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Graphical Abstract.

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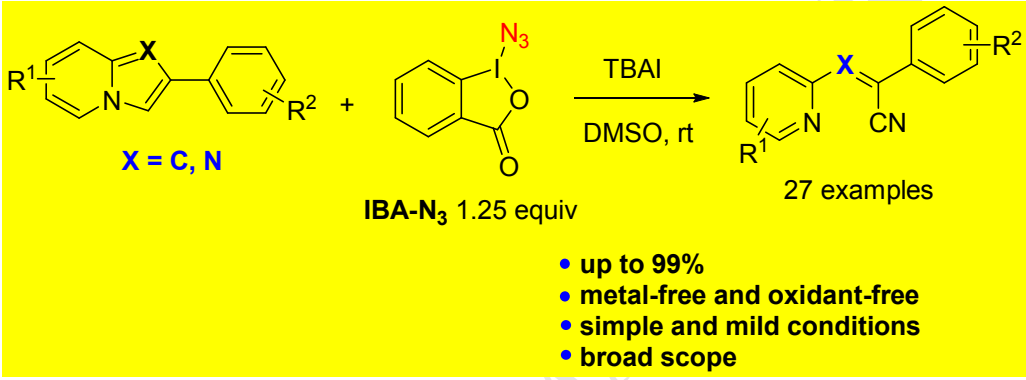
A mild, metal-free and efficient synthesis of 2,3-disubstituted acrylonitriles and α-iminonitriles from pyridine fused heterocycles has been developed. This transformation has demonstrated broad substrate scope, excellent functional group tolerance, mild reaction conditions, which will make make this procedure practical and synthetically useful.



Radical Ring opening Reaction of Pyridine fused Heterocycles with IBA-N3 catalyzed by Tetra-n-butylammonium Iodide

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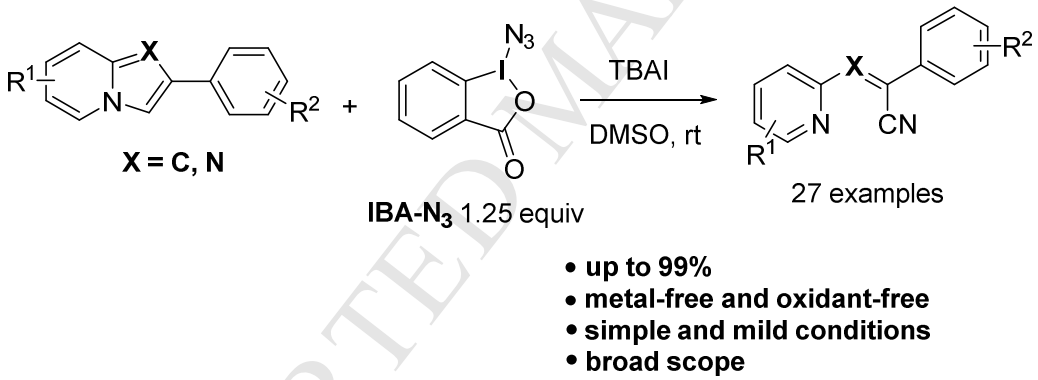
Abstract

A mild, metal-free and efficient synthesis of 2,3-disubstituted acrylonitriles and α-iminonitriles through radical ring opening reaction of pyridine fused heterocycles has been developed. The tetra-n-butylammonium iodide catalyst acts as a formal one-electron donor. Compared to the previous methods, which require excessive amounts of highly explosive azide sources and the addition of oxidants, this is a safe and convenient transformation.



Keywords: pyridine fused heterocycles; IBA-N_3; ring opening reaction

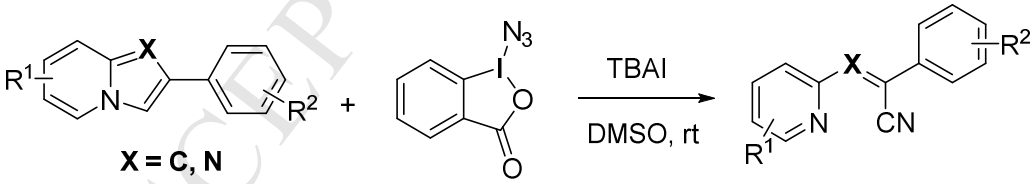
1. Introduction

Compounds with the nitrile functional group can be used as precursors in the manufacture of a large variety of consumer products, such as polyamides, pigments and dyes, pharmaceuticals, agrochemicals, and many other substances.[1] Moreover, nitriles are useful building blocks in the synthesis of heterocycles, as they can be readily converted into a variety of functional groups such as carboxylic acid, ketone, oxime, amine, amidine, etc.[2] 2,3-Disubstituted acrylonitriles represent an interesting class of biologically active compounds. These compounds have been shown to have spasmolytic,[3] estrogenic,[4] hypotensive,[5] antioxidative,[6] tuberculostatic,[7] antitrichomonal,[8] insecticidal,[9] and cytotoxic[10] activities. Bifunctional α-iminonitriles are common intermediates in organic synthesis and exhibit valuable dual reactivity, which have been used in a wide range of synthetic applications.[11] α-Iminonitriles have been viewed as precursors for the synthesis of other useful building blocks such as α-ketoacids, amides, amidines, N-alkylketene-imines and cyanoenamides.[12] Therefore, many chemical synthesis or chemical research areas can be

developed better if we use a safer and more convenient method to synthesize the compounds with the nitrile functional group.

The C-H bond functionalization strategy is an ideal way to the preparation of diverse heterocycles because it is a straightforward, atom economical, and synthetic step economical approach. Pyridine fused heterocycles such as imidazo[1,2-a]pyridines and indolizines are important intermediates in both medicinal chemistry and drug development[13-19] and easily be obtained from chemical preparation and commercial chemicals. As the pharmaceutical activities of imidazo[1,2-a]pyridines are shown to be dependent on the nature of the functionality at the C-3 position, a number of efficient methodologies have been developed for its C-3 functionalization using different strategies. Organic azides have been considered as important intermediates and building blocks in organic synthesis due to their synthetic versatility, especially as powerful precursors of nitrogen-containing reactive species and nitrogen-rich heterocycles.[20] In 2017, Karade group reported a ring-opening reaction of imidazo[1,2-a]pyridines using (diacetoxyiodo)benzene as oxidizing agent and NaN_3 as nitrogen source to the synthesis of α-iminonitriles.[21] However, in that case, the highly hazardous azide source NaN_3 was required in excessive amounts (3 equiv) and oxidant (diacetoxyiodo)benzene was needful. As such, the method for the ring opening reaction of imidazo[1,2-a]pyridines and indolizines via oxidant-free and thermally stable azide source has not been well developed. Herein, we report a metal-free and oxidant-free radical ring-opening reaction of imidazo[1,2-a]pyridines and indolizines with IBA-N_3, which is thermally stable (up to 130 °C) and can be stored for a long time, worked well for the C−H azidation of various organic substrates (**Scheme 1**).[22] What's more, this strategy was applicable to some other heterocycles like indolizines. To the best of our knowledge, this method described here constitutes the first example of the radical ring opening reaction of imidazo[1,2-a]pyridines and indolizines with IBA-N_3, which may be valuable for access to 2,3-disubstituted acrylonitriles and α-iminonitriles.

