Copper-catalysed regio- and stereoselective addition of *N*-heterocycles to *gem*-dihalo-olefins: synthesis of useful *N*-vinyl halides

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A facile synthesis of *N*-vinyl halides *via* a Cu(I)-catalysed highly regio- and stereoselective addition of imidazoles or benzimidazoles to *gem*-dihalo-olefins was reported. The reaction proceeded smoothly in the presence of TBAB to afford the desired products in moderate to good yields. Application to the synthesis of aryl vinyl ethers derivatives is demonstrated.

Keywords: copper, vinyl halides, *gem*-dihalo-olefins, *n*-heterocycles, addition reaction

The transition metal-catalysed addition reactions of alkenes and alkynes, particularly those involving hetero-atoms, can lead to the conversion of common unsaturated petroleum products into chemically and biologically important precursors.[1,2] Vinyl halides are useful synthetic intermediates in organic chemistry and the development of methods for their stereoselective synthesis is of importance. Their use as precursors to vinyl anions[3] and as coupling partners[4] in a wide range of transition metal-mediated coupling reactions has stimulated interest in their synthesis.

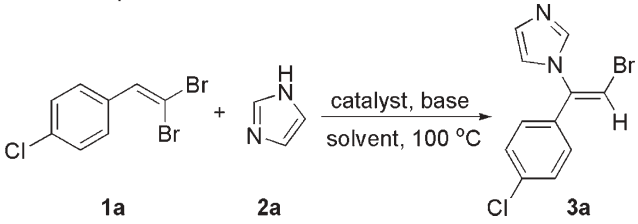
gem-Dihalo-olefins[5] can be conveniently obtained from aldehydes by using the Ramirez olefination[6] or the more recent modifications.[7,8] They are useful intermediates in the synthesis of terminal alkynes *via* the Corey–Fuchs reaction.[8] More recently, their reactivity in transition-metal-mediated reactions has been investigated. *gem*-Dibromoolefins have been shown to be especially useful substrates for palladium and copper catalysis and these reactions have resulted in versatile building blocks such as substituted alkenes and alkynes,[9] ynamides,[10] heterocycles[11] and other intermediates.[12] They can also be readily converted into (*E*)- and (*Z*)-vinyl bromides *via* stereoselective cross-coupling or other transformations.[13]

During our recent studies on copper-catalysed coupling reaction of imidazole with 1,1-dibromo-1-alkenes,[14] we found that some ligands, for examples L-proline, can provide minor amounts of *N*-(halovinyl)imidazoles as a by-product. We have examined this side-reaction of the addition of *N*-heterocycles to *gem*-dihalo-olefins. Although Kerwin *et al*.[15,16] observed the formation of these compounds with the same reported stereochemistry, the development of high-selective and effective method for this transformation is still desirable. Urabe *et al*.[17] reported the synthesis of these compounds *via* a additive-free nucleophilic addition using linear aliphatic haloacetylenes as substrates. However, this needs a higher reaction temperature. We decided to try to promote the formation of these useful *N*-vinyl halides with copper as a catalyst.

Results and discussion

Our initial investigation was based on the reaction of 1-chloro-4-(2,2-dibromovinyl)benzene **1a** with imidazole **2a** in the presence of 10 mol% of CuI in dioxan at 100 °C. With KOH as base, the product (*Z*)-1-(2-bromo-1-(4-chlorophenyl)vinyl)-1*H*-imidazole **3a** was obtained in 11% yields after 30 h in the absence of any ligand (Table 1, entry 1). Further study indicated that PPh_3 and Cs_2CO_3 are effective to this reaction (Table 1, entries 2–4). Interestingly, when tetrabutylammonium bromide (TBAB)[16] was added to the reaction mixture, the addition was markedly improved to form the desired addition product **3a** (Table 1, entry 5). We also observed that 2 equiv. of *gem*-dihalo-olefins was necessary (Table 1, entry 6). A decreased yield of **3a** was obtained when the catalyst loading be decreased to 5 mol% (Table 1, entry 7). We found, however, that an increase in reaction temperature from 100 to 120 °C leads to a decrease in yield (Table 1, entry 8). With K_3PO_4 as a base, the reaction was observed to give the corresponding product **3a** in 45% yield (Table 1, entry 9). Other additive such as TBAI or PEG-400 led to a low yield or no reaction at all (Table 1, entries 10 and 11). It is noted that when the reaction was carried out in the presence of TBAB under N_2 atmosphere, no product was obtained with 90% recovery of the starting material **2a**, which indicated that TBAB alone is ineffective in the reaction (Table 1, entry 12). In terms of solvent effect, dioxan is better than other solvents screened, such as DMF, toluene (Table 1, entries 12 and 13). $CuBr_2$ and CuCl showed poor catalytic activities (Table 1, entries 14 and 15). After the reaction conditions were screened and optimised, the addition product was afforded in 72% isolated yield using 10% CuI as the catalyst, Cs_2CO_3 as the base, and TBAB as the additive in dioxan at 100 °C for 30h (Table 1, entry 5). The stereochemistry was established by the NOESY analysis of **3a**.

