



Cite this: *RSC Adv.*, 2022, 12, 5919

Received 7th October 2021  
Accepted 21st November 2021

DOI: 10.1039/d1ra07438e

rsc.li/rsc-advances

# A multi pathway coupled domino strategy: I<sub>2</sub>/TBHP-promoted synthesis of imidazopyridines and thiazoles via sp<sup>3</sup>, sp<sup>2</sup> and sp C–H functionalization†

Yishou Wang, Shichen Li, Xinfeng Wang, Yiming Yao, Lei Feng\* and Chen Ma \*

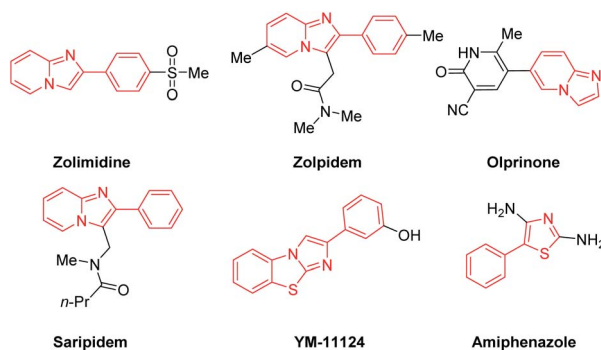
I<sub>2</sub>/TBHP-promoted, one-pot, multi pathway synthesis of imidazopyridines and thiazoles has been achieved through readily available ethylarenes, ethylenearenes and ethynearenes. I<sub>2</sub>/TBHP as an initiator and oxidant is used to realize the C–H functionalization of this domino reaction. Simple and available starting materials, wide range of functional group tolerance, high potential for drug activity of the products and application in production are the advantageous features of this method.

## Introduction

Nitrogen- and sulfur-containing heterocyclic scaffolds generally exhibit biological activities such as anti-inflammatory,<sup>1a</sup> anti-cancer,<sup>1b</sup> antibacterial,<sup>1c</sup> antiviral<sup>1d</sup> or signal conditioning activity.<sup>1e</sup> Such scaffolds can be found in many drug skeletons and natural products.<sup>2</sup> For example, zolimidine, zolpidem, olprinone and saripidem are commercialized drugs, and YM-11124 and amiphenazole play an important signal regulation role in life activities.<sup>3</sup> Therefore, exploring and developing new methods of synthesizing these compounds has very important commercial and application value (Scheme 1).

To date, there are many ways to synthesize imidazole or thiazole rings. In general, the usual synthetic strategy is the

direct condensation and cyclization of  $\alpha$ -halo acetophenone and 2-aminopyridine (scheme 2a).<sup>4</sup> Alternatively, acetophenone as a raw material, first completes the *ortho*-halogenation of the carbonyl group, and then condenses and cyclizes with 2-aminopyridine (Scheme 2b).<sup>5</sup> In recent years, some new synthetic methods have been developed. For instance, when ethylbenzene<sup>6</sup> and styrene<sup>7</sup> act as starting materials,  $\alpha$ -halo acetophenone is synthesized by adding an oxidant and a halogenating reagent (Scheme 2c and d). In addition,

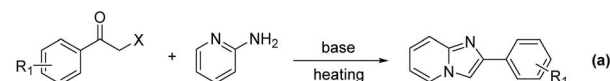


**Scheme 1** The drugs and biologically active compounds containing imidazopyridines or thiazoles units.

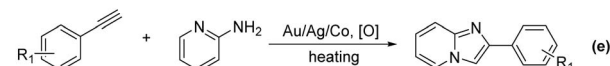
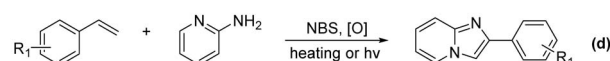
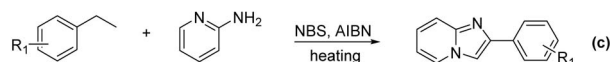
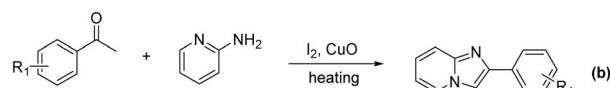
School of Chemistry and Chemical Engineering, Shandong University, Jinan, 250100, P. R. China. E-mail: chenma@sdu.edu.cn

† Electronic supplementary information (ESI) available: Detailed experimental procedures, characterization data and copies of NMR spectra. See DOI: 10.1039/d1ra07438e

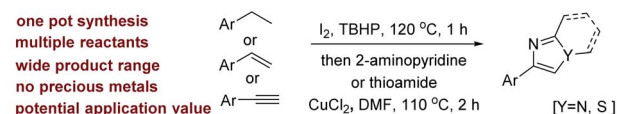
### traditional method



### recent method



### this work



**Scheme 2** Approach for the synthesis of imidazo[1,2-a]pyridine and thiazole.

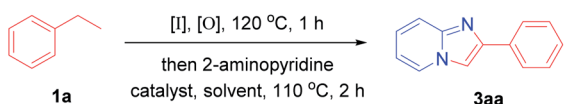


transition metal-catalyzed C–H bond activation methods for phenylacetylene<sup>8</sup> have been reported (Scheme 2e).

In the literature reported in the past,  $\alpha$ -bromo acetophenone has been used more often, and the reaction of  $\alpha$ -bromo acetophenone is more mature.<sup>9</sup> But  $\alpha$ -bromo acetophenone, as a chemical weapon used for tearing, can cause great harm to our scientific researchers and the environment.<sup>10</sup> Iodine compounds have better reactivity due to the easy removal of iodine, the reaction process is milder and greener, and the post-reaction treatment is also simple and convenient. Meanwhile, it is rare that ethylbenzene is directly functionalized as a raw material. Styrene mainly reacts by the addition of unsaturated bonds. Phenylacetylene yields the corresponding products through the coordinated activation of acetylene bonds by transition metals. While the reaction systems were not been reported which were simultaneously suitable for ethylbenzene, styrene and phenylacetylene. This has application value in the petrochemical industry, because the boiling points of ethylbenzene, styrene, and phenylacetylene are similar (136–145 °C). Their mixtures are widely present in industrial production,<sup>11</sup> for example, the process of cracking of petroleum and the process of dehydrogenating ethylbenzene to synthesize styrene.<sup>12</sup> The fact means that the system suitable for ethylbenzene, styrene and phenylacetylene has very cheap and readily available raw materials in practical applications. In this context, we developed a strategy that is applicable to them. This strategy can be used to synthesize imidazopyridines and thiazoles in one pot, and the source of raw materials is wide.  $\alpha$ -Iodo acetophenone is an intermediate in this system, which means it is more environmentally friendly. We also explored the mixed-amplified experiment of the system, which proves it has potential industrial application value.

We chose ethylbenzene and 2-aminopyridine as standard substrates to screen the most suitable reaction conditions (Table 1). The product **3aa** was obtained with a yield of 36% when CuI was used as a catalyst (entry 1). First, we studied the influence of different iodine sources on the reaction yield. When no iodine source, the target product can not be obtained, which proved iodine source necessary in the reaction process (entry 2). When *N*-iodosuccinimide (NIS), tetrabutylammonium iodide (TBAI) and KI were involved in the system, only trace products were formed (entry 3, 4 and 5). I<sub>2</sub> was used as the iodine source, the product was obtained with a considerable yield of 76% (entry 6). The oxidant was also crucial for this reaction. When Na<sub>2</sub>S<sub>2</sub>O<sub>8</sub>, dibenzoyl peroxide (BPO) and O<sub>2</sub> were used as oxidant in the reaction system, the yield of the product was 57%, 65% and a trace (entry 7, 8 and 9). Experiments showed that *tert*-butyl hydroperoxide (TBHP) is a better oxidant in the reaction system (entry 6). Then, the catalyst was optimized and screened. When no catalyst, the target product can be obtained with a yield of 30% (entry 10). When NH<sub>4</sub>Cl and FeCl<sub>3</sub> was added, the yield of the product was 27% and 34% (entry 11 and 12). The product can not be obtained when AlCl<sub>3</sub> and K<sub>2</sub>CO<sub>3</sub> were used as catalysts (entry 13 and 14). Other transition metal salts also were involved as catalysts, such as Cu(OAc)<sub>2</sub> and AgNO<sub>3</sub>, and the yield of **3aa** was not as good as when CuCl<sub>2</sub> was used (entry 15 and 16). Then, we tried different