Scheme 1. Methods for the ring opening reaction of imidazo[1,2-a]pyridines and indolizines.

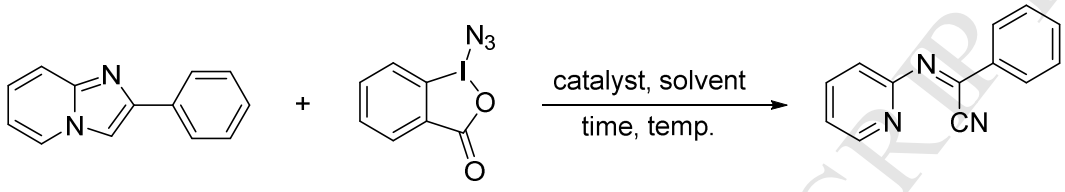


2. Results and Discussion

At the outset, the model reaction of 2-phenylimidazo[1,2-a]pyridine **1a** and IBA-N_3 **2** were carried out under natural light in the presence of 10 mol% of TBAI in DCE at 60 ^{o}C (**Table 1**). Since quaternary ammonium salts have been shown to be efficient catalysts in oxidative conversions mediated by I (III) reagents[23], and also in radical reactions[24], we hope quaternary ammonium salts would work well in this ring opening reaction. Gratifyingly, the product of the ring opening reaction **3a** was afforded in 66% yield after 24 h (**entry 1**). The molecular structure of product **3a** was confirmed by NMR spectra. The results show that using 20 mol% of LiI decreased the yield of **3a** to 64% (**entry 3**). The reaction of **1a** with **2** at room temperature appeared to have no change in the yield of **3a** (**entry 3**). It was found that only 37% yield of **3a** was obtained in the absence of TBAI (**entry 4**). This result revealed that

TBAI is necessary for our reaction. Then we turned our attention towards the role of solvent. Different solvents, including CH_3CN, DMSO and CH_2Cl_2, have also been investigated in details, which revealed that DMSO was the optimal choice (**entries 5-7**). To our delight, the product yields were improved remarkably by decreasing the reaction time from 24 h to 1 h.(**entries 8-10**). However, when we reduced the reaction time to 15 min, the reaction gave lower yields than that obtained in 1 h (**entry 11**). Hence, **entry 10** was chosen as the perfect optimized conditions for the evaluation of substrates.

Table 1. Optimization of the reaction conditions [a]



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

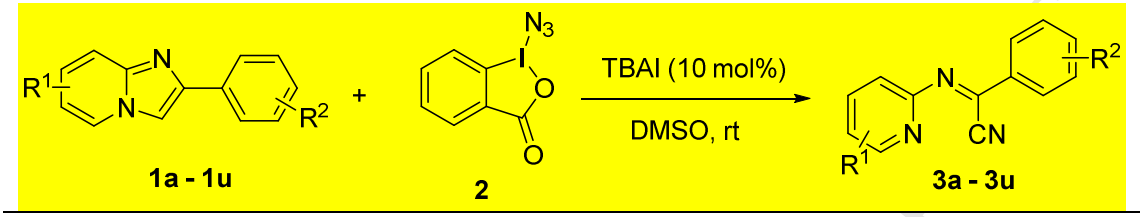
Entry	cat. (mol %)	Solvent	Time	Yield (%)[b]
1[c]	TBAI (10)	DCE	24 h	66
2[c]	LiI (20)	DCE	24 h	64
3	TBAI (10)	DCE	24 h	66
4	none	DCE	24 h	37
5	TBAI (10)	CH_3CN	24 h	76
6	TBAI (10)	DMSO	24 h	83
7	TBAI (10)	CH_2Cl_2	24 h	47
8	TBAI (10)	DMSO	12 h	86
9	TBAI (10)	DMSO	3 h	93
10	TBAI (10)	DMSO	1 h	96
11	TBAI (10)	DMSO	15 min	72

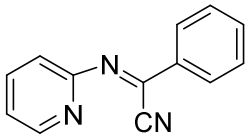
[a] Reaction conditions: 2-phenylimidazo[1,2-a]pyridine **1a** (0.2 mmol, 1.0 equiv.), IBA-N_3 **2** (0.25 mmol, 1.25 equiv.), catalyst and solvent (1.5 mL) at room temperature under ambient air, unless otherwise noted . [b] Isolated yield. [c] At 60 °C.

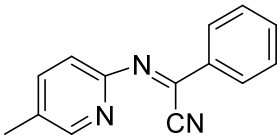
With this optimized reaction conditions in hand, we set out to investigate the substrate scope of the ring opening reaction. As shown in **Table 2**, a wide range of imidazo[1,2-a]pyridines with different substituents on either pyridine or phenyl ring were well tolerated under the standard conditions, giving the corresponding α-iminonitriles in satisfactory yield (**3a-3r**). In most cases, a high conversion of imidazo[1,2-a]pyridines occurred within 2 h. Imidazopyridines substituted with methyl group at different positions efficiently reacted with IBA-N_3 **2** to afford the respective products with excellent yields (**3b-3d**). Not surprisingly, a variety of functional groups, including electron-donating groups, such as methyl, methoxy, methylthio, and electron-withdrawing groups, such as fluoro, chloro, bromo, on the phenyl ring at the 4-position of imidazopyridines were well tolerated in this reaction system to obtain the α-iminonitriles in high yields (**3e-3j**). Meanwhile, the imidazopyridines with *meta*-substituents on the phenyl ring were also compatible to this reaction system with acceptable yields. The imidazopyridines bearing bromo, methoxy on the pyridine ring successfully reacted to give the desired products (**3n-3p**). Notably, modest

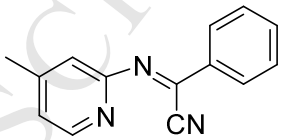
results were obtained in the case of the phenyl on the phenyl ring at the 4-position of imidazopyridine (**3q**). In addition, 2-thienylimidazo[1,2-a]pyridine and 2-phenylimidazo[1,2-a]pyrimidine also reacted well to afford the products **3r** and **3s** with good yields. Finally, simple imidazo[1,2-a]pyridines and other heterocycles were also investigated under the standard conditions (**3t, 3u, 1v,1w** and **1x**), but not compatible to this reaction system.