Table 1 Optimisation of reaction conditions[a]



1a **2a** **3a**

Entry	Catalyst	Ligand[b]	Additive[c]	Base	Solvent	Yield/%[d]
1	CuI			KOH	Dioxan	11
2	CuI			Cs_2CO_3	Dioxan	16
3	CuI	L-proline		Cs_2CO_3	Dioxan	13
4	CuI	PPh_3		Cs_2CO_3	Dioxan	40
5	CuI	PPh_3	TBAB	Cs_2CO_3	Dioxan	72
6	CuI	PPh_3	TBAB	Cs_2CO_3	Dioxan	46[e]
7	CuI	PPh_3	TBAB	Cs_2CO_3	Dioxan	55[f]
8	CuI	PPh_3	TBAB	Cs_2CO_3	Dioxan	37[g]
9	CuI	PPh_3	TBAB	K_3PO_4	Dioxan	45
10	CuI	PPh_3	TBAI	Cs_2CO_3	Dioxan	46
11	CuI	PPh_3	PEG-400	Cs_2CO_3	Dioxan	0
12	CuI		TBAB	Cs_2CO_3	DMF	0
13	CuI	PPh_3	TBAB	Cs_2CO_3	Toluene	19
14	$CuBr_2$	PPh_3	TBAB	Cs_2CO_3	Dioxan	26
15	CuCl	PPh_3	TBAB	Cs_2CO_3	Dioxan	37

[a] **1a** (1 mmol), **2a** (0.5 mmol), base (2 equiv.) and catalyst (10%) in 2 mL of solvent at 100 °C for 30 h under N_2.
[b] 20%.
[c] 1.2 equiv.; PEG=polyethylene glycol; TBAB, tetrabutylammonium bromide; TBAI, tetrabutylammonium iodide.
[d] Isolated yields.
[e] The ratio of **1a**:**2a**=1:1.
[f] Using 5% of CuI.
[g] The reaction run at 120 °C.

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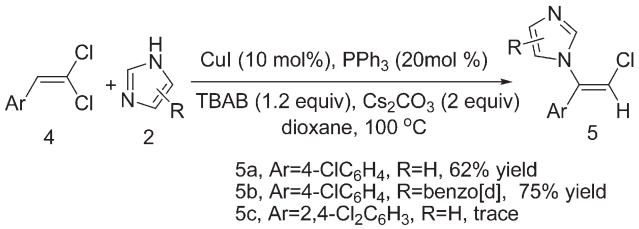
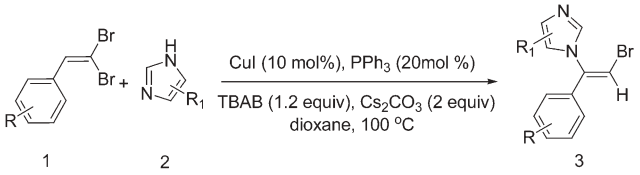
To demonstrate the efficiency and scope of the present method, we applied the above optimised reaction conditions to a variety of *gem*-dibromoolefins **1** and imidazoles or benzimidazoles **2**. The results are summarised in Tables 2 and 3. It was found that the reaction is general, thus, 1,1-dibromoalkenes bearing electron-donating and -withdrawing groups reacted smoothly to afford *N*-vinyl bromides **3a–s** in moderate to good yields. Electron-deficient substrates gave better yields. In the case of the 4-(2,2-dibromovinyl)benzonitrile, the low yield of the product could be explained by the formation of a homo-coupled bisalkyne byproduct in 15% yield. In general, various substituted imidazoles, including benzimidazoles, were successfully used in this copper-mediated addition to give the desired products. It should be noted that 2-nitro-1*H*-imidazole failed to afford the expected product. The structure of these products was further confirmed by the NOESY analysis of **3e**. Different substituents on aromatic rings have no effect on both regio- and stereoselectivity.

