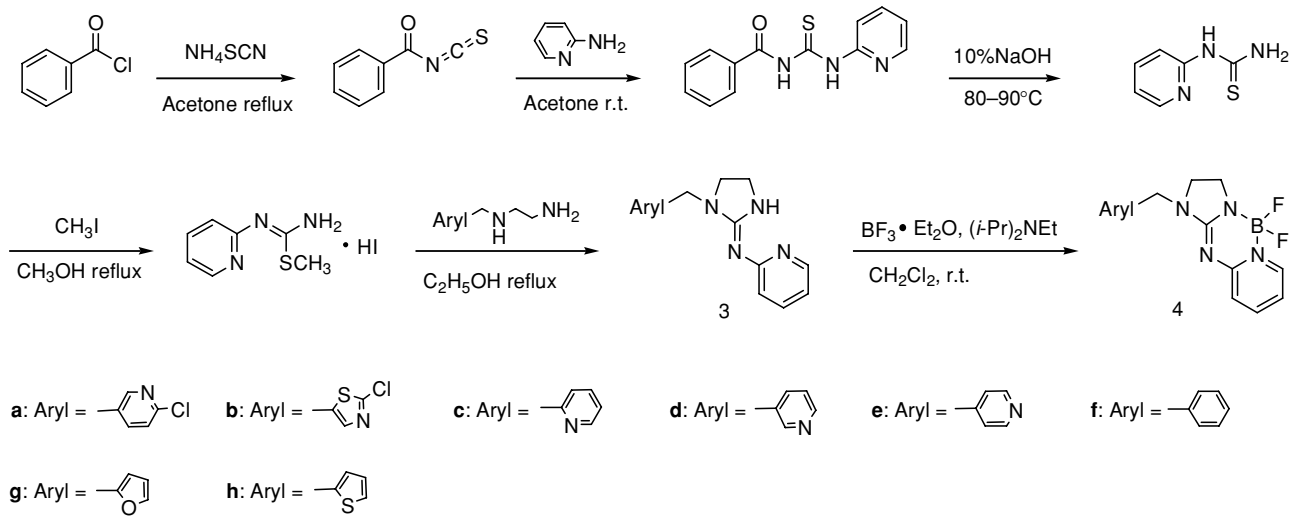
Synthesis of Arylmethyl-pyridyl-imino-imidazolines **3** *and* **4**

Following the literature procedure [21,22], compounds **3** were synthesized in five steps (Scheme 1). A reaction of benzoyl chloride with ammonium thiocyanate gave benzoyl isothiocyanate, which was used without purification to react with 2-aminopyridine, and aqueous-alkaline cleavage of the resultant *N*-pyridyl-*N*′-benzoylthiourea gave pyridylthiourea in 90% yield that was used to prepare 2-methyl-1-pyridin-2-yl-isothiourea hydroiodide in 95% yield. Compounds **3** were obtained in 60%–65% yields by reaction of *N*-(arylmethyl)-ethylenediamine with 2-methyl-1-pyridin-2-yl-isothiourea hydroiodide. The BF_2 complexes **4** were synthesized in 30%–35% yields by reaction of **3** with boron trifluoride diethyl etherate and *N*, *N*-diisopropylethylamine in dichloromethane at room temperature.

DISCUSSION

In the famous **BODIPY** (Fig. 2) [23], because of the steric proximity of the two pyrroles, the BF_2 can form a stable six-membered ring with the two nitrogen atoms in pyrroles. The **PDT** is synthesized similarly [24]. In the **(PNI)BF$_2$** case [17], BF_2 forms a stable pentacyclic ring with the two nitrogen atoms in imidazole and pyridine.

As in **PDT** agent and **(PNI)BF$_2$**, we predict **3** should form stable complex with BF_2. Indeed the formation of **4** by the complexation of BF_2 with **3** was achieved and characterized by IR, ^{1}H, ^{11}B, ^{19}F NMR, and HRMS. In the ^{1}H NMR spectra, the disappearance of the NH resonance signals of compound **3** in the case of BF_2 complexes **4** clearly indicates the deprotonation of the NH group in the imidazoline after the reaction. The structure of **4** is further supported by the disappearance of the medium intensity bands in the BF_2 complexes at 3430–3450 cm^{-1} in the IR spectra, which are the NH stretching bands in the free ligands **3**. In addition,



SCHEME 1 Synthesis of the compounds **3** and the BF_2 complexes **4**.

