NJC

PAPER

View Article Online
View Journal

Cite this: DOI: 10.1039/c8nj03339k

Visible-light-activated C–C and C–N bond formation in the synthesis of imidazo[1,2-*a*]pyridines and imidazo[2,1-*b*]thiazoles under catalyst and solvent-free conditions

Km Neha Shivhare,[a] Manish K. Jaiswal,[b] Anushree Srivastava,[a] Saurabh K. Tiwari[a] and I. R. Siddiqui *[a]

Received 4th July 2018,
Accepted 27th August 2018

DOI: 10.1039/c8nj03339k

rsc.li/njc

The formation of a 3-aminoimidazo-fused heterocyclic compound and its derivatives through a multicomponent one-pot reaction, activated by visible light, is reported. The noticeable feature of this protocol is the utilization of a universally available energy source to activate the reaction. The reported methodology is the first protocol that represents the implementation of visible light for this Ugi-type synthesis from 2-aminoheterocycles, aldehydes, and isocyanides as well as offers the advantages of improved selectivity, outstanding yields, solvent and catalyst-free conditions, environmental sustainability and convenient access to starting materials.

Introduction

Among nitrogen derivatives, imidazo-fused heterocycles are becoming more crucial in medicinal chemistry, because of their broad range of pharmacological and biological activities, such as antibacterial, antiviral, anti-inflammatory, and fungicidal properties. Commercially available drugs containing imidazo-fused heterocycle moieties are alpidem (anxiolytic drug), zolimidine (anti-ulcer drug), olprinone (PDE 3 inhibitor), zolpidem (hypnotic drug), saripidem and necopidem (sedative agents), and an optically active drug (GSK812397), with a prospect for the treatment of HIV infection, levamisole *etc.* shown in Fig. 1.[1–7]

Organic transformations activated by visible light have received considerable attention from the scientific community by virtue of their worthwhile and green perspectives.[8] Recently, organic chemist are exploring visible light as an efficient and versatile method to initiate various chemical transformations. Handling during the synthesis of organic compounds under exposure to visible light is safer than with ultraviolet light,[9] and the synthesized molecules are stable towards photodecomposition. Photo-induced protocols provide a radical pathway for such reactions to occur, which are otherwise complicated through conventional strategies.[10]

Hence, in continuation with our interest in the development of MCRs in a greener way, we represent a crucial one-pot strategy for the synthesis of imidazo-fused heterocyclic scaffolds using visible light *via* the Groebke–Blackburn–Bienaymé reaction (GBBR) using aldehydes, isocyanides, and 2-aminoheterocycle building blocks under catalyst- and solvent-free conditions at ambient temperature. Model reactions for the synthesis of imidazo[1,2-*a*]pyridines and imidazo[2,1-*b*]thiazoles are shown in Scheme 1.

A comparative account of the present work with previous reported protocols is shown in Scheme 2. Our intensive attention has been paid to green synthesis, Scheme 2 shows the tight legislation to maintain greenness in synthetic procedure direct to prevent the generation of waste, avoid the use of auxiliary substances, ambient temperature, and minimize the energy requirement with operational simplicity.

Due to their high pharmacological and biological activities, many strategies for the synthesis of imidazo-fused heterocycles from 2-amino heterocycles, aldehydes and isocyanides have been reported in the literature. Previous reactions dealing with aspects of these three reactants in the presence of zirconium(IV) chloride in polyethylene glycol-400,[11] β-cyclodextrin-SO_3H as a catalyst,[12] $Sc(OTf)_3$,[13] heterogeneous solid acid catalysts,[14] nano-catalysts,[15] zinc chloride,[16] K-10 clay,[17] and nano-magnetically modified sulfuric acid[18] *etc.* have been reported. Other recent strategies for the synthesis of imidazo[1,2-*a*]pyridines are Cu-catalysed reactions,[19–26] reactions with various solvents,[27,28] and reactions at high temperature.[29] Many of these procedures have many advantages; however, they have some issues such as the use of expensive catalysts, volatile solvents, high temperatures, isolation of intermediates, long reaction time and typical workup procedures. Therefore, we turn towards a greener methodology, which can overcome some drawbacks

[a] *Laboratory of Green Synthesis, Department of Chemistry, University of Allahabad, Allahabad-211002, India. E-mail: dr.irsiddiqui@gmail.com*
[b] *Indian Institute of Technology Delhi, Department of Chemistry, Hauz Khas, New Delhi 110016, India*