Using 1-chloro-4-(2, 2-dichlorovinyl)benzene as a test substrate, it was observed that the addition reaction proceeded smoothly to afford the desired products (Scheme **1**). We found however, that 2, 4-dichloro-1-(2, 2-dichlorovinyl)benzene was not a good substrate for the copper-catalysed addition reaction probably due to the effect of steric hindrance.



Scheme 1

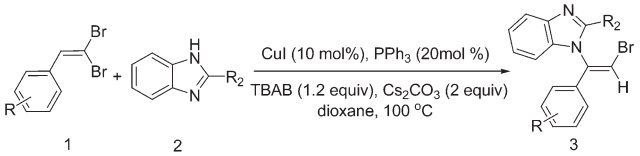
Table 2 Copper-catalysed addition of imidazole to 1,1-dibromo-1-alkenes[a]



Entry	R	R^1	Products	Yields/%
1	4-Cl	H	**3a**	72
2	4-Cl	2-Ethyl	**3b**	77
3	4-Cl	2-Isopropyl	**3c**	70
4	H	2-Methyl	**3d**	70
5	H	H	**3e**	50
6	3-Br	2-Isopropyl	**3f**	61
7	3-Br	2-Ethyl	**3g**	70
8	3-Br	2-Methyl	**3h**	57
9	4-CH_3	H	**3i**	39
10	4-CF_3	2-Isopropyl	**3j**	68
11	4-CF_3	2-Ethyl	**3k**	81
12	4-CF_3	2-Propyl	**3l**	70
13	3-Br	2-Propyl	**3m**	67
14	4-CN	2-Ethyl	**3n**	41

[a] 1 (1 mmol), 2 (0.5 mmol), base (2 equiv.), catalyst (10%) and TBAB (1.2 equiv.) in 2 mL of dioxane at 100 °C for 30 h under N_2.

Table 3 Copper-catalysed addition of benzimidazole to 1,1-dibromo-1-alkenes[a]



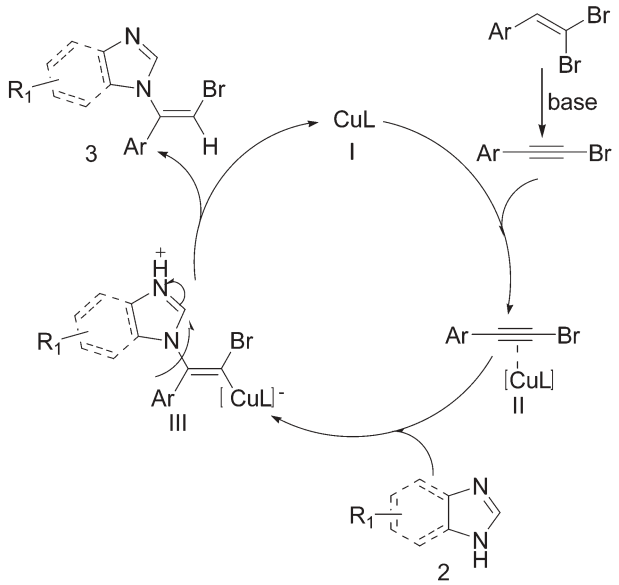
Entry	R	R^2	Products	Yields/%
1	4-Cl	H	3o	66
2	4-Cl	Methyl	3p	69
3	H	H	3q	58
4	3-Br	H	3r	69
5	4-CH_3	H	3s	46

[a] **1** (1 mmol), **2** (0.5 mmol), base (2 equiv.), catalyst (10%) and TBAB (1.2 equiv.) in 2 mL of dioxane at 100 °C for 30 h under N_2.