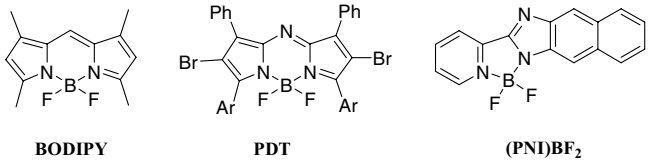


FIGURE 2 Structure of **BODIPY**,**PDT**, and **(PNI)BF_2**.

the formation of **4** is also supported by HRMS, ^{11}B, and ^{19}F NMR spectra, which clearly indicate the existence of one B atom and two Fatoms. In summary, we have sufficient evidence to prove the formation of **4**. We found **4** is stable at room temperature without nitrogen gas protection.

UV–Vis Absorption and Fluorescent Spectra Studies

BODIPY fluorophore, as a typical BF_2 complex, has excellent fluorescent characteristics, such as λ_{em} at about 550 nm, Stokes shifts at about 10 nm. Because the structure of BF_2 complexes **4** is similar to **BODIPY** fluorophore, optical characteristics of the complexes were also studied. The UV–vis absorption and fluorescent spectra of **4b, 4d, 4f**, and **4g** were measured, and the data were listed in Table 1. From Figs. 3 and 4, it is known that λ_{abs} is at about 330 nm, λ_{em} is at about 375 nm. The ε values are moderate because of its small conjugate system and imparity in the electron donor group. Therefore, modification of BF_2 complexes **4** by extending the conjugate system and introducing the suitable electron donor group should obtain excellent fluorophores.

Biological Activity

The fungicidal activities of the ligands **3** and the corresponding BF_2 complexes **4** against *Sphaerotheca fuliginea* were tested (Table 2). Results from our study shows that some ligands have moderate fungicidal activities, and most of the BF_2 complexes are more effective than their parent ligands under identical experiment conditions. Ligand **3f** has no activities, and **3h** has weak activities. After complexing with BF_2, the fungicidal activities of **4f** and **4h** increase significantly with the rate of inhibitory from 0% to 52.7% and 15.5% to 49.6%, respectively. However for ligands **3e** and **3d** with relatively high activity, after complexing with BF_2, the fungicidal activities of **4e** and **4d** increase only slightly or even decrease with the rate of inhibitory from 34.1% to 39.9% and 48.1% to 32.6%, respectively. The use of BF_2 complexes described herein belongs to a new class; the mechanism of antibacterial action is at present unknown to us. With comparison to

TABLE 1 Spectroscopic Properties of the BF_2 complexes **4b, 4d, 4f**, and **4g**

Complexes	λ_{abs}[a] *(nm)*	λ_{em}[b] *(nm)*	*log* ε	Φ_f[c]
4b	329	373	4.25	0.41
4d	332	376	4.21	0.27
4f	332	379	4.16	0.24
4g	330	376	4.11	0.37

[a]Absorption was measured in dichloromethane.
[b]Emission was measured in dichloromethane and excited at 330 nm.
[c]Quantum yield was measured quinine sulfate as quantum yield standard ($\Phi_f = 0.55$).

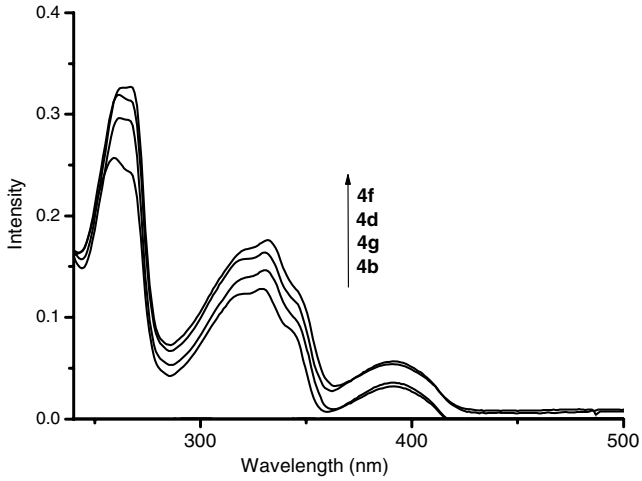


FIGURE 3 UV–vis spectra of the BF_2 complexes **4** in dichloromethane (1.0×10^{-5} M).