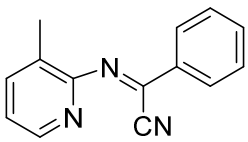
Table 2. The scope of imidazo[1,2-a]pyridines.[a,b]

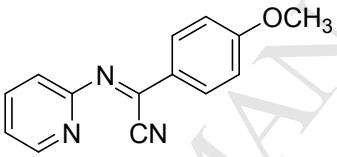



3a, 96%

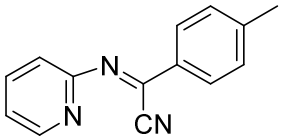

3b, 99%

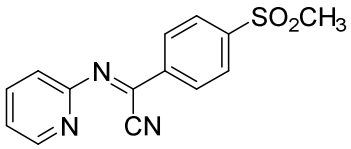

3c, 98%


3d, 99%

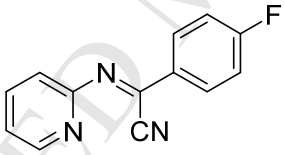


3e, 98%

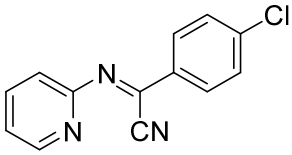

3f, 96%



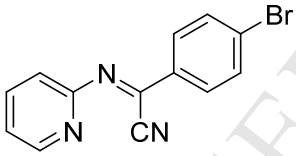
3g, 95%



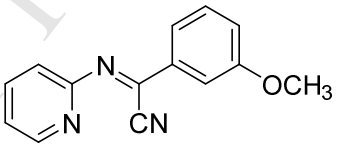
3h, 95%



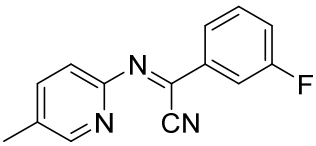
3i, 84%[c]



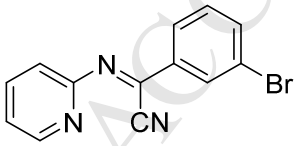
3j, 91%[d]



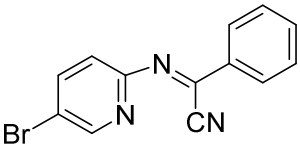
3k, 91%[c]



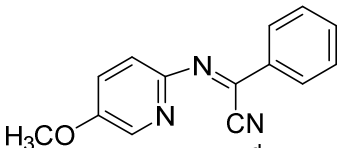
3l, 96%[c]



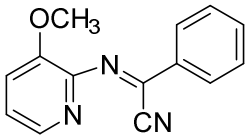
3m, 92%[c]



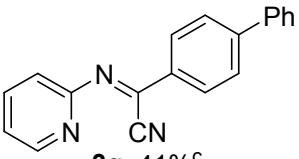
3n, 88%[e]



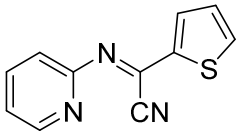
3o, 88%[d]



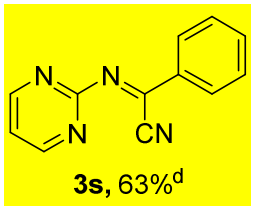
3p, 46%[d]



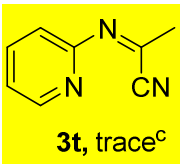
3q, 41%[c]



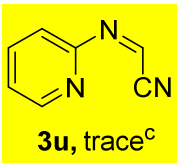
3r, 84%[c]



3s, 63%[d]



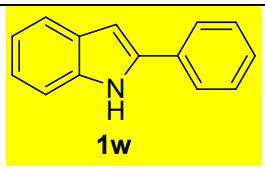
3t, trace[c]



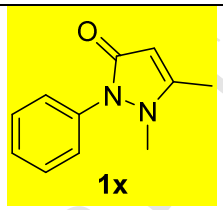
3u, trace[c]

Unreactive heterocycls (1v-1x)

1v



1w

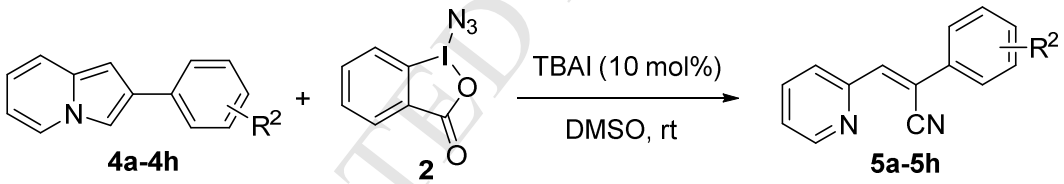


1x

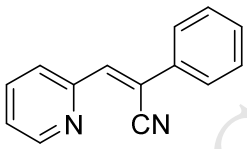
[a] Reaction conditions: **1** (0.2 mmol, 1 equiv.) and **2** (0.25 mmol, 1.25 equiv.) in the presence of TBAI (10 mol%) in DMSO (1.5 mL) at room temperature under ambient air for 1 h. [b] Isolated yields. [c] Reaction complete in 2 h. [d] Reaction complete in 5 h. [e] Reaction complete in 20 h.

To extend the scope of our methodology, we carried out the reaction with different substituted indolizines (**Table 3**). To our delight, indolizines afforded the 2,3-disubstituted acrylonitriles in modest to good yields under the optimized reaction conditions. The system tolerated the electronic effects of the substituents on the phenyl group, and both electron-withdrawing and -donating groups were found to be suitable substrates, affording the corresponding products **5a-5h** in 35-81 % yields. Interestingly, the phenyl on the phenyl ring at the 4-position of indolizine could also afford the desired product **5g** in moderate yield, which case is similar to **3q**.

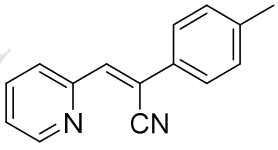
Table 3. The scope of indolizines. [a, b]