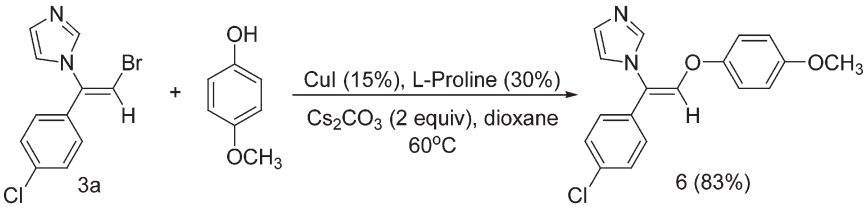
Formation of 1-bromoalkynes in the presence of base from 1,1-dibromo-1-alkenes is a well-known transformation[18] and these compounds have been identified in the crude reaction mixture. Although, so far, we cannot be certain of the actual role of TBAB in the formation of compound **3**, a tentative mechanism is depicted in Scheme **2**. First, the copper(I) species **I** coordinates to the alkynyl bromide, which is generated from 1,1-dibromo-1-alkene **1** *via* dehydrobromination, activating the triple bond. Subsequently the imidazole **2** acts as a nucleophile, attacking the triple bond to form vinyl copper intermediate **III**. The protonation which follows would lead to the expected compound **3** and regenerate the catalytic copper(I) species **I** in the process.

In order to show the applications of these products, we have demonstrated that aryl vinyl ethers derivatives can be readily obtained by treatment with phenol in the presence of copper and commercially available ligands under mild conditions in good yield (Scheme 3).

In summary, we have demonstrated the highly regio- and stereoselective formation of (*Z*)-*N*-vinyl halides by copper-catalysed addition of *N*-heterocycles to *gem*-dihalo-olefins. The reaction proceeded with several *gem*-dihalo-olefins and imidazoles or benzimidazoles to provide the desired *N*-vinyl halides in moderate to good yields. The products have been successfully applied to the highly stereo-selective synthesis of aryl vinyl ethers derivatives in the presence of commercially available copper reagents. Further studies on the applications of this method and on the use of other nucleophiles will be reported in due course.



Scheme 2 Plausible mechanism.



Scheme 3

Experimental

All reactions were carried out under nitrogen in oven-dried glassware with magnetic stirring. Flash column chromatography was performed over silica gel 200–300 mesh. NMR spectra were recorded for ^{1}H NMR at 400 MHz or 500 MHz, and ^{13}C NMR at 100 MHz or 125 MHz using TMS as internal standard. Mass spectroscopic data for the products were collected on an HRMS-APCI instrument or a low-resolution MS instrument using EI or ESI ionisation.

Synthesis of compounds **3** *and* **5***; general procedure*

A vessel with a magnetic stirrer bar was charged with imidazole derivative (0.5 mmol), CuI (10 mg, 0.05 mmol), Cs_2CO_3 (0.33 g, 1 mmol), PPh_3 (26 mg, 0.1 mmol) and tetrabutylammonium bromide (TBAB) (0.2 g, 0.6 mmol) under a nitrogen atmosphere. The reaction vessel was evacuated and backfilled with nitrogen three times. In a separate flask, a solution of dry dioxane (2 mL) containing the 1,1-dihalo-1-alkenes (1 mmol) was evacuated and back-filled with nitrogen gas three times. The dioxane solution was then added to the reaction flask via a syringe and the reaction mixture heated to 100 °C for 30 hours. The reaction mixture was cooled to room temperature, quenched with 5 mL of a saturated NH_4Cl solution, and extracted with ethyl acetate (3 x 10 mL). The combined organic phases were dried over anhydrous sodium sulfate, filtered and concentrated. The residue was purified by flash column chromatography with ethyl acetate (EA) and petroleum ether (Pet) as the eluent to afford the corresponding products:

*(Z)-1-(2-Bromo-1-(4-chlorophenyl)vinyl)-1*H*-imidazole* (**3a**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.67 (s, 1H), 7.34 (d, *J* = 8.1 Hz, 2H), 7.21 (s, 1H), 7.11 (d, *J* = 8.0 Hz, 2H), 6.98 (s, 1H), 6.80 (s, 1H).^{13}C NMR (126 MHz, $CDCl_3$) δ 139.5, 137.7, 136.2, 134.0, 129.6, 129.4, 127.6, 119.4, 102.8. HRMS (EI) calcd for $C_{11}H_8BrClN_2$ (M^+), 281.9559; found, 281.9554.