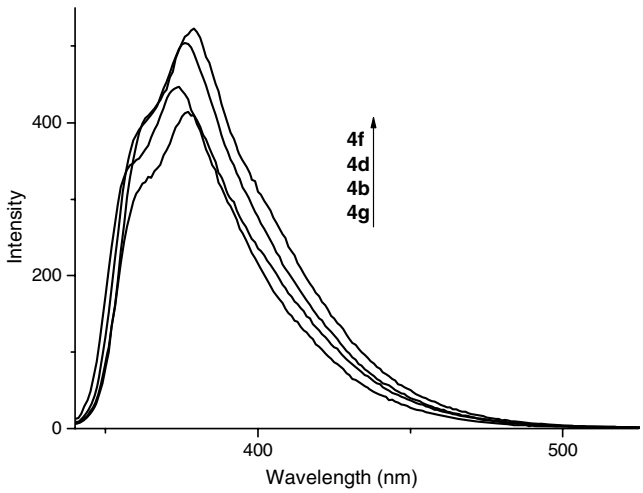


FIGURE 4 Fluorescent spectra of the BF_2 complexes **4** in dichloromethane (1.0×10^{-5} M).

TABLE 2 Fungicidal Activities of **3** and **4** against *Sphaerotheca fuliginea* at 500 mg/L[a]

Ligands	*Average Rate of Inhibitory (%)*	*BF_2 Complexes*	*Average Rate of Inhibitory (%)*
3a	–[b]	**4a**	42.6
3b	–	**4b**	33.3
3c	–	**4c**	28.7
3d	48.1	**4d**	32.6
3e	34.1	**4e**	39.9
3f	–	**4f**	52.7
3g	14	**4g**	42.6
3h	15.5	**4h**	49.6

[a]Only the results of effective compounds are listed.
[b]Represents no activity.

their parent ligands, the BF_2 complexes have better lipophilicity. One possible explanation could come from their better diffusion through the spore membrane to the site of action and ultimately kill the fungi [20]. Meanwhile, the introduction of BF_2 complexes with the pyridine in the ligands and forms a planar structure. We feel the more rigid structure in compound **4** could also be associated with the increased inhibitory activity.

CONCLUSION

A series of new ligands 1-arylmethyl-2-pyridylimino-imidazoline and their corresponding BF_2 complexes were designed and synthesized. The biological testing results show that most of the BF_2 complexes exhibit higher fungicidal activities than their parent ligands. To the best of our knowledge, this is the second case of BF_2 complexes as fungicides. Further work is in progress to fully understand the structure–activity relationships to design more active antifungal agents and excellent fluorophores.

EXPERIMENTAL

General

Melting points are obtained with an X-6 micro-melting point apparatus and are uncorrected. The infrared (IR) spectra are recorded on a Nicolet 20DXB FR-IR spectrometer using potassium bromide pellets or films. The ^{1}H NMR spectra are obtained on a Varian INOVA 400 MHz NMR spectrometer with DMSO-d_6 as the solvent and TMS as the internal standard. High-resolution mass spectra (HRMS) are obtained on HPLC-Q-Tof MS (Micro) spectrometer. Flash chromatography is performed on silica gel. All the solvents are analytic grade. All chemicals or reagents are purchased from commercial suppliers.

General Synthetic Procedure for **3** (**3a** and **3e** as Examples)