Table 1 Optimization of the reaction conditions<sup>a</sup>

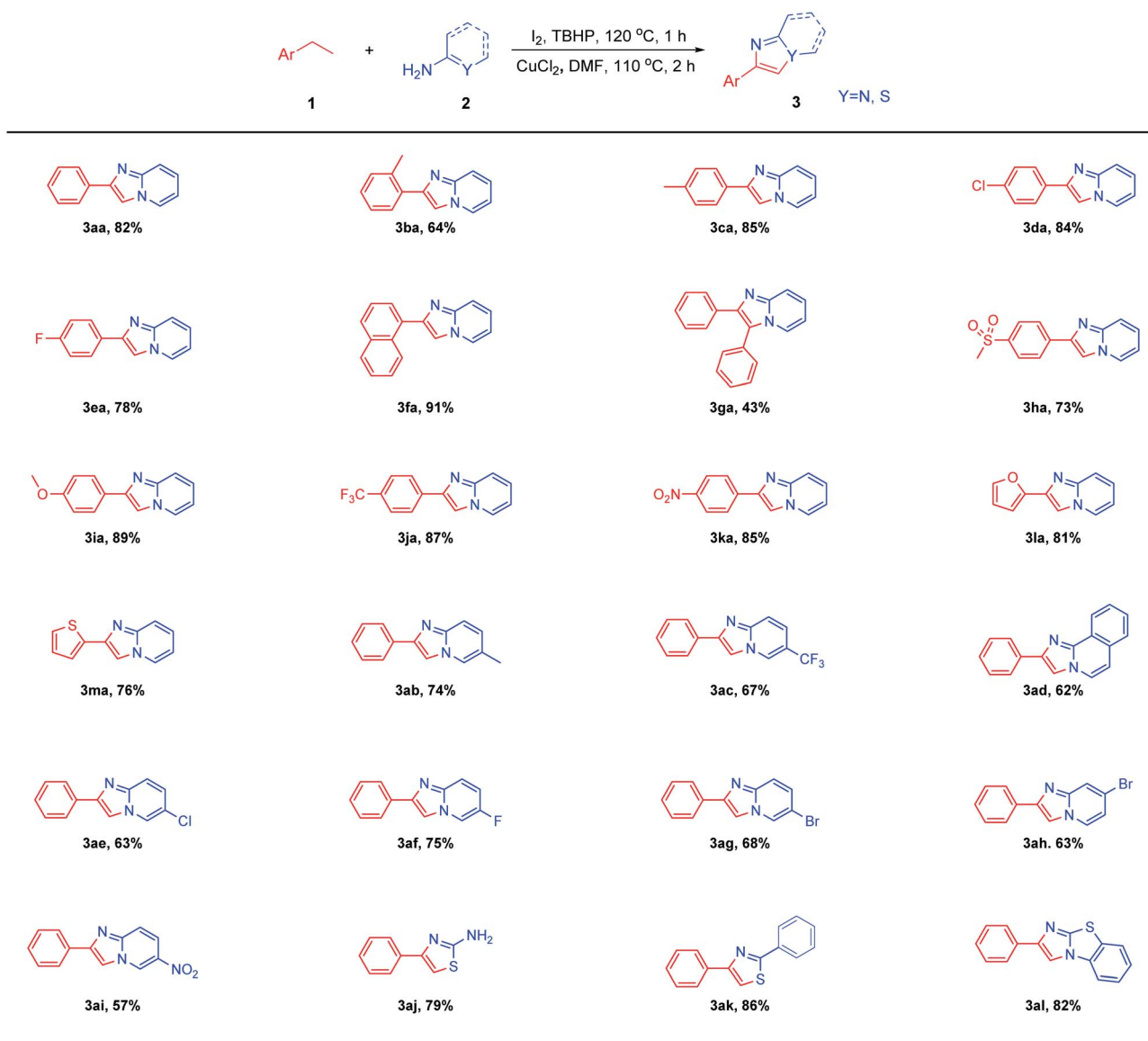
					
Entry	[I]	[O]	Catalyst	Solvent	Yield <sup>b</sup> , %
1	CuI	TBHP	—	DMSO	36
2	—	TBHP	CuCl <sub>2</sub>	DMSO	None
3	NIS	TBHP	CuCl <sub>2</sub>	DMSO	Trace
4	TBAI	TBHP	CuCl <sub>2</sub>	DMSO	Trace
5	KI	TBHP	CuCl <sub>2</sub>	DMSO	Trace
6	I <sub>2</sub>	TBHP	CuCl <sub>2</sub>	DMSO	76
7	I <sub>2</sub>	Na <sub>2</sub> S <sub>2</sub> O <sub>8</sub>	CuCl <sub>2</sub>	DMSO	57
8	I <sub>2</sub>	BPO	CuCl <sub>2</sub>	DMSO	65
9	I <sub>2</sub>	O <sub>2</sub>	CuCl <sub>2</sub>	DMSO	Trace
10	I <sub>2</sub>	TBHP	—	DMSO	30
11	I <sub>2</sub>	TBHP	NH <sub>4</sub> Cl	DMSO	27
12	I <sub>2</sub>	TBHP	FeCl <sub>3</sub>	DMSO	34
13	I <sub>2</sub>	TBHP	AlCl <sub>3</sub>	DMSO	None
14	I <sub>2</sub>	TBHP	K <sub>2</sub> CO <sub>3</sub>	DMSO	None
15	I <sub>2</sub>	TBHP	Cu(OAc) <sub>2</sub>	DMSO	52
16	I <sub>2</sub>	TBHP	AgNO <sub>3</sub>	DMSO	54
17	I <sub>2</sub>	TBHP	CuCl <sub>2</sub>	DCE	65
18	I <sub>2</sub>	TBHP	CuCl <sub>2</sub>	DMF	82
19	I <sub>2</sub>	TBHP	CuCl <sub>2</sub>	MeCN	78

<sup>a</sup> Reaction conditions: **1a** (1 mmol), [I] (0.4 mmol), [O] (3 mmol), 120 °C, 1 h then 2-aminopyridine (2.0 mmol), CuCl<sub>2</sub> (0.5 mmol), solvent (3 mL), 110 °C, 2 h. <sup>b</sup> Isolated yield.

solvents and found DMF was best (entry 17, 18 and 19). Finally, we determined that in the presence of I<sub>2</sub> (0.4 eq.), TBHP (3.0 eq.) and CuCl<sub>2</sub> (0.5 eq.), DMF as solvent, the product was obtained with a yield of 82%.

After determining the optimal reaction conditions, we explored the scope and limitations of this transformation by using substituted ethylarenes (Table 2). We found both the electron-deficient and electron-rich ethylarenes were suitable substrates to provide the desired products in moderate to excellent yields (**3aa–3ea**, **3ia–3ka**). This proved that the reaction has a wide range of application to ethylarenes connected with various groups. The reaction had a higher yield when the ethylarenes had a larger conjugated structure (**3ca**, **3fa**, **3ia**). Meanwhile, substrates with large steric hindrance like 2-methyl ethylbenzene and 1,2-diphenylethane were also tolerant to this reaction to afford the desired products in moderate yields (**3ba**, **3ga**). It was worth mentioning that **3ha** zolimidine can also be synthesized by this reaction with a relatively good yield. Zolimidine is a common gastroprotective drug which was used to treat stomach ulcers and gastroesophageal reflux disease. Excitingly, heteroarylethanes such as 2-ethylfuran and 2-ethylthiophene were also suitable for this reaction, and the products were obtained with relatively good yields (**3la**, **3ma**). The scope of 2-aminopyridines was also studied. To our satisfaction, when electron-donating and electron-withdrawing groups substituted 2-aminopyridines were subjected to this reaction, the corresponding products (**3ab–3ai**) were isolated in 57–75% yields. To our delight, structures with carbon–sulfur unsaturated double



Table 2 Substrate scope of various ethylarenes and 2-aminopyridines<sup>a</sup>

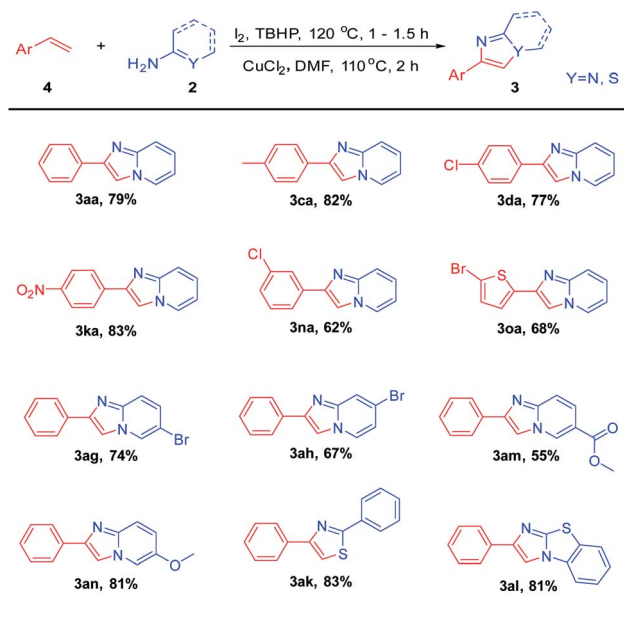
<sup>a</sup> Reaction conditions: **1a** (1 mmol), I<sub>2</sub> (0.4 mmol), TBHP (3 mmol), 120 °C, 1 h then 2-aminopyridine (2.0 mmol), CuCl<sub>2</sub> (0.5 mmol), solvent (3 mL), 110 °C, 2 h.

bonds like thiourea and benzothioamide, thiazole hybrid structures like  $\alpha$ -aminothiazole were also suitable for this reaction system, and the target products (**3aj–3al**) were furnished with good yields.