*(Z)-1-(2-Bromo-1-(4-chlorophenyl)vinyl)-2-ethyl-1*H*-imidazole* (**3b**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.33 (d, *J* = 8.5 Hz, 2H), 7.16 (s, 1H), 7.11–7.04 (m, 3H), 6.87 (s, 1H), 2.47 (q, *J* = 7.5 Hz, 2H), 1.25 (t, *J* = 7.5 Hz, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 149.7, 140.1, 136.2, 133.7, 129.7, 128.5, 126.8, 119.6, 107.4, 20.7, 12.2. HRMS (EI) calcd for $C_{13}H_{12}BrClN_2$ (M^+), 309.9872; found, 309.9870.

*(Z)-1-(2-Bromo-1-(4-chlorophenyl)vinyl)-2-isopropyl-1*H*-imidazole* (**3c**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.33 (d, *J* = 8.6 Hz, 2H), 7.18 (d, *J* = 1.1 Hz, 1H), 7.11 (s, 1H), 7.07 (d, *J* = 8.6 Hz, 2H), 6.85 (d, *J* = 1.3 Hz, 1H), 2.65 (dt, *J* = 13.7, 6.9 Hz, 1H), 1.20 (d, *J* = 6.9 Hz, 6H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 153.3, 139.7, 136.1, 133.4, 129.5, 127.7, 126.4, 119.2, 107.6, 26.7, 21.7. HRMS (EI) calcd for $C_{14}H_{14}BrClN_2$ (M^+), 324.0029; found, 324.0024.

*(Z)-1-(2-Bromo-1-phenylvinyl)-2-methyl-1*H*-imidazole* (**3d**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.43–7.32 (m, 3H), 7.10–7.13 (m, 3H), 7.07 (s, 1H), 6.88 (d, *J* = 0.8 Hz, 1H), 2.23 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 145.1, 141.1, 135.1, 130.0, 129.4, 128.4, 125.5, 119.6, 106.6, 13.3. HRMS (EI) calcd for $C_{12}H_{11}BrN_2$ (M^+), 262.0106; found, 262.0108.

*(Z)-1-(2-Bromo-1-phenylvinyl)-1*H*-imidazole* (**3e**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.68 (s, 1H), 7.42–7.33 (m, 3H), 7.21 (s, 1H), 7.18–7.15 (m, 2H), 7.00 (s, 1H), 6.77 (s, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 140.5, 137.8, 135.5, 130.0, 129.4, 129.0, 128.9, 128.7, 126.3, 119.6, 102.1. HRMS (EI) calcd for $C_{11}H_9BrN_2$ (M^+), 247.9949; found, 247.9953.

*(Z)-1-(2-Bromo-1-(3-bromophenyl)vinyl)-2-isopropyl-1*H*-imidazole* (**3f**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.52 (d, *J* = 8.1 Hz, 1H), 7.35 (t, *J* = 1.8 Hz, 1H), 7.23 (t, *J* = 8.0 Hz, 1H), 7.18 (d, *J* = 1.2 Hz, 1H), 7.15 (s, 1H), 7.01 (d, *J* = 8.0 Hz, 1H), 6.85 (d, *J* = 1.3 Hz, 1H), 2.65 (dt, *J* = 13.7, 6.9 Hz, 1H), 1.22 (d, *J* = 6.9 Hz, 6H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 153.5, 139.8, 137.3, 133.1, 130.9, 128.5, 128.4, 124.1, 123.7, 119.4, 108.6, 26.9, 22.0. HRMS (EI) calcd for $C_{14}H_{14}Br_2N_2$ (M^+), 367.9524; found, 367.9528.

*(Z)-1-(2-Bromo-1-(3-bromophenyl)vinyl)-2-ethyl-1*H*-imidazole* (**3g**): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48 (d, *J* = 7.6 Hz, 1H), 7.30 (s, 1H), 7.19 (t, *J* = 7.9 Hz, 1H), 7.13–7.10 (m, 2H), 6.98 (d, *J* = 7.9 Hz, 1H), 6.84 (s, 1H), 2.45 (q, *J* = 7.6 Hz, 2H), 1.21 (t, *J* = 7.6 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 149.4, 139.4, 136.8, 132.7, 130.6, 128.1, 123.8, 123.3, 119.3, 108.3, 20.3, 11.8. HRMS (EI) calcd for $C_{13}H_{12}Br_2N_2$ (M^+), 353.9367; found, 353.9357.