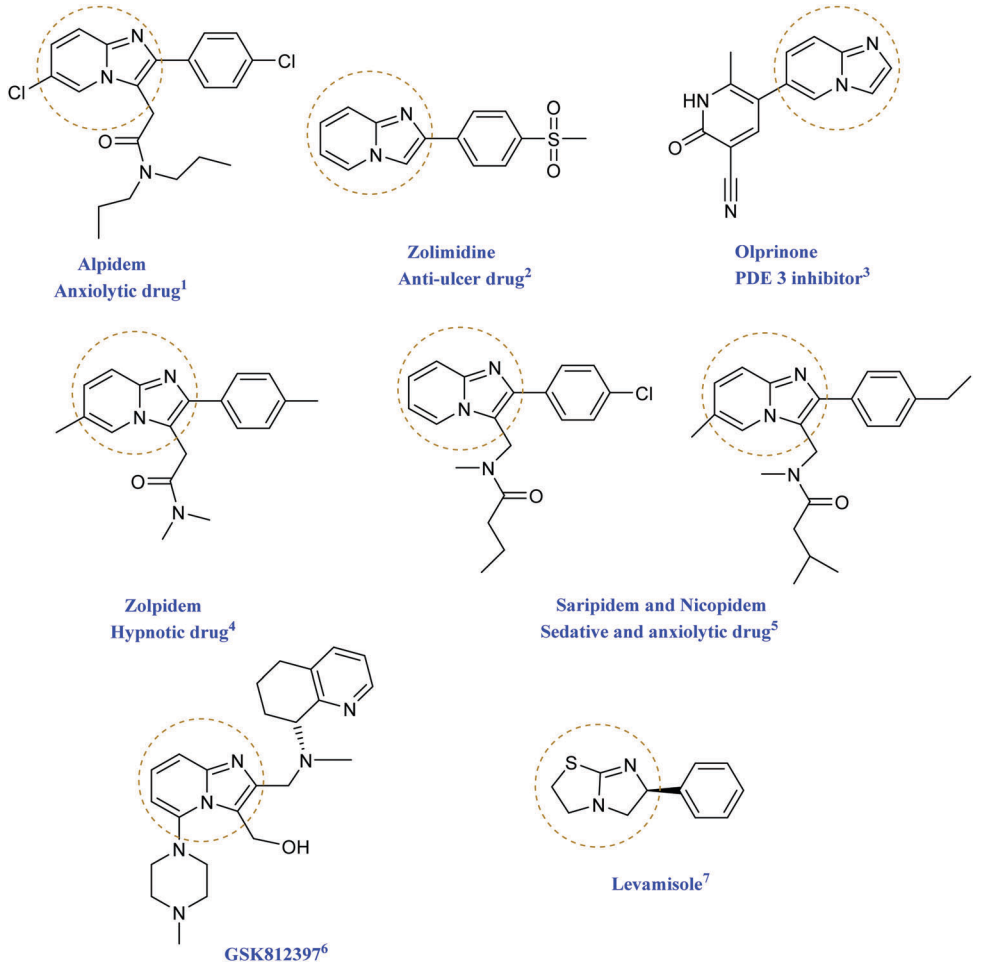
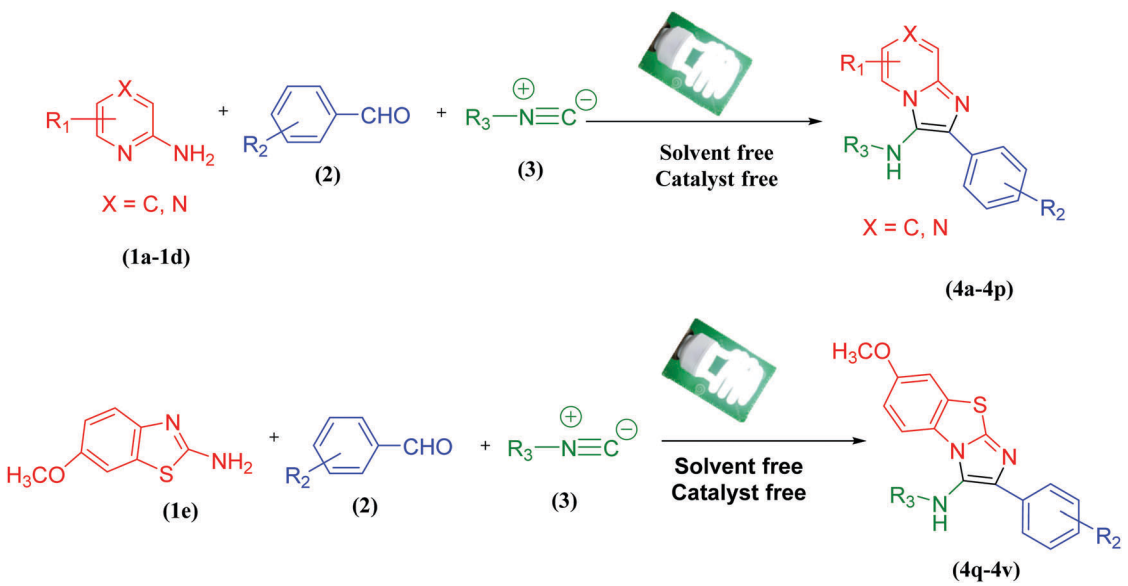
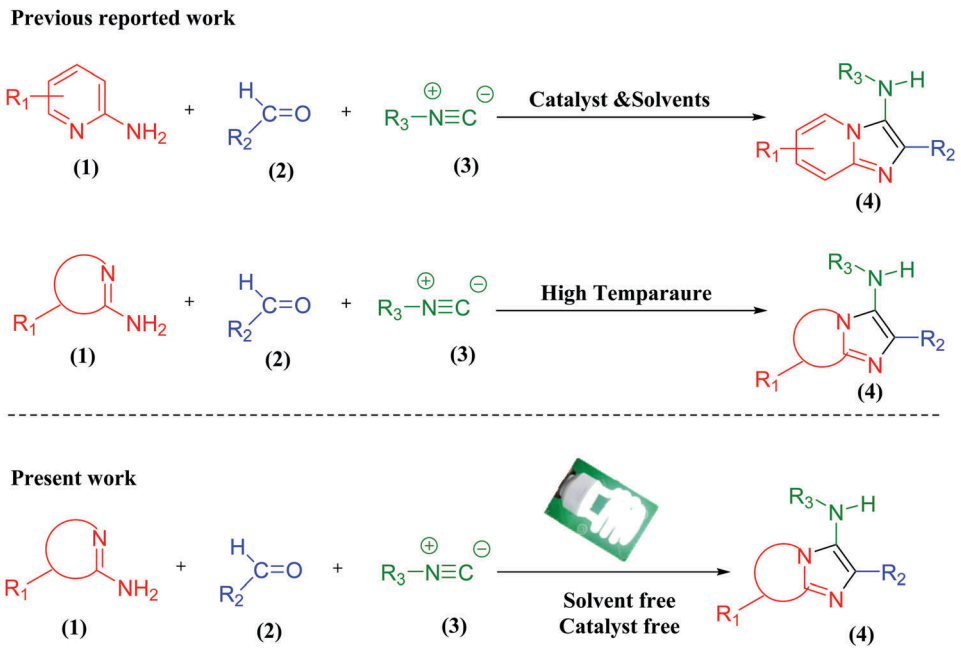