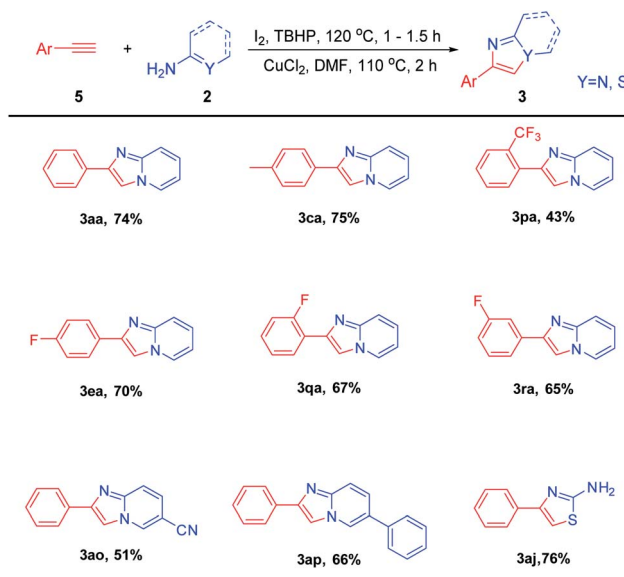
Having obtained encouraging results with ethylarenes, we turned our attention to C–H functionalization of ethylenearenes followed C–N bond construction coupling with 2-aminopyridines (Table 3). Excitingly, under optimized conditions, the corresponding product (**3aa**) can be obtained with a yield of 79%. Furthermore, whether styrenes were attached with electron-rich group such as –Me, or attached with electron-withdrawing groups such as –NO<sub>2</sub> and –Cl at the *meta* or *para* positions, the corresponding products can be obtained in good

yields (**3ca–3na**). The heterocycles, such as 2-bromo thiophene, did not affect the overall efficiency, and the corresponding products **3oa** were furnished in moderate yields. 2-Aminopyridines with halogen (5-Br, 4-Br), electron-deficient (5-COOMe), and electron-rich (4-OMe) groups reacted smoothly to afford the corresponding products (**3ag–3an**) in moderate to good yields. Finally, as expected, both benzothioamide and 2-aminothiazole were tolerant to this system, and the corresponding products (**3ak, 3al**) can be obtained with good yields.

With results of ethylarenes and ethylenearenes in hand, we tried the C–H functionalization of phenylacetylene and then reacted with 2-aminopyridines under the optimal reaction conditions (Table 4). Excitingly, **3aa** was provided with a yield of

**Table 3** Substrate scope of various ethylenearenes and 2-aminopyridines<sup>a</sup>

<sup>a</sup> Reaction conditions: **1a** (1 mmol),  $I_2$  (0.4 mmol), TBHP (3 mmol), 120 °C, 1–1.5 h then 2-aminopyridine (2.0 mmol),  $CuCl_2$  (0.5 mmol), solvent (3 mL), 110 °C, 2 h.

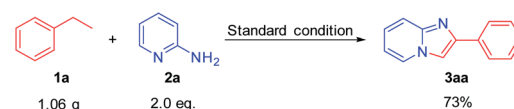
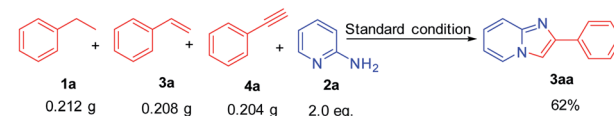
**Table 4** Substrate scope of various ethynearenes and 2-aminopyridines<sup>a</sup>

<sup>a</sup> Reaction conditions: **1a** (1 mmol),  $I_2$  (0.4 mmol), TBHP (3 mmol), 120 °C, 1–1.5 h then 2-aminopyridine (2.0 mmol),  $CuCl_2$  (0.5 mmol), solvent (3 mL), 110 °C, 2 h.

74%. The substituted phenylacetylene (4-Me) afforded the corresponding imdazo[1,2-*a*]pyridine in good yield. Meanwhile, substrates with large steric hindrance like 2-trifluoromethyl phenylacetylene was also tolerant to this reaction to afford **3pa** in moderate yields. The fluorine groups on different substitution positions (2-F, 3-F, 4-F) reacted smoothly to afford the corresponding products (**3ea**, **3qa**, **3ra**) in moderate to good yields. Finally, when nitrile or phenyl substituted 2-aminopyridines were subjected to this reaction, the corresponding products (**3ao**, **3ap**) were isolated in good yields. Thiourea also can react to get **3aj** in 76% yield.

In order to evaluate the practical application value and potential of this reaction system, we carried out a gram-scale amplification experiment under standard reaction conditions (Scheme 3). When the scale of ethylbenzene reached 10 mmol (1.06 g), this transformation proceeded smoothly and imdazo[1,2-*a*]pyridine **3aa** was obtained in 73% yield. Next, we made a bolder attempt, ethylbenzene (2 mmol), styrene (2 mmol) and phenylacetylene (2 mmol) were mixed together to examine this system, and the target product **3aa** can also be obtained with good yield. **3ak** can also be obtained from this mixed-amplified experiment in 67% yield. This proved it has great value in actual production applications.

In order to carefully explore the process of the mechanism in the reaction, some control experiments were performed (Scheme 4). It was found that ethylbenzene **1a** can be converted to acetophenone **1aa** under oxidant-promoted conditions.<sup>13</sup> **1aa** can be confirmed by HRMS and GC-MS. Acetophenone **1aa** can further react to obtain  $\alpha$ -iodo ketone **1ab** under the conditions of  $I_2$ /TBHP catalysis. **1ab** reacted with 2-aminopyridine smoothly to afford product **3aa** in 90% yield in  $CuCl_2$ /DMF conditions (Scheme 4a).  $\alpha$ -Iodo ketone **1ab** was an important

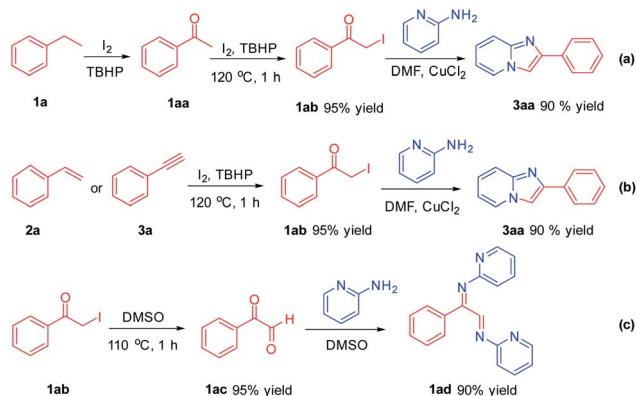
**(a)** Ethylbenzene as raw material for gram-scale synthesis of **3aa**<sup>a</sup>**(b)** Ethylbenzene, styrene and phenylacetylene as raw material for synthesis of **3aa**<sup>b</sup>**(c)** Ethylbenzene, styrene and phenylacetylene as raw material for synthesis of **3ak**<sup>c</sup>

**Scheme 3** Gram-scale synthesis of **3aa** and **3ak**. <sup>a</sup>Reaction conditions: **1a** (10 mmol),  $I_2$  (4 mmol), TBHP (30 mmol), 120 °C, 1 h 10 min then 2-aminopyridine (20 mmol),  $CuCl_2$  (5 mmol), solvent (20 mL), 110 °C, 4 h.

<sup>b</sup>Reaction conditions: **1a** (2 mmol), **3a** (2 mmol), **4a** (2 mmol),  $I_2$  (2.4 mmol), TBHP (18 mmol), 120 °C, 1 h 20 min then 2-aminopyridine (12 mmol),  $CuCl_2$  (3 mmol), solvent (10 mL), 110 °C, 2.5 h. <sup>c</sup>Reaction conditions: **1a** (2 mmol), **3a** (2 mmol), **4a** (2 mmol),  $I_2$  (2.4 mmol), TBHP (18 mmol), 120 °C, 1 h 20 min then **2k** (12 mmol),  $CuCl_2$  (3 mmol), solvent (10 mL), 110 °C, 2 h.







Scheme 4 The control experiments.

intermediate in the reaction process, which was also obtained from compound **2a** and **3a** (Scheme 4b).  $\alpha$ -Iodo ketone **1ab** was easily converted to phenylglyoxal **1ac** in DMSO,<sup>14</sup> and further condensed with 2-aminopyridine to form **1ad**, which also explained why the yield of **3aa** in DMSO was not as good as in DMF during the screening of reaction conditions (Scheme 4c).