Synthesis of **3a**. 2-Chloro-5-(chloromethyl)-pyridine (1.62 g, 10 mmol) in acetonitrile (30 mL) was added dropwise to ethylenediamine (2.40 g, 40 mmol) in acetonitrile (20 mL) while stirring in an ice bath. After removing from the ice bath, the mixture was stirred overnight at room temperature. The solvent was evaporated, and aqueous sodium hydroxide (1.0 M, 50 mL) was added to the residue and then extracted with dichloromethane. The organic layer was dried over anhydrous magnesium sulfate and evaporated to afford *N*-(2-chloro-pyridinylmethyl)-ethylenediamine (1.39 g, 75% yield). 2-Methyl-1-pyridin-2-yl-isothiourea hydroiodide was prepared from benzoyl chloride, ammonium thiocyanate, and 2-aminopyridine according to C. R. Rasmussen's methods [21]. *N*-(2-chloro-pyridinylmethyl)-ethylenediamine (0.93 g, 5 mmol) in ethanol (20 mL) was added dropwise to 2-methyl-1-pyridin-2-yl-isothiourea hydroiodide (1.63 g, 5.5 mmol) in ethanol (30 mL) at room temperature, and the mixture was refluxed for 4 h. After evaporating the solvent, affording the crude **3a** (0.93 g, 65% yield) was purified by silica gel chromatography (CH_2Cl_2/CH_3OH = 30:1, v/v). The ligands **3b–d** were similarly prepared.

Synthesis of **3e**. 4-Pyridylaldehyde (0.96 g, 10 mmol) was added dropwise to a solution of ethylenediamine (2.4 g, 40 mmol) in methanol (20 mL) and stirred at 0°C for 30 min. Then $NaBH_4$(0.57 g, 15 mmol) was added cautiously in small portions to the mixture at 0°C, and the mixture was allowed to warm to ambient temperature and stirred for 2 h. The resulting cloudy mixture was filtered, the filtrate was concentrated, and the residual oil was partitioned between dichloromethane and H_2O. The dichloromethane layer was dried over magnesium sulfate and evaporated to afford *N*-(4-pyridylmethyl)-ethylenediamine (1.02 g, 70% yield), and then which was reacted with the 2-methyl-1-pyridin-2-yl-isothiourea hydroiodide to afford **3e** in 62% yield by the similar method of **3a**. The ligands**3f–h** were similarly prepared.

General Synthetic Procedure for **4** (**4a** as an Example)

Boron trifluoride diethyl etherate ($BF_3{\cdot}Et_2O$) (1.42 g, 10 mmol) was added to a solution of **3a** (0.58 g, 2 mmol) and *N*,*N*-diisopropylethylamine (0.645 g, 5 mmol) in dichloromethane (20 mL) and stirred for 30 min at room temperature. The

resulting gelatinous emulsion was filtered, and the filtrate was concentrated, affording crude **4a** (0.14 g, 30% yield) was purified by silica gel chromatography (CH_2Cl_2/CH_3OH = 50:1, v/v).

*[1-(6-Chloro-pyridin-3-yl-methyl)-imidazolidinylidene]-pyridin-2-yl-amine (***3a***).* Yield, 65%; White powders; mp: 196.1–197.8°C; IR (KBr, cm^{-1}): 3435, 1613; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 9.58 (s, 1H), 8.48 (d, 1H, J = 2.0 Hz), 8.30 (d, 2H, J = 4.4 Hz), 7.91 (dd, 1H, J = 8.0 Hz, J = 2.0 Hz), 7.82 (t, 1H, J = 8.4 Hz), 7.57 (d, 1H, J = 8.0 Hz), 7.16 (d, 1H, J = 8.0 Hz), 7.11 (t, 1H, J = 6.0 Hz), 4.76 (s, 2H), 3.72 (t, 2H, J = 8.4 Hz), 3.33 (t, 2H, J = 8.4 Hz);^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 156.6, 150.2, 149.8, 144.2, 140.0, 139.8, 138.5, 131.6, 124.9, 119.1, 118.2, 46.7, 45.1, 42.0; HRMS (ESI) calculated for $C_{14}H_{15}N_5Cl$ [M + H^+] 288.1016, found 288.1009.

*[1-(2-Chloro-thiazol-5-yl-methyl)-imidazolidinylidene]-pyridin-2-yl-amine (***3b***).* Yield, 62%; light yellow powders; mp: 134.6–135.9°C; IR (KBr, cm^{-1}): 3433, 1623; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 9.99 (br, 1H), 8.36 (d, 1H, J = 2.4 Hz), 7.98 (t, 1H, J = 8.4 Hz) 7.82 (s, 1H), 7.34 (d, 1H, J = 8.0 Hz), 7.27 (t, 1H, J = 6.0 Hz), 4.99 (s, 2H), 3.75 (t, 2H, J = 8.4 Hz) 3.66 (t, 2H, J = 8.4 Hz); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 161.3, 158.5, 151.1, 146.6, 140.9, 137.4, 135.7, 118.9, 115.8, 46.3, 45.7, 41.0; HRMS (ESI) calculated for $C_{12}H_{13}N_5SCl$ [M + H^+] 294.0580, found 294.0566.