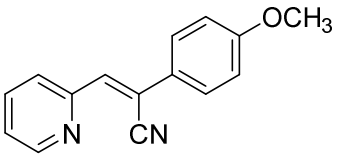
4a-4h **2** **5a-5h**



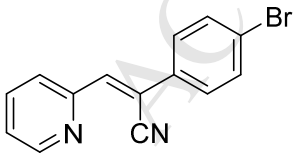
5a, 78%



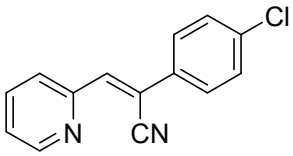
5b, 80%



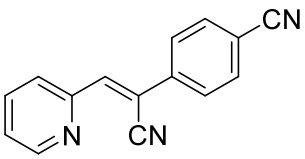
5c, 70%



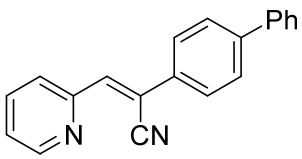
5d, 74%



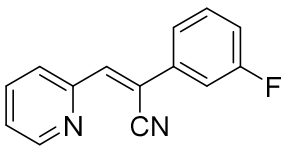
5e, 73%



5f, 70%



5g, 35%



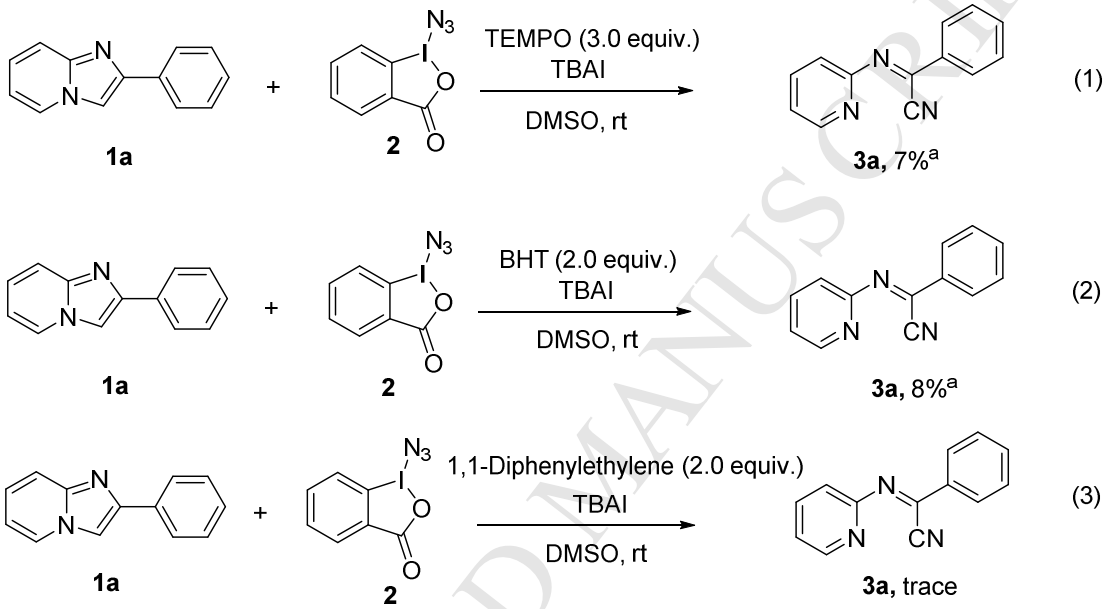
5h, 81%

[a] Reaction conditions: **4** (0.2 mmol, 1 equiv.) and **2** (0.25 mmol, 1.25 equiv.) in the presence of TBAI (10 mol%) in DMSO (1.5

mL) at room temperature under ambient air for 5 h. [b] Isolated yields.

A few control experiments were performed to understand the mechanistic path for the ring opening reaction of imidazopyridines (**Scheme 2**). When the radical scavengers 2,2,6,6-tetramethyl-1-piperidinyloxy (TEMPO) and 2,6-di-*tert*-butyl-4-methylphenol (BHT) were added separately to the reaction mixture, only a small amount of products were formed after reacting for 2 hours(**Scheme 2, eqs 1 and 2**) and most of the starting material could not react. In addition, almost no desired product **3a** was isolated when 1,1-diphenylethylene was added to the reaction (**Scheme 2, eq 3**). These results signify that the reaction possibly proceeds through a radical pathway.

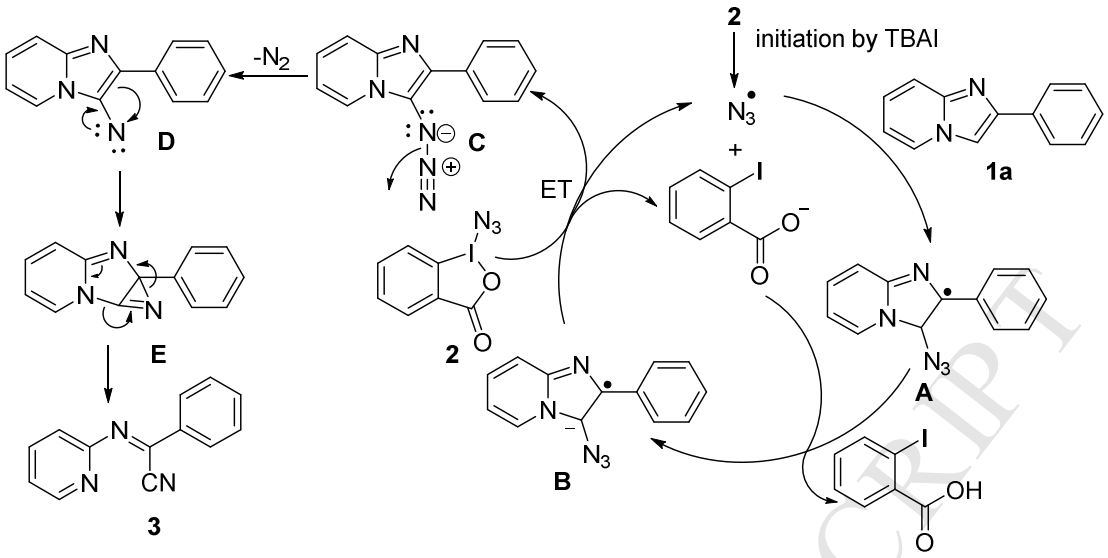
Scheme 2. Controlled Experiments.



[a] Isolated yields.

On the basis of these results and previous reports [25,26], the probable mechanism of the reaction is described in **Scheme 3**. The reaction is initiated through the reduction of the IBA-N_3 by TBAI, which acts as a formal one-electron donor [27,28] to produce 2-iodobenzoate and the $N_3^{\bullet}$ radical which will start the radical chain. The addition of $N_3^{\bullet}$ to imidazo[1,2-a]pyridine (**1a**) provide the radical intermediate **A**, which gets deprotonated by 2-iodobenzoate[26] to form the radical anion **B.** Then the radical anionic intermediate **B** transfers single-electron to the IBA-N_3 **2** to gave the 3-azido imidazo[1,2-a]pyridines **C** and the $N_3^{\bullet}$ radical thereby closing the catalytic cycle. It is well known that aryl azides thermally decompose to form nitrene as an intermediate[21]. Thus, unstable intermediate **C** may be thermally decomposed to form nitrene **D**, that gets trapped intramolecularly to form strained azirine **E** which can produce α-iminonitrile by a ring opening process[21]. Further work will be needed to support this speculative mechanism.

Scheme 3. Plausible Mechanism.



3. Conclusions

In summary, we have developed a metal-free and efficient synthetic method for the preparation of 2,3-disubstituted acrylonitriles and α-iminonitriles by the ring opening reaction of imidazo[1,2-a]pyridine with IBA-N_3 in the presence of TBAI as an initiator. Mechanistic investigations indicate that this reaction undergo a radical pathway. This transformation has demonstrated broad substrate scope, excellent functional group tolerance, mild reaction conditions, and avoids the use of oxidants. Further investigation on the application of this synthetic methodology is currently underway.

4. General Experiment Information

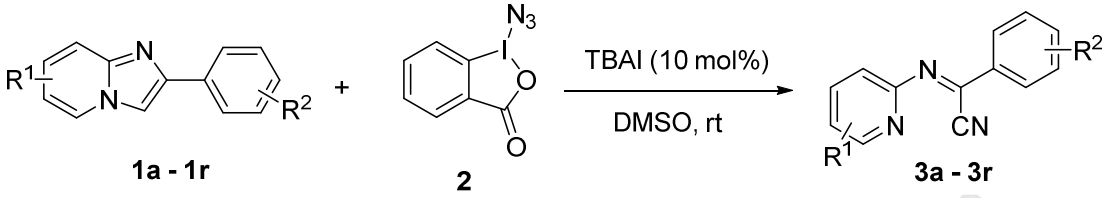
^{1}H NMR spectra were recorded on a Bruker DPX-400 (400 MHz) spectrometer with deuteraterated chloroform as solution. The chemical shifts δ are reported in ppm relative to tetramethylsilane. ^{13}C NMR spectra were recorded at 100 MHz on Bruker DPX-400. The chemical shifts δ are reported relative to residual $CHCl_3$ (δ-c = 77.00 ppm). ^{19}F NMR spectra were recorded at 376 MHz on Bruker DPX-400. The multiplicity of signals is designated by the following abbreviations: s (singlet), d (doublet), t (triplet), q (quartet), m (multiplet). Coupling constants *J* are reported in Hertz (Hz). High resolution mass spectra (HRMS) were obtained on an Agilent LC-MSD-Trap-XCT spectrometer with micromass MS software using electrospray ionisation (ESI). Silica gel was purchased from Qing Dao Hai Yang Chemical Industry Co. Melting points were recorded by XT4A micro melting point Measurement Instruments, thermometer was unrevised. Unless otherwise mentioned, solvents and reagents were purchased from commercial sources and used as received. All the imidazoheterocycles were prepared in accordance with methods described in the references[29,30]. IBA-N_3 **2** was prepared by the reported methods [31].