On the basis of the control experiments described above and reported literature,<sup>15</sup> a possible mechanism for multiple C–H activation followed by circularization cross-coupling is outlined in Scheme 5.

Initially, ethylbenzene was initiated by  $I_2$ /TBHP and underwent benzylic radical of ethylbenzene process to obtain 1-phenyl ethanol (A). Then, 1-phenyl ethanol (A) was converted to acetophenone (**1aa**) via TBHP oxidation, and **1aa** can be confirmed by TLC, HRMS and GC-MS. Acetophenone (**1aa**) on iodination offered  $\alpha$ -iodo acetophenone (**1ab**). Styrene (**3a**) and phenylacetylene (**4a**) can also be converted into this key intermediate (**1ab**) through the addition of hydroxyl radicals to unsaturated bonds and the catalysis of  $I_2$ /TBHP. **1ab** can be

confirmed by TLC and HRMS.  $\alpha$ -Iodo acetophenone (**1ab**) and **2a** condensed to obtain intermediate (B).  $Cu^{2+}$  coordinated with the two atoms in the C to activate, and the pair of electrons on the Y atom (Y = N, S) carried out a nucleophilic attack on the C–I bond.  $I^-$  left and C–Y was built to get intermediate D. The deprotonation of D provided the desired product **3aa**.

## Conclusions

In conclusion, we have developed a multi pathway, environmentally friendly domino synthesis strategy promoted by  $I_2$ /TBHP. This strategy is applicable to ethylarenes, ethylenearenes and ethynearenes that can react with 2-aminopyridine, 2-aminothiazole and benzothioamide to obtain the corresponding imidazole or thiazole structure. Its resistance to various substituent groups is also excellent. Its mixed-amplified experiment indicates the potential application in industrial production. Owing to the generality of the reaction, this protocol should be of great utility in organic methodology and industrial application.

## Experimental

### General information

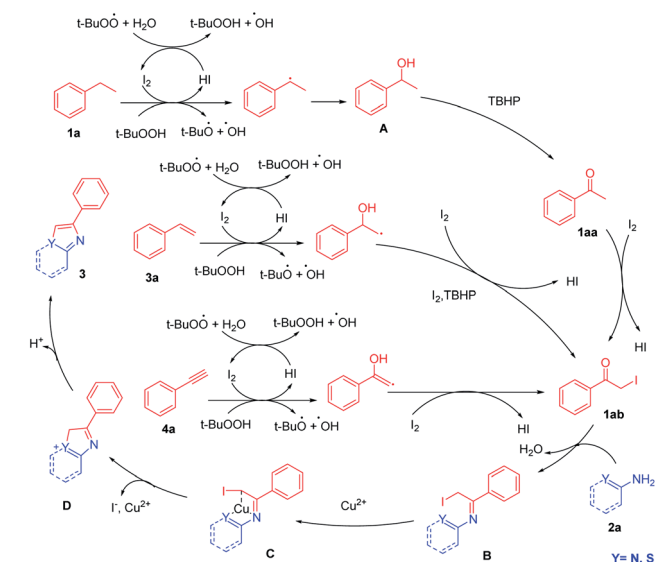
The Reagents and solvents are commercially purchased and used directly unless otherwise mentioned. All reactions were carried out in a sealed Schlenk tubes and monitored by TLC. Flash column chromatography was performed with silica gel (300–400 mesh).  $^1H$  and  $^{13}C$  NMR spectra were recorded on a Bruker Avance 400 instrument (400 MHz for  $^1H$  and 101 MHz for  $^{13}C$  NMR spectroscopy). Data were reported as chemical shifts in ppm relative to TMS (0.00 ppm) for  $^1H$  and  $CDCl_3$  (77.16 ppm) or  $DMSO-d_6$  (39.52 ppm) for  $^{13}C$ . HRMS spectra were measured on a Q-TOF instrument in positive-ion mode with an ESI ion source.

### General procedure for substrates

Ethyl arenes or ethylene arenes or ethyne arenes (1.0 mmol),  $I_2$  (0.40 mmol), *tert*-butyl hydroperoxide (TBHP, 3.5 mmol, 70%, aq. solution) were placed in a sealed tube equipped with a magnetic stirring bar. These mixtures were stirred and reacted at 120 °C for 1–1.5 h. After disappearance of the reactant monitored by TLC, 2-aminopyridine (2.0 mmol) and  $CuCl_2$  (0.5 mmol) in DMF (3 mL) was added to the sealed tube at 110 °C and heated for 2 h. After the reaction, 30 mL of saturated  $Na_2S_2O_3$  solution was added to the reaction solution to quench the remaining iodine. Then the solution was extracted with ethyl acetate (3  $\times$  30 mL), dried over anhydrous  $Na_2SO_4$ . The solid was removed by filtration, and the solution was concentrated under vacuum. The residue was purified through silica gel eluting with ethyl acetate/hexanes to give the product.

### Characterization data for the products

**2-Phenylimidazo[1,2-a]pyridine (3aa).** White solid was obtained in 82% isolated yield, mp = 135–137 °C.  $^1H$  NMR (400 MHz,  $DMSO-d_6$ )  $\delta$  8.53 (dt,  $J$  = 6.8, 1.2 Hz, 1H), 8.40 (s, 1H),



Scheme 5 The proposed reaction mechanism.

8.02–7.94 (m, 2H), 7.59 (dd,  $J = 9.1, 1.0$  Hz, 1H), 7.45 (t,  $J = 7.6$  Hz, 2H), 7.37–7.29 (m, 1H), 7.25 (ddd,  $J = 9.1, 6.7, 1.3$  Hz, 1H), 6.90 (td,  $J = 6.7, 1.2$  Hz, 1H).  $^{13}\text{C}$  NMR (101 MHz, DMSO- $d_6$ )  $\delta$  145.29, 144.82, 134.39, 129.18, 128.17, 127.35, 126.04, 124.99, 117.11, 112.74, 109.57. HRMS  $m/z$  (ESI) calcd for  $[\text{C}_{13}\text{H}_{10}\text{N}_2 + \text{H}]^+$ : 195.0917 found: 195.0911.

**2-(*o*-Tolyl)imidazo[1,2-*a*]pyridine (3ba).** White solid was obtained in 64% isolated yield, mp = 101–103 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  6.68 (d,  $J = 6.8$  Hz, 1H), 6.47 (d,  $J = 6.7$  Hz, 1H), 6.40–6.10 (m, 2H), 5.83 (s, 3H), 5.80–5.59 (m, 1H), 5.33 (t,  $J = 6.7$  Hz, 1H), 1.11 (s, 3H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  145.24, 144.65, 135.77, 133.22, 130.92, 129.73, 127.81, 126.04, 125.57, 124.66, 117.51, 112.33, 110.78, 22.66. HRMS  $m/z$  (ESI) calcd for  $[\text{C}_{14}\text{H}_{12}\text{N}_2 + \text{H}]^+$ : 209.1079 found: 209.1078.

**2-(*p*-Tolyl)imidazo[1,2-*a*]pyridine (3ca).** White solid was obtained in 85% isolated yield, mp = 144–145 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.01 (d,  $J = 6.7$  Hz, 1H), 7.83 (d,  $J = 8.2$  Hz, 2H), 7.75 (s, 1H), 7.60 (d,  $J = 9.1$  Hz, 1H), 7.23 (d,  $J = 7.9$  Hz, 2H), 7.11 (ddd,  $J = 9.1, 6.8, 1.3$  Hz, 1H), 6.69 (td,  $J = 6.7, 1.2$  Hz, 1H), 2.37 (s, 3H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  145.85, 145.59, 137.79, 130.95, 129.45, 125.93, 125.55, 124.52, 117.37, 112.28, 107.80, 21.33. HRMS  $m/z$  (ESI) calcd for  $[\text{C}_{14}\text{H}_{12}\text{N}_2 + \text{H}]^+$ : 209.1079 found: 209.1079.

**2-(4-Chlorophenyl)imidazo[1,2-*a*]pyridine (3da).** White solid was obtained in 84% isolated yield, mp = 202–205 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.10–7.91 (m, 2H), 7.80–7.70 (m, 2H), 7.53 (d,  $J = 9.1$  Hz, 1H), 7.35 (d,  $J = 8.9$  Hz, 1H), 7.20 (t,  $J = 7.9$  Hz, 1H), 7.13–7.05 (m, 1H), 6.69 (t,  $J = 6.8$  Hz, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  144.65, 143.58, 132.68, 131.18, 127.89, 126.23, 124.59, 123.98, 116.52, 111.64, 107.16. HRMS  $m/z$  (ESI) calcd for  $[\text{C}_{13}\text{H}_9\text{ClN}_2 + \text{H}]^+$ : 229.0533 found: 229.0524.