*(Z)-1-(2-Bromo-1-(3-bromophenyl)vinyl)-2-methyl-1*H*-imidazole* (**3h**): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49 (d, *J* = 7.9 Hz, 1H), 7.30 (s, 1H), 7.20 (t, *J* = 7.9 Hz, 1H), 7.10–7.08 (m, 2H), 6.99 (d, *J* = 7.9 Hz, 1H), 6.84 (s, 1H), 2.21 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 144.7, 139.5, 136.8, 132.7, 130.6, 128.5, 128.1, 123.9, 123.3, 119.2, 108.1, 13.1. HRMS (EI) calcd for $C_{12}H_{10}Br_2N_2$ (M^+), 339.9211; found, 339.9216.

*(Z)-1-(2-Bromo-1-p-tolylvinyl)-1*H*-imidazole* (**3i**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.68 (s, 1H), 7.19 (d, *J* = 3.1 Hz, 1H), 7.16 (d, *J* = 8.1 Hz, 2H), 7.05 (d, *J* = 8.2 Hz, 2H), 7.00 (s, 1H), 6.71 (s, 1H), 2.35 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 140.5, 140.4, 137.8, 132.8, 129.7, 129.2, 126.3, 119.6, 101.0, 21.3. HRMS (EI) calcd for $C_{12}H_{11}BrN_2$ (M^+), 262.0106; found, 262.0103.

*(Z)-1-(2-Bromo-1-(4-(trifluoromethyl)phenyl)vinyl)-2-isopropyl-1*H*-imidazole* (**3j**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.62 (d, *J* = 8.2 Hz, 2H), 7.27 (t, *J* = 8.0 Hz, 3H), 7.18 (s, 1H), 6.86 (s, 1H), 2.63 (dt, *J* = 13.6, 6.8 Hz, 1H), 1.24 (d, *J* = 6.8 Hz, 6H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 153.5, 140.1, 138.7, 129.0, 126.4, 126.4, 125.7, 119.2, 109.7, 26.9, 22.0. HRMS (EI) calcd for $C_{15}H_{14}BrF_3N_2$ (M^+), 358.0292; found, 358.0279.

*(Z)-1-(2-Bromo-1-(4-(trifluoromethyl)phenyl)vinyl)-2-ethyl-1*H*-imidazole* (**3k**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.63 (d, *J* = 8.2 Hz, 2H), 7.27–7.21 (m, 4H), 6.90 (s, 1H), 2.51 (q, *J* = 7.5 Hz, 2H), 1.26 (t, *J* = 7.5 Hz, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 149.5, 139.5, 138.0, 127.9, 126.4, 126.3, 125.6, 119.4, 109.8, 20.3, 11.9. HRMS (EI) calcd for $C_{14}H_{12}BrF_3N_2$ (M^+), 344.0136; found, 344.0135.

*(Z)-1-(2-Bromo-1-(4-(trifluoromethyl)phenyl)vinyl)-2-propyl-1*H*-imidazole* (**3l**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.63 (d, *J* = 8.1 Hz, 2H), 7.28–7.23 (m, 3H), 7.20 (s, 1H), 6.90 (s, 1H), 2.44 (t, *J* = 7.6 Hz, 2H), 1.72 (dd, *J* = 14.6, 7.4 Hz, 2H), 0.90 (t, *J* = 7.4 Hz, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 148.5, 139.6, 138.1, 128.1, 126.3, 126.3, 125.6, 119.4, 109.6, 28.9, 21.0, 13.9. HRMS (EI) calcd for $C_{15}H_{14}BrF_3N_2$ (M^+), 358.0292; found, 358.0300.