*[1-Pyridin-2-yl-methyl-imidazolidinylidene]-pyridin-2-yl-amine (***3c***).* Yield, 60%; white powders; mp: 149.3–151.1°C; IR (KBr, cm^{-1}): 3428, 1596; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 9.94 (s, 1H), 8.59 (d, 1H, J = 4.4 Hz), 8.37 (dd, 1H, J = 0.8 Hz, J = 4.0 Hz), 7.93–7.86 (m, 2H), 7.49 (d, 1H, J = 7.6 Hz), 7.37 (t, 1H, J = 7.6 Hz), 7.27–7.22 (m, 2H), 4.94 (s, 2H), 3.83 (t, 2H, J = 8.4 Hz), 3.67 (t, 2H, J = 8.4 Hz); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 155.5, 154.3, 153.4, 146.8, 139.6, 138.0, 137.3, 123.0, 122.2, 116.8, 112.8, 49.0, 46.9, 42.0; HRMS (ESI) calculated for $C_{14}H_{16}N_5$ [M + H^+] 254.1406, found 254.1398.

*[1-Pyridin-3-yl-methyl-imidazolidinylidene]-pyridin-2-yl-amine (***3d***).* Yield, 58%; White powders; mp: 149.3–151.1°C; IR (KBr, cm^{-1}): 3436, 1595; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 9.65 (br, 1H), 8.63 (s, 1H), 8.56 (d, 1H, J = 3.6 Hz), 8.31 (d, 1H, J = 4.0 Hz), 7.86–7.81 (m, 2H), 7.44 (dd, 1H, J = 4.8 Hz, J = 2.8 Hz), 7.20 (d, 1H, J = 8.4 Hz), 7.13 (t, 1H, J = 5.6 Hz) 4.78 (s, 2H), 3.73 (t, 2H, J = 8.4 Hz), 3.52 (t, 2H, J = 8.4 Hz); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 155.2, 149.1, 148.9, 146.4, 139.5, 135.5, 130.9, 128.5, 123.8, 119.3, 114.4, 46.1, 45.8, 41.7; HRMS (ESI) calculated for $C_{14}H_{16}N_5$ [M + H^+] 254.1406, found 254.1402.

*[1-Pyridin-4-yl-methyl-imidazolidinylidene]-pyridin-2-yl-amine (***3e***)..* Yield, 62%; White powders; mp: 191.8–193.6°C; IR (KBr, cm^{-1}): 3428, 1605; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 9.76 (br, 1H), 8.60 (d, 1H, J = 3.6 Hz), 8.34 (s, 1H) 7.86 (t, 1H, J = 6.4 Hz), 7.40 (d, 2H, J = 3.2 Hz), 7.22–7.09 (m, 2H), 4.82 (s, 2H), 3.77 (t, 2H, J = 8.4 Hz), 3.59 (t, 2H, J = 8.4 Hz);^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 155.6, 149.9, 146.4, 144.7, 139.4, 127.7, 122.2, 119.1, 114.6, 47.2, 46.4, 41.7; HRMS (ESI) calculated for $C_{14}H_{16}N_5$ [M + H^+] 254.1406, found 254.1416.

*[1-Benzyl-imidazolidinylidene]-pyridin-2-yl-amine (***3f***).* Yield, 65%; light yellow powders; mp: 138.9–140.6°C; IR (KBr, cm^{-1}): 3434, 1613; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 9.89 (br, 1H), 8.36 (dd, 1H, J = 5.2 Hz, J = 1.2 Hz), 7.93 (t, 1H, J = 7.6 Hz), 7.46–7.32 (m, 6H), 7.24 (t, 1H, J = 5.2 Hz), 4.81 (s, 2H), 3.79 (t, 2H, J = 8.8 Hz), 3.56 (t, 2H, J = 8.8 Hz); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 155.4, 153.4, 146.6, 139.5, 138.0, 134.9, 128.8, 127.6, 119.5, 116.7, 114.1, 111.6; HRMS (ESI) calculated for $C_{15}H_{17}N_4$ [M + H^+] 253.1453, found 253.1448.