**2-(4-Fluorophenyl)imidazo[1,2-*a*]pyridine (3ea).** White solid was obtained in 78% isolated yield, mp = 163–165 °C.  $^1\text{H}$  NMR (600 MHz, DMSO- $d_6$ )  $\delta$  9.25–9.21 (m, 1H), 8.77 (s, 1H), 8.02–7.94 (m, 4H), 7.61 (dd,  $J = 8.4, 6.9$  Hz, 2H), 7.58–7.52 (m, 1H).  $^{13}\text{C}$  NMR (151 MHz, DMSO- $d_6$ )  $\delta$  138.85, 136.65, 132.35, 129.78, 128.88, 128.68, 126.32, 126.28, 125.66, 122.61, 112.98, 110.77. HRMS  $m/z$  (ESI) calcd for  $[\text{C}_{13}\text{H}_9\text{FN}_2 + \text{H}]^+$ : 213.0829 found: 213.0813.

**2-(Naphthalen-1-yl)imidazo[1,2-*a*]pyridine (3fa).** White solid was obtained in 91% isolated yield, mp = 158–160 °C.  $^1\text{H}$  NMR (600 MHz,  $\text{CDCl}_3$ )  $\delta$  8.46 (dd,  $J = 1.7, 0.8$  Hz, 1H), 8.07 (dt,  $J = 6.8, 1.2$  Hz, 1H), 7.93 (dd,  $J = 8.5, 1.7$  Hz, 1H), 7.90 (d,  $J = 0.7$  Hz, 1H), 7.88–7.84 (m, 1H), 7.82 (d,  $J = 8.5$  Hz, 1H), 7.80–7.74 (m, 1H), 7.64 (dq,  $J = 9.1, 1.0$  Hz, 1H), 7.46–7.37 (m, 2H), 7.14 (ddd,  $J = 9.1, 6.7, 1.3$  Hz, 1H), 6.73 (td,  $J = 6.7, 1.2$  Hz, 1H).  $^{13}\text{C}$  NMR (151 MHz,  $\text{CDCl}_3$ )  $\delta$  145.54, 145.27, 133.73, 133.29, 130.51, 128.43, 128.39, 127.72, 126.35, 126.09, 125.70, 125.29, 124.96, 124.10, 117.36, 112.80, 108.60. HRMS  $m/z$  (ESI) calcd for  $[\text{C}_{17}\text{H}_{12}\text{N}_2 + \text{H}]^+$ : 245.1079 found: 245.1060.

**2,3-Diphenylimidazo[1,2-*a*]pyridine (3ga).** White solid was obtained in 43% isolated yield, mp = 149–151 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.95 (d,  $J = 6.9$  Hz, 1H), 7.68 (t,  $J = 7.7$  Hz, 3H), 7.57–7.40 (m, 5H), 7.34–7.14 (m, 4H), 6.72 (t,  $J = 6.8$  Hz, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  144.78, 142.33, 134.11, 130.74, 129.84, 129.58, 128.93, 128.30, 128.12, 127.52, 124.78, 123.31, 121.10,

117.53, 112.34. HRMS  $m/z$  (ESI) calcd for  $[\text{C}_{19}\text{H}_{14}\text{N}_2 + \text{H}]^+$ : 271.1236 found: 271.1231.

**2-(4-(Methylsulfonyl)phenyl)imidazo[1,2-*a*]pyridine (3ha).** White solid was obtained in 73% isolated yield, mp = 242–244 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.21–8.13 (m, 3H), 8.05–7.96 (m, 3H), 7.67 (d,  $J = 9.2$  Hz, 1H), 7.25 (ddd,  $J = 9.1, 6.7, 1.3$  Hz, 1H), 6.85 (td,  $J = 6.8, 1.2$  Hz, 1H), 3.11 (s, 3H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  145.98, 143.57, 139.28, 139.26, 127.94, 126.60, 125.86, 125.57, 117.87, 113.11, 109.69, 44.64. HRMS  $m/z$  (ESI) calcd for  $[\text{C}_{14}\text{H}_{12}\text{N}_2\text{O}_2\text{S} + \text{H}]^+$ : 273.0698 found: 273.0680.

**2-(4-Methoxyphenyl)imidazo[1,2-*a*]pyridine (3ia).** White solid was obtained in 89% isolated yield, mp = 133–135 °C.  $^1\text{H}$  NMR (600 MHz,  $\text{CDCl}_3$ )  $\delta$  7.95 (dq,  $J = 6.7, 1.1$  Hz, 1H), 7.81–7.76 (m, 2H), 7.65–7.61 (m, 1H), 7.51 (dt,  $J = 9.1, 1.1$  Hz, 1H), 7.03 (ddt,  $J = 9.2, 6.7, 1.3$  Hz, 1H), 6.90–6.84 (m, 2H), 6.62 (tt,  $J = 6.7, 1.4$  Hz, 1H), 3.74 (d,  $J = 1.0$  Hz, 3H).  $^{13}\text{C}$  NMR (151 MHz,  $\text{CDCl}_3$ )  $\delta$  159.61, 145.63, 145.57, 127.31, 126.44, 125.49, 124.50, 117.20, 114.15, 112.25, 107.26, 55.31. HRMS  $m/z$  (ESI) calcd for  $[\text{C}_{14}\text{H}_{12}\text{N}_2\text{O} + \text{H}]^+$ : 225.1029 found: 225.1029.

**2-(4-(Trifluoromethyl)phenyl)imidazo[1,2-*a*]pyridine (3ja).** White solid was obtained in 87% isolated yield, mp = 196–198 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  6.68–6.56 (m, 3H), 6.44 (s, 1H), 6.20 (d,  $J = 8.2$  Hz, 3H), 5.76 (dd,  $J = 15.4, 8.7$  Hz, 1H), 5.34 (d,  $J = 6.7$  Hz, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  145.65, 143.91, 136.91, 129.97, 129.64, 126.16, 125.75 (q,  $J = 4.4$  Hz), 125.54, 122.90, 117.62, 113.05, 109.05. HRMS  $m/z$  (ESI) calcd for  $[\text{C}_{14}\text{H}_9\text{F}_3\text{N}_2 + \text{H}]^+$ : 263.0797 found: 263.0794.

**2-(4-Nitrophenyl)imidazo[1,2-*a*]pyridine (3ka).** Yellow solid was obtained in 85% isolated yield, mp = 258–261 °C.  $^1\text{H}$  NMR (600 MHz, DMSO- $d_6$ )  $\delta$  8.65 (d,  $J = 0.7$  Hz, 1H), 8.58 (dt,  $J = 6.8, 1.3$  Hz, 1H), 8.34–8.29 (m, 2H), 8.26–8.21 (m, 2H), 7.63 (dt,  $J = 9.1, 1.0$  Hz, 1H), 7.31 (ddd,  $J = 9.1, 6.7, 1.3$  Hz, 1H), 6.96 (td,  $J = 6.8, 1.2$  Hz, 1H).  $^{13}\text{C}$  NMR (151 MHz, DMSO- $d_6$ )  $\delta$  146.96, 145.73, 142.47, 140.99, 127.74, 126.78, 126.40, 124.67, 117.47, 113.41, 112.17. HRMS  $m/z$  (ESI) calcd for  $[\text{C}_{13}\text{H}_9\text{N}_3\text{O}_2 + \text{H}]^+$ : 240.0774 found: 240.0766.

**2-(Furan-2-yl)imidazo[1,2-*a*]pyridine (3la).** White solid was obtained in 81% isolated yield, mp = 88–90 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.98 (dt,  $J = 6.8, 1.3$  Hz, 1H), 7.68 (s, 1H), 7.50 (d,  $J = 9.0$  Hz, 1H), 7.38 (d,  $J = 1.1$  Hz, 1H), 7.07 (ddd,  $J = 9.2, 6.8, 1.3$  Hz, 1H), 6.81 (d,  $J = 2.6$  Hz, 1H), 6.66 (td,  $J = 6.8, 1.2$  Hz, 1H), 6.42 (dd,  $J = 3.4, 1.8$  Hz, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  148.57, 144.53, 141.02, 136.88, 124.63, 123.95, 116.30, 111.49, 110.56, 106.83, 105.65. HRMS  $m/z$  (ESI) calcd for  $[\text{C}_{11}\text{H}_8\text{N}_2\text{O} + \text{H}]^+$ : 185.0716 found: 185.0696.