*(Z)-1-(2-Bromo-1-(3-bromophenyl)vinyl)-2-propyl-1*H*-imidazole* (**3m**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.53 (d, *J* = 8.4 Hz, 1H), 7.33 (t, *J* = 1.6 Hz, 1H), 7.23 (t, *J* = 7.9 Hz, 1H), 7.19 (d, *J* = 1.0 Hz, 1H), 7.13 (s, 1H), 7.00 (d, *J* = 7.9 Hz, 1H), 6.89 (d, *J* = 1.2 Hz, 1H), 2.45 (t, *J* = 7.7 Hz, 2H), 1.72 (dd, *J* = 15.1, 7.5 Hz, 2H), 0.90 (t, *J* = 7.5 Hz, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 148.4, 139.4, 136.8, 132.9, 130.7, 128.2, 127.8, 123.9, 123.5, 119.5, 108.5, 28.9, 21.0, 13.9. HRMS (EI) calcd for $C_{14}H_{14}Br_2N_2$ (M^+), 367.9524; found, 367.9529.

*(Z)-4-(2-Bromo-1-(2-ethyl-1*H*-imidazol-1-yl)vinyl)benzonitrile* (**3n**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.67 (d, *J* = 8.5 Hz, 2H), 7.30 (s, 1H), 7.24 (d, *J* = 8.5 Hz, 2H), 7.18 (s, 1H), 6.88 (s, 1H), 2.46 (q, *J* = 7.5 Hz, 2H), 1.25 (t, *J* = 7.5 Hz, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 149.7, 139.7, 139.3, 133.3, 129.2, 126.0, 119.4, 118.2, 113.6, 111.0, 20.7, 12.2. HRMS (EI) calcd for $C_{14}H_{12}BrN_3$ (M^+), 301.0215; found, 301.0217.

*(Z)-1-(2-Bromo-1-(4-chlorophenyl)vinyl)-1*H*-benzo[d]imidazole* (**3o**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.08 (s, 1H), 7.88 (d, *J* = 8.1 Hz, 1H), 7.35–7.29 (m, 3H), 7.24–7.21 (m, 1H), 7.11 (d, *J* = 8.7 Hz, 2H), 7.05 (s, 1H), 6.96 (d, *J* = 8.1 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 143.5, 143.0, 138.6, 136.4, 133.4, 132.9, 129.7, 127.5, 124.1, 123.2,

120.8, 111.6, 105.4. HRMS (EI) calcd for $C_{15}H_{10}BrClN_2$ (M^+), 331.9716; found, 331.9719.

(Z)-1-(2-Bromo-1-(4-chlorophenyl)vinyl)-2-methyl-1H-benzo[d]imidazole (**3p**): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.77 (d, *J* = 7.9 Hz, 1H), 7.31 (d, *J* = 1.0 Hz, 2H), 7.28 (d, *J* = 3.0 Hz, 2H), 7.20 (t, *J* = 7.6 Hz, 1H), 7.09–7.03 (m, 3H), 2.44 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 150.9, 142.7, 138.2, 135.9, 134.1, 132.8, 129.5, 126.5, 122.9, 122.6, 119.3, 110.0, 108.9, 13.9. HRMS (EI) calcd for $C_{16}H_{12}BrClN_2$ (M^+), 345.9872; found, 345.9880.

(Z)-1-(2-Bromo-1-phenylvinyl)-1H-benzo[d]imidazole (**3q**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.07 (s, 1H), 7.88 (d, *J* = 8.1 Hz, 1H), 7.40 (t, *J* = 7.3 Hz, 1H), 7.35–7.28 (m, 3H), 7.21 (t, *J* = 7.6 Hz, 1H), 7.17 (d, *J* = 7.5 Hz, 2H), 7.03 (s, 1H), 6.99 (d, *J* = 8.1 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 143.4, 143.0, 139.5, 134.8, 132.9, 130.1, 129.2, 128.9, 128.8, 126.1, 123.7, 122.9, 120.6, 111.5, 104.7. HRMS (EI) calcd for $C_{15}H_{11}BrN_2$ (M^+), 298.0106; found, 298.0109.

(Z)-1-(2-Bromo-1-(3-bromophenyl)vinyl)-1H-benzo[d]imidazole (**3r**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.06 (s, 1H), 7.89 (d, *J* = 8.1 Hz, 1H), 7.54 (d, *J* = 8.0, Hz, 1H), 7.43 (d, *J* = 1.5 Hz, 1H), 7.32 (t, *J* = 7.6 Hz, 1H), 7.24 (t, *J* = 7.8 Hz, 1H), 7.18 (t, *J* = 7.9 Hz, 1H), 7.08 (s, 1H), 7.02 (d, *J* = 7.9 Hz, 1H), 6.99 (d, *J* = 8.1 Hz, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 143.3, 142.7, 138.1, 136.8, 133.1, 132.7, 130.7, 128.9, 124.7, 123.9, 123.4, 123.0, 120.7, 111.3, 106.3. HRMS (EI) calcd for $C_{15}H_{10}Br_2N_2$ (M^+), 375.9211; found, 375.9216.