*[1-Furan-2-yl-methyl-imidazolidinylidene]-pyridin-2-yl-amine (***3g***).* Yield, 66%; light yellow powders; mp: 214.8–216.2°C; IR (KBr, cm^{-1}): 3428, 1615; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 10.37 (s, 1H), 8.47 (d, 1H, J = 8.0 Hz), 8.21 (d, 1H, J = 4.4 Hz), 7.77 (t, 1H, J = 8.0 Hz), 7.38 (s, 1H), 7.13 (t, 1H, J = 6.0 Hz), 6.81 (d, 1H, J = 3.2 Hz), 6.35 (s, 1H), 5.43 (s, 2H), 3.93 (t, 2H, J = 9.2 Hz), 3.82 (t, 2H, J = 9.2 Hz); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 155.3, 148.1, 146.8, 143.6, 139.7, 138.0, 119.9, 116.7, 113.9, 110.7, 46.3, 41.8, 40.0; HRMS (ESI) calculated for $C_{13}H_{15}N_4O$ [M+H^+] 243.1246, found 243.1242.

*[1-Thiophen-2-yl-methyl-imidazolidinylidene]-pyridin-2-yl-amine (***3h***).* Yield, 64%; white powders; mp: 210.8–212.4°C; IR (KBr, cm^{-1}): 3438, 1613; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 10.35 (br, 1H), 8.42 (d, 1H, J = 8.4 Hz), 8.22 (d, 1H, J = 3.2 Hz), 7.76 (t, 1H, J = 7.2 Hz), 7.34 (d, 1H, J = 3.2 Hz), 7.28 (d, 1H, J = 5.2 Hz), 7.12 (t, 1H, J = 7.2 Hz), 6.99 (t, 1H, J = 3.6 Hz), 5.60 (s, 2H), 3.91 (t, 2H, J = 5.6 Hz), 3.76 (t, 2H, J = 5.6 Hz); ^{13}C NMR

(100 MHz, DMSO-d_6) δ (ppm): 155.5, 154.7, 146.4, 140.0, 136.7, 127.8, 127.1, 126.7, 119.6, 114.2, 45.9, 43.0, 41.7; HRMS (ESI) calculated for $C_{13}H_{15}N_4S$ [M + H^+] 259.1017, found 259.1013.

*BF_2[1-(6-Chloro-pyridin-3-yl-methyl)-imidazolidinylidene]-pyridin-2-yl-amine (**4a**)*. Yield, 30%; white powders; mp: 150.4–151.8°C; IR (KBr, cm^{-1}): 1653, 1562, 1257; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 8.47 (d, 1H, $J = 2.4$ Hz), 8.28 (d, 1H, $J = 6.4$ Hz), 8.15 (t, 1H, $J = 8.0$ Hz), 7.90 (dd, 1H, $J = 8.4$ Hz, $J = 2.4$ Hz) 7.56 (d, 1H, $J = 8.0$ Hz), 7.34 (t, 2H, $J = 8.4$ Hz), 4.73 (s, 2H), 3.80 (t, 2H, $J = 9.6$ Hz), 3.63 (t, 2H, $J = 9.6$ Hz); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 156.5, 150.2, 149.9, 149.6, 144.2, 140.0, 139.8, 138.5, 131.6, 124.8, 119.1, 46.7, 45.1, 42.0; ^{11}B NMR (128.4 MHz, DMSO-d_6) δ (ppm): 1.07 (s); ^{19}F NMR (376.5 MHz, DMSO-d_6) δ (ppm): −140.57 (d, $J = 35.3$ Hz); HRMS (ESI) calculated for $C_{14}H_{14}BN_5F_2Cl$ [M + H^+] 336.0999, found 336.1009.