**2-(Thiophen-2-yl)imidazo[1,2-*a*]pyridine (3ma).** White solid was obtained in 76% isolated yield, mp = 136–138 °C.  $^1\text{H}$  NMR (600 MHz,  $\text{CDCl}_3$ )  $\delta$  7.84 (dt,  $J = 6.7, 1.2$  Hz, 1H), 7.54 (d,  $J = 0.7$  Hz, 1H), 7.44 (dq,  $J = 9.1, 1.0$  Hz, 1H), 7.31 (dd,  $J = 3.6, 1.2$  Hz, 1H), 7.16 (dd,  $J = 5.0, 1.2$  Hz, 1H), 6.99–6.91 (m, 2H), 6.55 (td,  $J = 6.7, 1.2$  Hz, 1H).  $^{13}\text{C}$  NMR (151 MHz,  $\text{CDCl}_3$ )  $\delta$  145.35, 140.71, 137.55, 127.78, 125.50, 125.02, 124.86, 123.69, 117.10, 112.51, 107.50. HRMS  $m/z$  (ESI) calcd for  $[\text{C}_{11}\text{H}_8\text{N}_2\text{S} + \text{H}]^+$ : 201.0487 found: 201.0468.

**2-(3-Chlorophenyl)imidazo[1,2-*a*]pyridine (3na).** White solid was obtained in 62% isolated yield, mp = 107–109 °C.  $^1\text{H}$  NMR (600 MHz,  $\text{CDCl}_3$ )  $\delta$  8.05 (dt,  $J = 6.8, 1.2$  Hz, 1H), 7.89 (t,  $J =$



1.9 Hz, 1H), 7.78 (d,  $J = 0.7$  Hz, 1H), 7.76 (dt,  $J = 7.7, 1.4$  Hz, 1H), 7.58 (dq,  $J = 9.1, 1.0$  Hz, 1H), 7.29 (t,  $J = 7.8$  Hz, 1H), 7.22 (dd,  $J = 7.9, 2.1, 1.1$  Hz, 1H), 7.13 (dd,  $J = 9.1, 6.7, 1.3$  Hz, 1H), 6.74 (td,  $J = 6.7, 1.2$  Hz, 1H).  $^{13}\text{C}$  NMR (151 MHz,  $\text{CDCl}_3$ )  $\delta$  145.55, 144.14, 135.33, 134.79, 130.03, 128.03, 126.13, 125.73, 125.30, 124.14, 117.55, 112.89, 108.55. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{13}\text{H}_9\text{ClN}_2 + \text{H}]^+$ : 229.0533 found: 229.0516.

#### 2-(5-Bromothiophen-2-yl)imidazo[1,2-*a*]pyridine (30a).

White solid was obtained in 68% isolated yield, mp = 140–142 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  6.60 (d,  $J = 6.8$  Hz, 1H), 6.38–6.08 (m, 2H), 5.89–5.69 (m, 2H), 5.55 (d,  $J = 3.8$  Hz, 1H), 5.33 (t,  $J = 6.7$  Hz, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  145.14, 139.49, 138.49, 137.85, 130.72, 125.61, 124.23, 117.16, 113.09, 112.16, 107.42. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{11}\text{H}_7\text{BrN}_2\text{S} + \text{H}]^+$ : 278.9592 found: 278.9573.

#### 2-(2-(Trifluoromethyl)phenyl)imidazo[1,2-*a*]pyridine (3pa).

White solid was obtained in 43% isolated yield, mp = 90–92 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.05 (dt,  $J = 6.8, 1.2$  Hz, 1H), 7.91 (d,  $J = 7.4$  Hz, 1H), 7.73 (s, 1H), 7.68 (d,  $J = 6.6$  Hz, 1H), 7.59–7.52 (m, 2H), 7.38 (t,  $J = 7.7$  Hz, 1H), 7.11 (dd,  $J = 9.1, 6.8, 1.3$  Hz, 1H), 6.72 (td,  $J = 6.8, 1.2$  Hz, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  143.72, 141.27, 132.25, 131.55, 130.72, 126.78, 126.45, 125.05 (q,  $J = 5.8$  Hz), 124.68, 123.89, 121.96, 116.67, 111.58, 110.41. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{14}\text{H}_9\text{F}_3\text{N}_2 + \text{H}]^+$ : 263.0797 found: 263.0796.

2-(2-Fluorophenyl)imidazo[1,2-*a*]pyridine (3qa). White solid was obtained in 67% isolated yield, mp = 94–97 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.29 (td,  $J = 7.6, 2.7$  Hz, 1H), 8.04 (dt,  $J = 6.8, 1.2$  Hz, 1H), 7.97 (d,  $J = 3.9$  Hz, 1H), 7.56 (dd,  $J = 9.1, 1.0$  Hz, 1H), 7.27–7.15 (m, 2H), 7.13–7.03 (m, 2H), 6.70 (td,  $J = 6.8, 1.2$  Hz, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  160.51, 158.04, 143.77, 138.07, 127.85 ( $J = 8.6$  Hz), 124.71, 123.98, 123.47 ( $J = 3.3$  Hz), 120.42 ( $J = 12.2$  Hz), 116.39, 114.62 ( $J = 22.1$  Hz), 111.46, 111.06 ( $J = 15.2$  Hz). HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{13}\text{H}_9\text{FN}_2 + \text{H}]^+$ : 213.0829 found: 213.0826.

2-(3-Fluorophenyl)imidazo[1,2-*a*]pyridine (3ra). White solid was obtained in 65% isolated yield, mp = 101–103 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.09 (dt,  $J = 6.8, 1.2$  Hz, 1H), 7.83 (s, 1H), 7.77–7.57 (m, 3H), 7.38 (td,  $J = 8.0, 5.9$  Hz, 1H), 7.17 (dd,  $J = 9.1, 6.8, 1.3$  Hz, 1H), 7.01 (tdd,  $J = 8.4, 2.7, 1.0$  Hz, 1H), 6.78 (td,  $J = 6.8, 1.2$  Hz, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  164.49, 162.05, 145.65, 144.56 ( $J = 2.8$  Hz), 136.06 ( $J = 8.3$  Hz), 130.21 ( $J = 8.3$  Hz), 125.66, 125.01, 121.58 ( $J = 2.9$  Hz), 117.61, 114.71 ( $J = 21.4$  Hz), 112.80 ( $J = 22.1$  Hz), 108.54. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{13}\text{H}_9\text{FN}_2 + \text{H}]^+$ : 213.0829 found: 213.081.

6-Methyl-2-phenylimidazo[1,2-*a*]pyridine (3ab). White solid was obtained in 74% isolated yield, mp = 176–177 °C.  $^1\text{H}$  NMR (600 MHz,  $\text{CDCl}_3$ )  $\delta$  7.89–7.84 (m, 2H), 7.81 (dq,  $J = 2.1, 1.1$  Hz, 1H), 7.68 (d,  $J = 0.7$  Hz, 1H), 7.47 (d,  $J = 9.1$  Hz, 1H), 7.38–7.32 (m, 2H), 7.27–7.21 (m, 1H), 6.94 (dd,  $J = 9.2, 1.7$  Hz, 1H), 2.23 (d,  $J = 1.1$  Hz, 3H).  $^{13}\text{C}$  NMR (151 MHz,  $\text{CDCl}_3$ )  $\delta$  145.30, 144.63, 133.71, 128.72, 128.03, 127.89, 125.96, 123.35, 122.19, 116.76, 107.86, 18.12. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{14}\text{H}_{12}\text{N}_2 + \text{H}]^+$ : 209.1079 found: 209.1074.

#### 2-Phenyl-6-(trifluoromethyl)imidazo[1,2-*a*]pyridine (3ac).

White solid was obtained in 67% isolated yield, mp = 165–166 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.42 (s, 1H), 7.88 (dd,  $J =$

9.8, 1.6 Hz, 3H), 7.66 (d,  $J = 9.5$  Hz, 1H), 7.39 (t,  $J = 7.5$  Hz, 2H), 7.33–7.22 (m, 2H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  146.69, 144.26, 131.81, 127.86, 127.63, 125.21, 123.55 (q,  $J = 5.9$  Hz), 121.15, 119.61 (q,  $J = 2.7$  Hz), 117.10, 115.74, 108.19. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{14}\text{H}_9\text{F}_3\text{N}_2 + \text{H}]^+$ : 263.0797 found: 263.0794.

2-Phenylimidazo[2,1-*a*]isoquinoline (3ad). White solid was obtained in 62% isolated yield, mp = 144–146 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.74 (d,  $J = 7.9$  Hz, 1H), 8.01 (d,  $J = 6.8$  Hz, 2H), 7.86 (d,  $J = 7.2$  Hz, 1H), 7.79 (s, 1H), 7.70–7.60 (m, 2H), 7.59–7.52 (m, 1H), 7.45 (t,  $J = 7.7$  Hz, 2H), 7.32 (t,  $J = 7.3$  Hz, 1H), 7.00 (d,  $J = 7.2$  Hz, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  143.97, 143.28, 133.95, 129.51, 128.76, 128.20, 128.15, 127.65, 126.97, 125.89, 123.80, 123.55, 122.97, 113.17, 109.88. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{17}\text{H}_{12}\text{N}_2 + \text{H}]^+$ : 245.1079 found: 245.1072.