(Z)-1-(2-Bromo-1-p-tolylvinyl)-1H-benzo[d]imidazole (**3s**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.06 (s, 1H), 7.87 (d, *J* = 8.1 Hz, 1H), 7.30 (t, *J* = 7.6 Hz, 1H), 7.21 (t, *J* = 7.6 Hz, 1H), 7.13 (d, *J* = 8.2 Hz, 2H), 7.05 (d, *J* = 8.2 Hz, 2H), 7.01–6.95 (m, 2H), 2.34 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 143.3, 143.0, 140.4, 139.4, 132.9, 132.0, 129.9, 126.0, 123.6, 122.8, 120.5, 111.6, 103.5, 21.3. HRMS (EI) calcd for $C_{16}H_{13}BrN_2$ (M^+), 312.0262; found, 312.0266.

(Z)-1-(2-Chloro-1-(4-chlorophenyl)vinyl)-1H-imidazole (**5a**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.68 (s, 1H), 7.36 (d, *J* = 8.5 Hz, 2H), 7.21 (s, 1H), 7.12 (d, *J* = 8.5 Hz, 2H), 7.00 (s, 1H), 6.58 (s, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 137.9, 137.1, 136.2, 133.3, 129.6, 129.4, 127.7, 119.6, 113.3. HRMS (EI) calcd for $C_{11}H_8Cl_2N_2$ (M^+), 238.0065; found, 238.0067.

(Z)-1-(2-Chloro-1-(4-chlorophenyl)vinyl)-1H-benzo[d]imidazole (**5b**): ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.06 (s, 1H), 7.88 (d, *J* = 8.1 Hz, 1H), 7.32 (dd, *J* = 7.6, 5.7 Hz, 3H), 7.23 (t, *J* = 7.6 Hz, 1H), 7.11 (d, *J* = 8.5 Hz, 2H), 6.95 (d, *J* = 8.1 Hz, 1H), 6.84 (s, 1H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 143.4, 142.9, 136.2, 136.0, 132.9, 132.5, 129.5, 127.3, 123.9, 123.0, 120.7, 115.7, 111.4. HRMS (EI) calcd for $C_{15}H_{10}Cl_2N_2$ (M^+), 288.0221; found, 288.0229.

Synthesis of compound **6***; general procedure*

A vessel with a magnetic stirrer bar was charged with Cs_2CO_3 (660 mg, 2.0 mmol), CuI (30 mg, 0.15 mmol, 15 mol%), L-proline (35 mg, 0.30 mmol, 30 mol%), (Z)-1-(2-bromo-1-(4-chlorophenyl)vinyl)-1*H*-imidazole (290 mg, 1 mmol), 4-methoxyphenol (190 mg, 1.2 mmol), and dioxane (2 mL) under a nitrogen atmosphere. The reaction vessel was evacuated and backfilled with nitrogen three times and heated to 60 °C for 24 hours. The cooled reaction mixture was dissolved in H_2O and extracted with ethyl acetate. The combined organic layer was dried ($MgSO_4$). The product was further purified by column chromatography with ethyl acetate (EA) and petroleum ether (Pet) as eluent to afford (*Z*)-1-(1-(4-chlorophenyl)-2-(4-methoxyphenoxy)vinyl)-1*H*-imidazole 270 mg. (yield: 83%); Yellow oil; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.72 (s, 1H), 7.33 (d, *J* = 8.5 Hz, 2H), 7.16 (t, *J* = 9.1 Hz, 3H), 7.06–6.99 (m, 3H), 6.91–6.85 (m, 3H), 3.79 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 156.3, 150.7, 137.2, 134.4, 132.8, 129.1, 129.0, 128.5, 127.2, 120.1, 117.9, 114.9, 107.0, 55.7; MS (ESI) *m/z* 327.2 ($[M+H]^+$); HRMS (EI) calcd for $C_{18}H_{15}ClN_2O_2$ (M^+), 326.0822; found, 326.0824.

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