4.1. General procedure of the ring opening reaction pyridine fused heterocycles.

4.1.1 General procedure of the ring opening reaction of imidazo[1,2-a]pyridines.

A 25 mL schlenk-flask was equipped with a magnetic stir bar and charged with imidazo[1,2-a]pyridine **1** (0.2 mmol, 1.0 equiv.), IBA-N_3 **2** (0.25 mmol, 1.25 equiv.), TBAI (10 mol%), and DMSO (1.5 mL). The reaction mixture was then stirred at room temperature under ambient air for the specified reaction time (see **Table 2**). Then the mixture was diluted with CH_2Cl_2 and washed with water three times, then washed with saturated NaCl solution.

The organic layers dried over anhydrous Na_2SO_4, concentrated in vacuo, and purified by chromatography on silica gel (Elutent: petroleum ether - EtOAc) to give the pure products.



4.1.2 General procedure of the ring opening reaction of indolizines.

A 25 mL schlenk-flask was equipped with a magnetic stir bar and charged with 2-phenylindolizine **4** (0.2 mmol, 1.0 equiv.), IBA-N_3 **2** (0.25 mmol, 1.25 equiv.), TBAI (10 mol%), and DMSO (1.5 mL). The reaction mixture was then stirred at room temperature under ambient air for 5 h. The mixture was diluted with CH_2Cl_2 and washed with water three times, then washed with saturated NaCl solution. The organic layers dried over anhydrous Na_2SO_4, concentrated in vacuo, and purified by chromatography on silica gel (Elutent: petroleum ether - EtOAc) to give the pure products.

4.2 Characterization data for products

(*Z*)-N-(pyridin-2-yl)benzimidoyl cyanide (3a)[32]**:** Yellow solid (39.7 mg, 96% yield); mp: 61-63 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.60-8.59 (m, 1H), 8.24-8.21 (m, 2H), 7.83 (td, *J* = 7.8, 1.8 Hz, 1H), 7.63-7.59 (m, 1H), 7.55-7.51 (m, 2H), 7.29-7.25 (m, 2H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 159.2, 148.9, 141.1, 138.3, 133.6, 133.4, 129.0, 128.7, 123.0, 118.4, 111.5. IR (cm^{-1}): 3059, 2213, 1579, 1456, 1427, 1216, 1003, 742, 686. .HRMS (ESI^+): calcd for $C_{13}H_9N_3$ $[M+H]^+$: 208.0869, found 208.0870.

(*Z*)-N-(5-methylpyridin-2-yl)benzimidoyl cyanide (3b): Yellow solid (43.7 mg, 99%); mp: 50-52 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.42-8.41 (m, 1H), 8.22-8.20 (m, 2H), 7.64-7.57 (m, 2H), 7.54-7.50 (m, 2H), 7.20 (d, *J* = 8.1 Hz, 1H), 2.39 (s, 3H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 156.8, 149.0, 140.2, 138.8, 133.8, 133.1, 129.0, 128.6, 118.5, 111.8, 18.3. IR (cm^{-1}): 2925, 2361, 2210, 1569, 1468, 1228, 1008, 773, 687. HRMS (ESI^+): calcd for $C_{14}H_{11}N_3$ $[M+H]^+$: 222.1026, found 222.1029.

(*Z*)-N-(4-methylpyridin-2-yl)benzimidoyl cyanide (3c)[32]**:** Yellow liquid (43.3 mg, 98%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.46 (d, *J* = 5.0 Hz, 1H), 8.24-8.21 (m, 2H), 7.64-7.60 (m, 1H), 7.57-7.51 (m, 2H), 7.10 (d, *J* = 6.3 Hz, 2H), 2.44 (s, 3H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 159.3, 149.7, 148.6, 141.0, 133.7, 133.3, 129.0, 128.7, 124.0, 118.9, 111.6, 21.1. IR (cm^{-1}): 2923, 2215, 1597, 1549, 1450, 1246, 1011, 773, 688. HRMS (ESI^+): calcd for $C_{14}H_{11}N_3$ $[M+H]^+$: 222.1026, found 222.1029.

(*Z*)-N-(3-methylpyridin-2-yl)benzimidoyl cyanide (3d)[32]**:** Yellow solid (43.7 mg, 99%); mp: (61-63 °C) ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.40 (dd, *J* = 4.8, 1.1 Hz, 1H), 8.26-8.23 (m, 2H), 7.63-7.58 (m, 2H), 7.55-7.51 (m, 2H), 7.19 (dd, *J* = 7.5, 4,8 Hz, 1H), 2.37 (s, 3H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 157.5, 146.1, 140.2, 139.2, 133.9, 133.2, 129.0, 128.6, 128.1, 123.4, 111.8, 17.3. IR (cm^{-1}): 2923, 2211, 1602, 1564, 1449, 1415, 1228, 1112, 736, 682. .HRMS (ESI^+): calcd for $C_{14}H_{11}N_3$ $[M+H]^+$: 222.1026, found 222.1029.

(*Z*)-4-methoxy-N-(pyridin-2-yl)benzimidoyl cyanide (3e)[32]**:** Yellow solid (46.4 mg, 98%); mp: (74-76 °C). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.59-8.57 (m, 1H), 8.19-8.15 (m, 2H), 7.81 (td, *J* = 7.7, 1.8 Hz, 1H), 7.26-7.21 (m, 2H), 7.03-6.99 (m, 2H), 3.89 (m, 3H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 163.9, 159.5, 148.8, 140.4, 138.2, 130.8, 126.5, 122.5, 118.1, 114.5, 111.6, 55.7. IR

(cm^{-1}): 3053, 2961, 2840, 2214, 1582, 1510, 1459, 1427, 1260, 1173, 1031, 839, 743, 673. .HRMS (ESI^+): calcd for $C_{14}H_{11}N_3O$ $[M+H]^+$:238.0975, found 238.0978.

(*Z*)-4-methyl-N-(pyridin-2-yl)benzimidoyl cyanide (3f)[32]**:** Yellow solid (42.4 mg, 96%); mp: (88-90 °C). ^1H NMR (400 MHz, $CDCl_3$) δ 8.58 (dd, *J* = 4.7, 0.9 Hz, 1H), 8.10 (d, *J* = 8.3 Hz, 2H), 7.82 (td, *J* = 7.7, 1.8 Hz, 1H), 7.33 (d, *J* = 8.1 Hz, 2H), 7.27-7.22 (m, 2H), 2.44 (s, 3H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 159.4, 148.9, 144.4, 141,0, 138.2, 131,1, 129.8, 128.7, 122.7, 118.2, 111.6, 21,8. IR (cm^{-1}): 2919, 2214, 1576, 1558, 1458, 1428, 1297, 1212, 1001, 798, 722, 670. .HRMS (ESI^+): calcd for $C_{14}H_{11}N_3$ $[M+H]^+$: 222.1026, found 222.1027.