6-Chloro-2-phenylimidazo[1,2-*a*]pyridine (3ae). White solid was obtained in 63% isolated yield, mp = 206–209 °C.  $^1\text{H}$  NMR (600 MHz,  $\text{DMSO}-d_6$ )  $\delta$  9.25–9.21 (m, 1H), 8.77 (s, 1H), 8.02–7.98 (m, 3H), 7.96 (dd,  $J = 9.5, 1.9$  Hz, 1H), 7.61 (dd,  $J = 8.4, 6.9$  Hz, 2H), 7.58–7.52 (m, 1H).  $^{13}\text{C}$  NMR (151 MHz,  $\text{DMSO}-d_6$ )  $\delta$  138.85, 136.65, 132.35, 129.78, 128.88, 126.32, 126.28, 125.66, 122.61, 112.98, 110.77. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{13}\text{H}_9\text{ClN}_2 + \text{H}]^+$ : 229.0533 found: 229.0525.

6-Fluoro-2-phenylimidazo[1,2-*a*]pyridine (3af). White solid was obtained in 75% isolated yield, mp = 186–189 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.97–7.90 (m, 1H), 7.83 (d,  $J = 6.9$  Hz, 2H), 7.74 (s, 1H), 7.56 (dd,  $J = 9.8, 5.1$  Hz, 1H), 7.41–7.17 (m, 3H), 7.00 (dd,  $J = 10.2, 8.0, 2.4$  Hz, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  152.27 ( $J = 237$  Hz), 151.10, 145.83, 142.27, 132.16, 127.77, 127.21, 124.97, 116.25 ( $J = 118$  Hz), 111.18 ( $J = 41$  Hz), 108.49. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{13}\text{H}_9\text{FN}_2 + \text{H}]^+$ : 213.0829 found: 213.0830.

6-Bromo-2-phenylimidazo[1,2-*a*]pyridine (3ag). White solid was obtained in 68% isolated yield, mp = 184–186 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.19 (s, 1H), 7.86 (d,  $J = 7.0$  Hz, 2H), 7.75 (s, 1H), 7.49 (d,  $J = 9.6$  Hz, 1H), 7.37 (t,  $J = 8.0$  Hz, 2H), 7.28 (t,  $J = 7.4$  Hz, 1H), 7.17 (dd,  $J = 9.5, 1.8$  Hz, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  145.31, 142.88, 131.86, 127.81, 127.40, 127.34, 125.08, 123.41, 116.98, 107.25, 106.53. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{13}\text{H}_9\text{BrN}_2 + \text{H}]^+$ : 273.0028 found: 273.0031.

7-Bromo-2-phenylimidazo[1,2-*a*]pyridine (3ah). White solid was obtained in 63% isolated yield, mp = 180–182 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.92 (d,  $J = 7.4$  Hz, 1H), 7.89–7.83 (m, 2H), 7.77 (d,  $J = 3.7$  Hz, 2H), 7.37 (t,  $J = 7.5$  Hz, 2H), 7.32–7.17 (m, 1H), 6.83 (dd,  $J = 7.1, 1.9$  Hz, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  145.20, 144.52, 131.81, 127.81, 127.40, 125.08, 124.75, 118.57, 117.63, 115.56, 107.26. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{13}\text{H}_9\text{BrN}_2 + \text{H}]^+$ : 273.0028 found: 273.0030.

6-Nitro-2-phenylimidazo[1,2-*a*]pyridine (3ai). Yellow solid was obtained in 57% isolated yield, mp = 171–173 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{DMSO}-d_6$ )  $\delta$  9.84 (d,  $J = 2.3$  Hz, 1H), 8.63 (s, 1H), 8.01 (d,  $J = 6.9$  Hz, 2H), 7.96 (dd,  $J = 9.9, 2.3$  Hz, 1H), 7.75 (d,  $J = 9.9$  Hz, 1H), 7.54–7.45 (m, 2H), 7.40 (t,  $J = 7.3$  Hz, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{DMSO}-d_6$ )  $\delta$  147.91, 145.46, 136.97, 133.16, 129.44, 129.15, 128.55, 126.40, 119.54, 116.52, 112.16. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{13}\text{H}_9\text{N}_3\text{O}_2 + \text{H}]^+$ : 240.0774 found: 240.0769.

4-Phenylthiazol-2-amine (3aj). White solid was obtained in 79% isolated yield, mp = 147–149 °C.  $^1\text{H}$  NMR (400 MHz,





$\text{CDCl}_3$ )  $\delta$  7.73–7.65 (m, 2H), 7.31 (dd,  $J$  = 8.3, 6.7 Hz, 2H), 7.26–7.16 (m, 1H), 6.64 (s, 1H), 5.22 (s, 2H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  166.42, 150.10, 133.53, 127.58, 126.73, 124.95, 101.70. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_9\text{H}_8\text{N}_2\text{S} + \text{H}]^+$ : 177.0487 found: 177.0479.

**2,4-Diphenylthiazole (3ak).** White solid was obtained in 86% isolated yield, mp = 101–104 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.00–7.89 (m, 4H), 7.36 (m,  $J$  = 7.9, 5.8 Hz, 6H), 7.30–7.24 (m, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  167.90, 156.31, 134.55, 133.79, 130.08, 128.96, 128.78, 128.21, 126.65, 126.49, 112.66. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{15}\text{H}_{11}\text{NS} + \text{H}]^+$ : 238.0688 found: 238.0680.

**2-Phenylbenzo[d]imidazo[2,1-*b*]thiazole (3al).** White solid was obtained in 82% isolated yield, mp = 142–146 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.86 (s, 1H), 7.79 (d,  $J$  = 7.0 Hz, 2H), 7.60 (d,  $J$  = 8.1 Hz, 1H), 7.50 (d,  $J$  = 9.2 Hz, 1H), 7.39–7.29 (m, 3H), 7.28–7.15 (m, 2H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  147.03, 146.57, 132.74, 131.08, 129.21, 127.69, 126.48, 125.14, 124.13, 123.82, 123.33, 111.59, 105.81. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{15}\text{H}_{10}\text{N}_2\text{S} + \text{H}]^+$ : 251.0644 found: 251.0639.

**Methyl 2-phenylimidazo[1,2-*a*]pyridine-6-carboxylate (3am).** White solid was obtained in 55% isolated yield, mp = 174–175 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.81 (dd,  $J$  = 1.7, 1.0 Hz, 1H), 7.92–7.85 (m, 2H), 7.83 (s, 1H), 7.64 (dd,  $J$  = 9.4, 1.7 Hz, 1H), 7.55 (d,  $J$  = 9.4 Hz, 1H), 7.37 (dd,  $J$  = 8.2, 6.7 Hz, 2H), 7.32–7.25 (m, 1H), 3.88 (s, 3H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  164.27, 146.53, 145.04, 131.96, 128.74, 127.80, 127.50, 125.17, 123.38, 115.66, 115.48, 107.91, 51.43. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{15}\text{H}_{12}\text{N}_2\text{O}_2 + \text{H}]^+$ : 253.0978 found: 253.0976.

**6-Methoxy-2-phenylimidazo[1,2-*a*]pyridine (3an).** White solid was obtained in 81% isolated yield, mp = 102–105 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  7.85 (d,  $J$  = 7.1 Hz, 2H), 7.73 (s, 1H), 7.57 (d,  $J$  = 2.3 Hz, 1H), 7.47 (d,  $J$  = 9.8 Hz, 1H), 7.36 (t,  $J$  = 7.7 Hz, 2H), 7.21 (d,  $J$  = 14.2 Hz, 1H), 6.90 (dd,  $J$  = 9.7, 2.4 Hz, 1H), 3.75 (s, 3H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  148.36, 141.59, 132.57, 129.90, 127.71, 126.82, 124.77, 119.04, 116.53, 108.17, 106.40, 55.15. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{14}\text{H}_{12}\text{N}_2\text{O} + \text{H}]^+$ : 225.1029 found: 225.1034.

**2-Phenylimidazo[1,2-*a*]pyridine-6-carbonitrile (3ao).** White solid was obtained in 51% isolated yield, mp = 240–243 °C.  $^1\text{H}$  NMR (600 MHz,  $\text{CDCl}_3$ )  $\delta$  8.50 (t,  $J$  = 1.3 Hz, 1H), 7.92–7.86 (m, 3H), 7.65 (d,  $J$  = 9.3 Hz, 1H), 7.40 (dd,  $J$  = 8.4, 6.9 Hz, 2H), 7.35–7.29 (m, 1H), 7.22 (dd,  $J$  = 9.3, 1.7 Hz, 1H).  $^{13}\text{C}$  NMR (151 MHz,  $\text{CDCl}_3$ )  $\delta$  148.21, 144.69, 132.26, 131.52, 129.06, 128.99, 126.38, 124.72, 118.39, 116.47, 108.97, 98.83. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{14}\text{H}_9\text{N}_3 + \text{H}]^+$ : 220.0875 found: 220.0869.