*BF_2[1-(2-Chloro-thiazol-5-yl-methyl)-imidazolidinylidene]-pyridin-2-yl-amine (**4b**)*. Yield, 32%; white powders; mp: 151.5–152.3°C; IR (KBr, cm^{-1}): 1646, 1566, 1243; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 8.03 (d, 1H, $J = 5.2$ Hz), 7.69 (t, 1H, $J = 7.2$ Hz), 7.45 (s, 1H), 7.07(d, 1H, $J = 6.4$ Hz), 6.88 (t, 1H, $J = 6.4$ Hz), 4.70 (s, 2H), 3.81 (t, 2H, $J = 8.8$ Hz), 3.52 (t, 2H, $J = 8.8$ Hz); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 159.0, 156.1, 150.7, 141.8, 140.9, 137.2, 136.2, 121.2, 115.0, 45.1, 40.9, 40.1; ^{11}B NMR (128.4 MHz, DMSO-d_6) δ (ppm): 1.01 (s); ^{19}F NMR (376.5 MHz, DMSO-d_6) δ (ppm): –140.36 (d, $J = 35.0$ Hz); HRMS (ESI) calculated for $C_{12}H_{12}BN_5F_2SCl$ [M + H^+] 342.0563, found 342.0547.

*BF_2[1-Pyridin-2-yl-methyl-imidazolidinylidene]-pyridin-2-yl-amine (**4c**)*. Yield, 28%; white powders; mp: 156.8–158.1°C; IR (KBr, cm^{-1}): 1638, 1568, 1244; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 8.82 (d, 1H, $J = 5.2$ Hz), 8.45 (t, 1H, $J = 8.0$ Hz), 8.19 (d, 1H, $J = 6.0$ Hz), 8.02 (t, 1H, $J = 7.2$ Hz), 7.96 (d, 1H, $J = 7.6$ Hz), 7.88 (t, 1H, $J = 7.2$ Hz), 7.21 (t, 1H, $J = 6.4$ Hz), 7.15 (d, 1H, $J = 8.8$ Hz), 4.98 (s, 2H), 3.83 (t, 2H, $J = 8.8$ Hz), 3.73 (t, 2H, $J = 8.8$ Hz); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 158.5, 154.2, 153.4, 144.9, 144.2, 143.5, 140.3, 138.3, 125.5, 120.2, 117.2, 47.6, 42.0, 40.4; ^{11}B NMR (128.4 MHz, DMSO-d_6) δ (ppm): 1.06 (s); ^{19}F NMR (376.5 MHz, DMSO-d_6) δ (ppm): –140.58 (d, $J = 35.4$ Hz); HRMS (ESI) calculated for $C_{14}H_{15}BN_5F_2$ [M + H^+] 302.1389, found 302.1385.

*BF_2[1-Pyridin-3-ylmethyl-imidazolidinylidene]-pyridin-2-yl-amine (**4d**)*. Yield, 25%; white powders; mp: 138.3–139.1°C; IR (KBr, cm^{-1}): 1638, 1555, 1218; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 8.58 (s, 1H), 8.53 (s, 1H), 8.02–7.74 (m, 3H), 7.40 (s, 1H), 7.08–7.00 (m, 2H), 4.63 (s, 2H), 3.69 (t, 2H, $J = 7.2$ Hz), 3.52 (t, 2H, $J = 7.2$ Hz); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 159.8, 156.9, 149.7, 149.2, 142.0, 137.6, 136.1, 132.9, 124.2, 121.7, 115.1, 45.5, 41.2, 40.6;^{11}B NMR (128.4 MHz, DMSO-d_6) δ (ppm): 1.07 (s); ^{19}F NMR (376.5 MHz, DMSO-d_6) δ (ppm): –140.48 (d, $J = 35.1$ Hz); HRMS (ESI) calculated for $C_{14}H_{15}BN_5F_2$ [M + H^+] 302.1389, found 302.1396.

*BF_2[1-Pyridin-4-yl-methyl-imidazolidinylidene]-pyridin-2-yl-amine (**4e**)*. Yield, 26%; white powders; mp: 131.8–133.3°C; IR (KBr, cm^{-1}): 1638, 1541, 1233; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 8.55 (s, 2H), 8.02 (d, 1H, $J = 5.2$ Hz), 7.84 (t, 1H, $J = 7.2$ Hz), 7.32 (s, 1H), 7.02 (t, 2H, $J = 8.0$ Hz), 4.63 (s, 2H), 3.73 (t, 2H, $J = 8.4$ Hz), 3.54 (t, 2H, $J = 8.4$ Hz); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 159.2, 156.5, 149.8, 146.0, 141.5, 137.1, 122.4, 122.1, 114.6, 46.3, 45.5, 40.8; ^{11}B NMR (128.4 MHz, DMSO-d_6) δ (ppm): 1.10 (s); ^{19}F NMR (376.5 MHz, DMSO-d_6) δ (ppm): –140.50 (d, $J = 36.1$ Hz); HRMS (ESI) calculated for $C_{14}H_{15}BN_5F_2$ [M + H^+] 302.1389, found 302.1378.