(*Z*)-4-(methylsulfonyl)-N-(pyridin-2-yl)benzimidoyl cyanide (3g): Yellow solid (54.1 mg, 95%); mp: (155-157 °C). ^1H NMR (400 MHz, $CDCl_3$) δ 8.65-8.63 (m, 1H), 8.45-8.43 (m, 2H), 8.14-8.11 (m, 2H), 7.90 (td, *J* = 7.7, 1.8 Hz, 1H), 7.39-7.35 (m, 2H), 3.13 (s, 3H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 157.9, 148.9, 144.2, 138.5, 138.2, 129.5, 128.1, 128.0, 124.2, 119.9, 111.4, 44.4. IR (cm^{-1}): 2920, 2203, 1573, 1546, 1427, 1395, 1294, 1143, 1005, 844, 781, 728. HRMS (ESI^+): calcd for $C_{14}H_{11}N_3O_2S$ $[M+H]^+$: 286.0645, found 286.0649.

(*Z*)-4-fluoro-N-(pyridin-2-yl)benzimidoyl cyanide (3h): Yellow solid (42.7 mg, 95%); mp (122-124 °C). ^1H NMR (400 MHz, $CDCl_3$) δ 8.60-8.59 (m, 1H), 8.26-8.22 (m, 2H), 7.83 (td, *J* = 7.7, 1.8 Hz, 1H), 7.30-7.19 (m, 4H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 167.1, 164.6, 158.8, 148.9, 139.6, 138.3, 131.1 (d, *J* = 9.3 Hz), 130.0 (d, *J* = 3.0 Hz), 123.1, 118.6, 116.5, 116.3, 111.5. ^{19}F NMR (376 MHz, $CDCl_3$) δ -104.3. IR (cm^{-1}): 2215, 1578, 1503, 1428, 1234, 1157, 842, 737, 663. HRMS (ESI^+): calcd for $C_{13}H_8N_3F$ $[M+H]^+$: 226.0775, found 226.0776.

(*Z*)-4-chloro-N-(pyridin-2-yl)benzimidoyl cyanide (3i)[32]**:** Yellow solid (40.5 mg, 84%); mp (108-109 °C). ^1H NMR (400 MHz, $CDCl_3$) δ 8.60 (d, *J* = 4.5 Hz, 1H), 8.17 (d, *J* = 8.6 Hz, 2H), 7.85 (td, *J* = 7.7, 1.7 Hz, 1H), 7.52 (d, *J* = 8.7 Hz, 2H), 7.31-7.26 (m, 2H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 158.7, 148.9, 139.8, 139.7, 138.4, 132.2, 129.9, 129.4, 123.3, 118.9, 111.4. IR (cm^{-1}): 2210, 1578, 1429, 1401, 1092, 1008, 836, 795, 736. HRMS (ESI^+): calcd for $C_{13}H_8N_3Cl$ $[M+H]^+$ 242.0480, found 242.0482.

(*Z*)-4-bromo-N-(pyridin-2-yl)benzimidoyl cyanide (3j): Yellow solid (51.9 mg, 91%); mp (96-98 °C). ^1H NMR (400 MHz, $CDCl_3$) δ 8.60 (dd, *J* = 4.8, 0.8 Hz, 1H), 8.10-8.07 (m, 2H), 7.84 (td, *J* = 7.7, 1.8 Hz, 1H), 7.69-7.65 (m, 2H), 7.31-7.27 (m, 2H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 158.7, 148.9, 139.8, 138.3, 132.6, 132.3, 130.0, 128.5, 123.3, 118.9, 111.4. IR (cm^{-1}): 3052, 2209, 1576, 1549, 1474, 1426, 1069, 998, 831, 794, 742. HRMS (ESI^+): calcd for $C_{13}H_8N_3Br$ $[M+H]^+$ 285.9974, found 285.9979.

(*Z*)-3-methoxy-N-(pyridin-2-yl)benzimidoyl cyanide (3k): Yellow liquid (43.1 mg, 91%); ^1H NMR (400 MHz, $CDCl_3$) δ 8.60 (m, 1H), 7.85-7.78 (m, 2H), 7.75-7.74 (m, 1H), 7.44 (t, *J* = 8.0 Hz, 1H), 7.29-7.25 (m, 2H), 7.17-7.14 (m, 1H), 3.88 (s, 3H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 160.0, 159.1, 148.9, 141.1, 138.3, 134.9, 130.0, 122.9, 122.0, 120.3, 118.3, 112.0, 111.5, 55.6. IR (cm^{-1}): 3057, 3004, 2940, 2838, 2216, 1583, 1485, 1460, 1429, 1288, 1227, 1023, 876, 797, 743, 704. HRMS (ESI^+): calcd for $C_{14}H_{11}N_3O$ $[M+H]^+$ 238.0975, found 238.0979.

(*Z*)-3-fluoro-N-(5-methylpyridin-2-yl)benzimidoyl cyanide (3l): Yellow solid (45.9 mg, 96%); mp (67-69 °C).^1H NMR (400 MHz, $CDCl_3$) δ 8.43-8.42 (m, 1H), 8.01-7.98 (m, 1H), 7.95-7.92 (m, 1H), 7.66-7.63 (m, 1H), 7.53-7.48 (m, 1H), 7.31-7.26 (m, 1H), 7.23 (d, *J* = 8.0 Hz, 1H), 2.40 (s, 3H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 162.9,(d, *J* = 248.2 Hz), 156.1, 149.0, 138.8, 138.4 (d, *J* = 3.5 Hz), 136.1 (d, *J* = 7.7 Hz), 133.7, 130.6 (d, *J* = 8.0 Hz), 124.7 (d, *J* =

2.9 Hz), 120.1 (d, *J* = 21.6 Hz), 119.1, 114.8 (d, *J* = 24.0 Hz), 111.7, 18.2. IR (cm^{-1}): 2924, 2211, 1574, 1473, 1442, 1250, 837, 791. HRMS (ESI^+): calcd for $C_{14}H_{10}N_3F$ $[M+H]^+$ 240.0932, found 240.0931.

(*Z*)-3-bromo-N-(pyridin-2-yl)benzimidoyl cyanide (3m): Yellow liquid (52.5 mg, 92%); ^1H NMR (400 MHz, $CDCl_3$) δ 8.61-8.60 (m, 1H), 8.38 (t, *J* = 1.8 Hz, 1H), 8.15-8.13 (m, 1H), 7.85 (td, *J* = 7.7, 1.9 Hz, 1H), 7.74-7.71 (m, 1H), 7.41 (t, *J* = 7.9 Hz, 1H), 7.32-7.29 (m, 2H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 158.4, 148.9, 139.2, 138.4, 136.1, 135.5, 131.1, 130.5, 127.6, 123.5, 123.3, 119.1, 111.4. IR (cm^{-1}): 3062, 2213, 1558, 1463, 1427, 1216, 796, 745, 699. HRMS (ESI^+): calcd for $C_{13}H_8N_3Br$ $[M+H]^+$ 285.9974, found 285.9981.