**2,6-Diphenylimidazo[1,2-*a*]pyridine (3ap).** White solid was obtained in 66% isolated yield, mp = 178–180 °C.  $^1\text{H}$  NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  9.98 (s, 1H), 9.77 (s, 1H), 9.26 (d,  $J$  = 10.6 Hz, 1H), 8.50–8.16 (m, 5H), 7.75–6.94 (m, 5H), 6.86 (d,  $J$  = 8.2 Hz, 1H).  $^{13}\text{C}$  NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  161.99, 158.51, 150.01, 149.93, 147.54, 146.39, 137.89, 137.69, 119.19, 118.82, 114.11, 109.50. HRMS  $m/z$  (ESI): calcd for  $[\text{C}_{19}\text{H}_{14}\text{N}_2 + \text{H}]^+$ : 271.1236 found: 271.1243.

## Conflicts of interest

There are no conflicts to declare.

## Acknowledgements

We are grateful to the National Science Foundation of China (no. 21572117) and the Shandong Key Research Program (no. 2019JZZY021015 and 2019GHY112053) for their financial support. We are also grateful to the Analytical Center for Structural Constituent and Physical Property of Core Facilities Sharing Platform, Shandong University for their technology and service support.

## Notes and references

- (a) I. B. Sayeed, V. Lakshma Nayak, M. A. Shareef, N. K. Chouhan and A. Kamal, *MedChemComm*, 2017, **8**, 1000–1006; (b) R. Lefin, M. M. van der Walt, P. J. Milne and G. Terre'Blanche, *Bioorg. Med. Chem. Lett.*, 2017, **27**, 3963–3967; (c) B. S. Santaniello, M. J. Price and J. K. Murray Jr, *J. Chem. Educ.*, 2017, **94**, 388–391; (d) A. R. Katritzky, Y. J. Xu and H. J. Tu, *Org. Chem.*, 2003, **68**, 4935–4937; (e) R. Martin, M. Rodriguez Rivero and S. L. Buchwald, *Angew. Chem., Int. Ed.*, 2006, **45**, 7079–7082.
- A. J. Stasyuk, M. Banasiewicz, M. K. Cyrański and D. T. Gryko, *J. Org. Chem.*, 2012, **77**, 5552–5558.
- (a) S. Z. Langer, S. Arbilla, J. Benavides and B. Scatton, *Adv. Biochem. Psychopharmacol.*, 1990, **46**, 61; (b) K. Mizushige, T. Ueda, K. Yukiiri and H. Suzuki, *Cardiovasc. Drug Rev.*, 2002, **20**, 163; (c) L. Almirante, L. Polo, A. Mugnaini, E. Provinciali, P. Rugarli, A. Biancotti, A. Gamba and W. Murmann, *J. Med. Chem.*, 1965, **8**, 305; (d) R. J. Boerner and H. J. Moller, *Psychopharmakother.*, 1997, **4**, 145; (e) N. Gunaganti, A. Kharbanda, N. R. Lakkaniga, L. Zhang, R. Cooper, H. Y. Li and B. Frett, *Chem. Commun.*, 2018, **54**, 12954–12957; (f) T. Guo, J. J. Liang, S. Yang, H. Chen, Y. N. Fu, S. L. Han and Y. H. Zhao, *Org. Biomol. Chem.*, 2018, **16**, 6039–6046.
- (a) S. Ulloora, A. V. Adhikari and R. Shabaraya, *Chin. Chem. Lett.*, 2013, **24**, 853–856; (b) A. Herath, R. Dahl and N. D. P. Cosford, *Org. Lett.*, 2010, **12**, 412–415.
- (a) M.-L. Feng, S.-Q. Li, S.-Y. Chen and X.-Q. Yu, *Green Chem.*, 2019, **21**, 1619–1624; (b) D. C. Mohan, S. N. Rao, C. Ravi and S. Adimurthy, *Asian J. Org. Chem.*, 2014, **3**, 609–613; (c) W. Ge, X. Zhu and Y. Wei, *Eur. J. Org. Chem.*, 2013, **27**, 6015–6020.
- L. Chen, H. Zhu, J. Wang and H. Liu, *Molecules*, 2019, **24**(5), 893/1–893/13.
- (a) H. Shinde Mahesh and A. Kshirsagar Umesh, *Green Chem.*, 2016, **18**(6), 1455–1458; (b) S. Samanta, S. Jana, S. Mondal, K. Monir, S. K. Chandraa and A. Hajraa, *Org. Biomol. Chem.*, 2016, **14**(22), 5073–5078; (c) A. Das and K. R. Justin Thomas, *Asian J. Org. Chem.*, 2020, **9**(11), 1820–1825.
- (a) S. k. Rasheed, D. N. Rao and P. Das, *Asian J. Org. Chem.*, 2016, **5**(10), 1213–1218; (b) S. K. Samantaa and M. K. Bera, *Org. Biomol. Chem.*, 2019, **17**(26), 6441–6449; (c) E. P. A. Talbot, M. Richardson, J. M. McKenna and F. D. Toste, *Adv. Synth. Catal.*, 2014, **356**(4), 687–691; (d) C. He, J. Hao, H. Xu, Y. Mo, H. Liu, J. Han and A. Lei, *Chem. Commun.*, 2012, **48**(90), 11073–11075; (e) P. Starkov,





- F. Rota, J. M. D'Oyley and T. D. Sheppard, *Adv. Synth. Catal.*, 2012, **354**(17), 3217–3224; (f) J. Zeng, Y. J. Tan and X.-W. Liu, *Org. Lett.*, 2012, **14**, 4386–4389; (g) Y. Gao, M. Yin and H. Jiang, *Adv. Synth. Catal.*, 2013, **355**, 2263–2273.
- 9 (a) B. Hoi and P. H. Ng, *J. Org. Chem.*, 1954, **19**, 1370–1375; (b) E. S. Hand and W. W. Paudler, *J. Org. Chem.*, 1978, **43**(4), 658–663.
- 10 (a) C. S. Kerem, G. Sertac and E. Erhan, *J. Forensic Sci.*, 2016, **61**, 551–554; (b) M. M. Roberto, *Med. Sci. Law*, 2020, **39**, 79–84; (c) L. Annie, S. Andrew and S. Hoffman Robert, *J. Emerg. Med.*, 2007, **32**, 309–310.
- 11 (a) T.-K. Ariana, H. Jurn and K. Rajamani, *Langmuir*, 2015, **12**, 3771–3778; (b) B. Cao, H. Hinode and T. Kajiuchi, *J. Membr. Sci.*, 1999, **156**, 43–47; (c) M. Michael, V. Frederik and A. Luc, *J. Am. Chem. Soc.*, 2010, **132**(43), 15277–15285.
- 12 (a) C. Yu and H. Xu, *Sep. Purif. Technol.*, 2011, **78**, 249–252; (b) V. Zhyznevskiy, R. Tsybukh and V. Gumenetskiy, *React. Kinet. Catal. L.*, 2000, **71**, 209–215; (c) R. Watanabe, S. Yasushi and M. Masahiko, *Catal. Lett.*, 2009, **131**, 54–58.
- 13 (a) K.-P. Shing, B. Cao and C.-M. Che, *J. Am. Chem. Soc.*, 2018, **140**, 7032–7042; (b) G. Urgoitia, R. SanMartin and E. Domínguez, *Chem. Commun.*, 2015, **51**, 4799–4802; (c) M. Munkir Hossain and S.-G. Shyu, *Tetrahedron*, 2016, **72**(29), 4252–4257.
- 14 (a) K. K. Durga Rao Viswanadham, M. Prathap Reddy, P. Sathyanarayana, O. Ravi, R. Kant and S. Reddy Bathula, *Chem. Commun.*, 2014, **50**(88), 13517–13520; (b) S. Guha, K. Imran, P. Mukherjee and G. Sekar, *Chem. Commun.*, 2017, **53**(79), 10942–10945; (c) Y.-p. Zhu, F.-c. Jia, M.-c. Liu and A.-x. Wu, *Org. Lett.*, 2012, **14**(17), 4414–4417.
- 15 (a) Q. Cai, M.-C. Liu, B.-M. Mao, X. Xie, F.-C. Jia, Y.-P. Zhu and A.-X. Wu, *Chin. Chem. Lett.*, 2015, **26**, 881–884; (b) K. S. Vadagaonkar, H. P. Kalmode, K. Murugan and A. C. Chaskar, *RSC Adv.*, 2015, **5**, 5580–5590; (c) H. P. Kalmode, K. S. Vadagaonkar and A. C. Chaskar, *RSC Adv.*, 2014, **4**, 60316–60326.