*BF_2[1-Benzyl-imidazolidinylidene]-pyridin-2-yl-amine (**4f**)*. Yield, 34%; light yellow powders; mp: 159.2–160.3°C; IR (KBr cm^{-1}): 1639, 1551, 1205; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 8.03 (m, 1H), 7.67 (m, 1H), 7.37–7.25 (m, 6H), 6.87 (m, 1H), 4.70 (s, 2H), 3.82 (t, 2H, $J = 8.4$ Hz), 3.47 (t, 2H, $J = 8.4$ Hz); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 159.2, 156.5, 141.4, 137.0, 136.7, 128.6, 127.7, 127.3, 121.2, 114.4, 47.1, 45.1, 40.7; ^{11}B NMR (128.4 MHz, DMSO-d_6) δ (ppm): 1.08 (s); ^{19}F NMR (376.5 MHz, DMSO-d_6) δ (ppm): –140.71 (d, $J = 36.5$ Hz); HRMS (ESI) calculated for $C_{15}H_{16}BN_4F_2$ [M + H^+] 301.1436, found 301.1423.

*BF_2[1-Furan-2-yl-methyl-imidazolidinylidene]-pyridin-2-yl-amine (**4g**)*. Yield, 33%; white powders; mp: 214.8–216.2°C; IR (KBr, cm^{-1}): 1640, 1555, 1224; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 7.99 (d, 1H, $J = 5.2$ Hz), 7.62 (m, 1H), 7.38 (s, 1H), 7.02 (d, 1H, $J = 9.2$ Hz), 6.80 (m, 1H), 6.34–6.29 (m, 2H), 4.61 (s, 2H), 3.70 (t, 2H, $J = 9.2$ Hz), 3.51 (t, 2H, $J = 9.2$ Hz); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 159.1, 156.4, 150.0, 142.9, 141.5, 137.0, 121.2, 114.5, 110.5, 108.5, 45.3, 40.6, 40.4; ^{11}B NMR (128.4 MHz, DMSO-d_6) δ (ppm): 1.13 (s); ^{19}F NMR

(376.5 MHz, DMSO-d_6) δ (ppm): –140.58 (d, $J = 35.0$ Hz); HRMS (ESI) calculated for $C_{13}H_{14}BN_4OF_2$ [M + H^+] 291.1229, found 291.1217.

*BF_2[1-Thiophen-2-yl-methyl-imidazolidinylidene]-pyridin-2-yl-amine (***4h***).* Yield, 30%; light yellow powders; mp: 148.7–150.5°C; IR (KBr, cm^{-1}): 1639, 1544, 1245; ^{1}H NMR (400 MHz, DMSO-d_6) δ (ppm): 7.98 (d, 1H, $J = 5.2$ Hz), 7.61 (t, 1H, $J = 8.0$ Hz), 7.22 (d, 1H, $J = 4.8$ Hz), 7.03–6.93 (m, 3H), 6.79 (t, 1H, $J = 5.2$ Hz), 4.76 (s, 2H), 3.77 (t, 2H, $J = 9.2$ Hz), 3.48 (t, 2H, $J = 9.2$ Hz); ^{13}C NMR (100 MHz, DMSO-d_6) δ (ppm): 159.0, 156.4, 141.5, 138.8, 137.1, 127.1, 126.8, 126.1, 121.2, 114.6, 44.8, 42.0, 40.7; ^{11}B NMR (128.4 MHz, DMSO-d_6) δ (ppm): 1.14 (s); ^{19}F NMR (376.5 MHz, DMSO-d_6) δ (ppm): –140.55 (d, $J = 34.6$ Hz); HRMS (ESI) calculated for $C_{13}H_{14}BN_4SF_2$ [M + H^+] 307.1000, found 307.1004.

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