(*Z*)-N-(5-bromopyridin-2-yl)benzimidoyl cyanide (3n): Yellow solid (50.5 mg, 88%); mp (101-103 °C).^1H NMR (400 MHz, $CDCl_3$) δ 8.64-8.63 (m, 1H), 8.22-8.19 (m, 2H), 7.94 (dd, *J* = 8.4, 2.4 Hz, 1H), 7.64-7.60 (m, 1H), 7.55-7.51 (m, 2H), 7.18 (dd, *J* = 8.4, 0.5 Hz, 1H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 157.5, 149.9, 141.3, 140.9, 133.6, 133.5, 129.1, 128.8, 120.2, 119.6, 111.4. IR (cm^{-1}): 2925, 2213, 1566, 1450, 1365, 1235, 1003, 843, 769, 679. HRMS (ESI^+): calcd for $C_{13}H_8N_3Br$ $[M+H]^+$ 285.9974, found 285.9976.

(*Z*)-N-(5-methoxypyridin-2-yl)benzimidoyl cyanide (3o): Yellow solid (41.5 mg, 88%); mp (51-53 °C).^1H NMR (400 MHz, $CDCl_3$) δ 8.29 (t, *J* = 1.7 Hz, 1H), 8.22-8.20 (m, 2H), 7.59-7.55 (m, 1H), 7.53-7.49 (m, 2H), 7.33 (d, *J* = 1.8 Hz, 2H), 3.91 (s, 3H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 155.8, 151.6, 138.0, 135.5, 134.2, 132.7, 128.9, 128.4, 122.7, 121.3, 112.4, 56.0. IR (cm^{-1}): 2841, 2209, 1597, 1571, 1471, 1300, 1269, 1029, 838, 771, 735, 688. HRMS (ESI^+): calcd for $C_{14}H_{11}N_3O$ $[M+H]^+$ 238.0975, found 238.0976.

(*Z*)-N-(3-methoxypyridin-2-yl)benzimidoyl cyanide (3p): Yellow liquid (21.8 mg, 46%); ^1H NMR (400 MHz, $CDCl_3$) δ 8.24-8.22 (m, 2H), 8.16 (dd, *J* = 4.7, 1.4 Hz, 1H), 7.63-7.58 (m, 1H), 7.55-7.51 (m, 2H), 7.32 (dd, *J* = 8.2, 1.3 Hz, 1H), 7.26 (dd, *J* = 8.2, 4.7 Hz, 1H), 3.91 (s, 3H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 149.6, 148.2, 142.0, 139.7, 133.7, 133.3, 129.0, 128.8, 123.9, 119.3, 111.6, 55.8. IR (cm^{-1}): 2936, 2840, 2215, 1605, 1566, 1458, 1427, 1283, 1231, 1071, 1009, 780, 687. HRMS (ESI^+): calcd for $C_{14}H_{11}N_3O$ $[M+H]^+$ 238.0975, found 238.0977.

(*Z*)-N-(pyridin-2-yl)-[1,1'-biphenyl]-4-carbimidoyl cyanide (3q): Yellow solid (23.2 mg, 41%); mp (147-149 °C).^1H NMR (400 MHz, $CDCl_3$) δ 8.62-8.60 (m, 1H), 8.30 (dt, *J* = 8.2, 1.3 Hz, 2H), 7.84 (td, *J* = 7.7, 1.7 Hz, 1H), 7.76 (dt, *J* = 8.6, 1.9 Hz, 2H), 7.68-7.65 (m, 2H), 7.51-7.47 (m, 2H), 7.44-7.40 (m, 1H), 7.30-7.27 (m, 2H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 159.2, 148.9, 146.1, 140.7, 139.5, 138.3, 132.6, 129.3, 129.0, 128.4, 127.6, 127.3, 122.9, 118.5, 111.6. IR (cm^{-1}): 2922, 2211, 1574, 1549, 1402, 1000, 845, 794, 767, 732, 693. HRMS (ESI^+): calcd for $C_{19}H_{13}N_3$ $[M+H]^+$ 284.1182, found 284.1185.

(*E*)-N-(pyridin-2-yl)thiophene-2-carbimidoyl cyanide (3r): Yellow solid (35.5 mg, 84%); mp (56-58 °C).^1H NMR (400 MHz, $CDCl_3$) δ 8.58 (dd, *J* = 4.8, 0.9 Hz, 1H), 7.94 (dd, *J* = 3.8, 1.0 Hz, 1H), 7.81 (td, *J* = 7.7, 1.8 Hz, 1H), 7.64 (dd, *J* = 5.0, 1.0 Hz, 1H), 7.30-7.25 (m, 2H), 7.20 (dd, *J* = 5.0, 3,9 Hz, 1H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 158.0, 148.7, 141.3, 138.3, 134.6, 134.0, 133.6, 128.5, 123.2, 119.6, 111.5. IR (cm^{-1}): 3083, 2217, 1580, 1551, 1459, 1414, 1214, 851, 798, 720. HRMS (ESI^+): calcd for $C_{13}H_7N_3S$ $[M+H]^+$ 214.0433, found 214.0434.

(*Z*)-N-(Pyrimidin-2-yl)benzimidoyl cyanide (3s): Yellow solid (26 mg, 63%); mp (85-87 °C) ^1H NMR (400 MHz, $CDCl_3$) δ 8.79 (d, *J* = 4.6 Hz, 2H), δ 8.21-8.19 (m, 2H), δ 7.59 (t, *J* = 7.39 Hz, 1H), δ 7.51-7.47 (m, 2H), δ 7.21 (t, *J* = 4.7Hz, 1H). ^{13}C NMR 100 MHz, $CDCl_3$ δ

165.3, 158.9, 144.4, 134.2, 132.8, 129.2, 129.1, 119.1, 110.7. IR (cm^{-1}): 2925, 2221, 1594, 1560, 1450, 1400, 1248, 1010, 830, 688. HRMS (ESI^+): calcd for $C_{12}H_9N_4$ $[M+H]^+$ 209.0822, found 209.0821.

(*Z*)-2-phenyl-3-(pyridin-2-yl)acrylonitrile (5a): Yellow solid (31.6 mg, 78%); mp (44-46 ^oC).^1H NMR (400 MHz, $CDCl_3$) δ 8.75 (d, *J* = 4.2 Hz, 1H), 7.95 (d, J = 7.9 Hz, 1H), 7.80 (td, *J* = 7.7, 1.7 Hz, 1H), 7.76-7.72 (m, 2H), 7.65 (s, 1H), 7.48-7.40 (m, 3H), 7.33-7.30 (m, 1H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 152.2, 150.0, 141.0, 136.8, 134.0, 129.8, 129.1, 126.4, 124.3, 124.1, 117.4, 114.9. IR (cm^{-1}): 3057, 2214, 1579, 1494, 1458, 1428, 906, 762, 690. :HRMS (ESI^+): calcd for $C_{14}H_{10}N_2$ $[M+H]^+$ 207.0917, found 207.0917.

(*Z*)-3-(pyridin-2-yl)-2-(p-tolyl)acrylonitrile (5b): Yellow solid (35.2 mg, 80%); mp (78-81 ^oC).^1H NMR (400 MHz, $CDCl_3$) δ 8.74 (dd, *J* = 4.7, 0.6 Hz, 1H), 7.93 (d, *J* = 7.9 Hz, 1H), 7.78 (td, *J* = 7.7, 1.7 Hz, 1H), 7.63 (d, *J* = 8.3 Hz, 2H), 7.60 (s, 1H), 7.31-7.29 (m, 1H), 7.25 (d, *J* = 8.1 Hz, 2H). 2,39 (s, 3H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 152.4, 149.9, 140.1, 140.0, 136.8, 131.2, 129.8, 126.2, 124.1, 123.9, 117.5, 114.8, 21.3. IR (cm^{-1}): 3050, 2361, 2212, 1577, 1511, 1464, 1429, 906, 814, 772, 735. HRMS (ESI^+): calcd for $C_{15}H_{12}N_2$ $[M+H]^+$ 221.1073, found 221.1074.

(*Z*)-2-(4-methoxyphenyl)-3-(pyridin-2-yl)acrylonitrile (5c): Yellow liquid (33.0 mg, 70%); ^1H NMR (400 MHz, $CDCl_3$) δ 8.73 (d, *J* = 4.4 Hz, 1H), 7.92 (d, *J* = 7.9 Hz, 1H), 7.78 (td, *J* = 7.7, 1.7 Hz, 1H), 7.70-7.67 (m, 2H), 7.53 (s, 1H), 7.30-7.27 (m, 1H), 6.99-6.95 (m, 2H), 3.85 (s, 3H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 160.9, 152,5, 149.9, 138.8, 136.7, 127.7, 126.4, 123.9, 123.8, 117.6, 114.5, 114,4, 55.5. IR (cm^{-1}): 3049, 2838, 2215, 1603, 1680, 1512, 1462, 1431, 1032, 831, 779, 741. HRMS (ESI^+): calcd for $C_{15}H_{12}N_2O$ $[M+H]^+$ 237.1022, found 237.1025.

(*Z*)-2-(4-bromophenyl)-3-(pyridin-2-yl)acrylonitrile (5d): Yellow solid (42.0 mg, 74%); mp (138-140 ^oC).^1H NMR (400 MHz, $CDCl_3$) δ 8.76-8.74 (m, 1H), 7.90 (d, *J* = 7.9 Hz, 1H), 7.80 (td, *J* = 7.7, 1.7 Hz, 1H), 7.62-7.57 (m, 5H), 7.34-7.31 (m, 1H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 151.8, 150.0, 141.2, 136.8, 132.9, 132.3, 127.8, 124.5, 124.3, 124.1, 117.0, 113.8. IR (cm^{-1}): 3048, 2215, 1577, 1558, 1486, 1473, 1108, 821, 742, 702. HRMS (ESI^+): calcd for $C_{14}H_9N_2Br$ $[M+H]^+$ 285.0022, found 285.0022.

(*Z*)-2-(4-chlorophenyl)-3-(pyridin-2-yl)acrylonitrile (5e): Yellow solid (35.0 mg, 73%); mp (92-94 ^oC).^1H NMR (400 MHz, $CDCl_3$) δ 8.76-8.75 (m, 1H), 7.91 (d, *J* = 7.9 Hz, 1H), 7.80 (td, *J* = 7.7, 1.6 Hz, 1H), 7.69-7.66 (m, 2H), 7.64 (s, 1H), 7.43 (d, *J* = 8.6 Hz, 2H), 7.34-7.31 (m, 1H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 151.9, 150.0, 141.2, 136.8, 135.9, 132.5, 129.3, 127.6, 124.5, 124.2, 117.1, 113.7. IR (cm^{-1}): 2217, 1401, 1147, 823, 768, 736. HRMS (ESI^+): calcd for $C_{14}H_9N_2Cl$ $[M+H]^+$ 241.0527, found 241.0529

(*Z*)-4-(1-cyano-2-(pyridin-2-yl)vinyl)benzonitrile (5f) : Yellow solid (32.3 mg, 70%); mp (157-159 ^oC).^1H NMR (400 MHz, $CDCl_3$) δ 8.79-8.78 (m, 1H), 7.91 (d, *J* = 7.9 Hz, 1H), 7.88-7.82 (m, 3H), 7.77-7.72 (m, 2H), 7.72 (s, 1H), 7.40-7.36 (m, 1H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 151.3, 150.2, 143.5, 138.3, 137.0, 132.8, 126.9, 125.0, 124.8, 118.1, 116.6, 113.2, 113.1. IR (cm^{-1}): 3069, 2222, 1657, 1401, 1002, 831, 776, 739. HRMS (ESI^+): calcd for $C_{15}H_9N_3$ $[M+H]^+$ 232.0869, found 232.0870.

(*Z*)-2-([1,1'-biphenyl]-4-yl)-3-(pyridin-2-yl)acrylonitrile (5g): Yellow solid (19.7 mg, 35%); mp (138-140 ^oC).^1H NMR (400 MHz, $CDCl_3$) δ 8.77-8.76 (m, 1H), 7.97 (d, *J* = 8.0 Hz, 1H), 7.84-7.78 (m, 3H), 7.70-7.68 (m, 3H), 7.64 (d, *J* = 1.4 Hz, 1H), 7.62 (s, 1H), 7.49-7.45 (m,

2H), 7.40-7.37 (m, 1H), 7.34-7.30 (m, 1H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 152.2, 150.0, 142.6, 140.6, 139.8, 136.8, 132.8, 128.9, 127.9, 127.7, 127.1, 126.8, 124.3, 124.1, 117.4, 114.5. IR (cm^{-1}): 3064, 2319, 2213, 1666, 1578, 1402, 996, 905, 837, 765, 728, 689. HRMS (ESI^+): calcd for $C_{20}H_{14}N_2$ $[M+H]^+$ 283.1230, found 283.1232.

(*Z*)-2-(3-fluorophenyl)-3-(pyridin-2-yl)acrylonitrile (5h): Yellow solid (36.3 mg, 81%); mp (138-140 ^{o}C).^{1}H NMR (400 MHz, $CDCl_3$) δ 8.76 (dd, *J* = 4.7, 0.6 Hz, 1H), 7.91 (d, *J* = 7.9 Hz, 1H), 7.81 (td, *J* = 7.7, 1.7 Hz, 1H), 7.64 (s, 1H), 7.56-7.53 (m, 1H), 7.46-7.40 (m, 2H), 7.36-7.32 (m, 1H), 7.15-7.10 (m, 1H). ^{13}C NMR 100 MHz, $CDCl_3$ δ 164.3, 161.8, 151.7, 150.1, 141.9, 136.9, 136.2 (d, *J* = 8.0 Hz), 130.7 (d, *J* = 8.5 Hz), 124.5 (d, *J* = 18.5 Hz), 122.1 (d, *J* = 2.9 Hz), 117.0, 116.7 (d, *J* = 21.3 Hz), 113.7 (d, *J* = 2.8 Hz), 113.3 (d, *J* = 23.6 Hz). IR (cm^{-1}): 2216, 1582, 1400, 1272, 1160, 821, 778, 736. HRMS (ESI^+): calcd for $C_{14}H_9N_2F$ $[M+H]^+$ 225.0823, found 225.0822.

Conflicts of interest

There are no conflicts of interest to declare.

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Supplementary Material

Supplementary data associated with this article can be found in the online version.

Highlights

1. Radical ring opening reaction of pyridine fused heterocycles with IBA-N_3.
2. The synthesis of acrylonitriles and α-iminonitriles at room temperature.
3. Clean reaction, ease of product isolation and a simple experimental procedure.