Fig. 1 Examples of biologically active compounds containing an imidazo-fused heterocycle framework.



Scheme 1 Model reactions for the synthesis of imidazo[1,2-*a*]pyridine and imidazo[2,1-*b*]thiazole derivatives.

discussed above. As a continuation of our research on the synthesis of heterocyclic compounds in an eco-friendly manner,[30–32] we report a catalyst-free, solvent-free visible light mediated methodology in the present work.



Scheme 2 Comparison of the present work with previous reported protocols.

Results and discussion

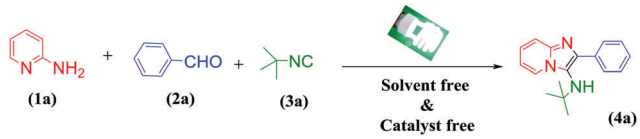
We performed the GBBR among aldehydes, isocyanides and 2-aminoheterocycles using visible light as an activator. Owing to our initial study, considerable attention has been paid to the reaction conditions; since two of the reactants among three were in the liquid physical state, we thought of carrying out this reaction under solvent free conditions. We have taken all three reactants together with 1 mmol of (**1a**), 1 mmol of (**2a**) and 1 mmol of (**3a**) in a closed round bottom flask and a CFL (24 W) was used as the source of visible light. Under this condition, we obtained 97% yield within 3 hours (Table 1, entry 1). Product formation (**4a**) was confirmed by TLC analysis by the appearance of a dark spot of the product after 3 hours. Excellent results were obtained when the first set of reaction conditions tried, the reactions were repeated for optimizing the visible light intensity for the sake of reducing the intensity of visible light used (Table 1, entry 2).

To understand the role of visible light for activation of the reaction, the reaction was also performed in the absence of the CFL at room temperature (Table 1, entry 4), and only a trace amount of the product was formed, which indicated the crucial role of visible light in the reaction.

A control experiment indicated that only a trace amount of product (**4a**) was formed when the reaction was performed in the dark at room temperature (Scheme 3, entry 1). When the reaction was performed at different temperatures like 35 °C and 60 °C, the corresponding product was obtained in 18% and 29% yield (Scheme 3, entry 2 & 3), respectively. These observations indicated that the compact fluorescent lamp (CFL) plays an important role in the reported reaction procedure. Reactions were also repeated in the presence of photocatalysts such as Rose Bengal and Eosin Y (Scheme 3, entry 4 & 5) but did not enhance the yield of the product, hence we observed *via* control experiments that a catalyst free condition (Scheme 3, entry 6) was appreciable over others for our adopted route. When the reaction was carried out in the presence of radical inhibitors such as benzoquinone[33] and (2,2,6,6-tetramethylpiperidin-1-yl)oxyl (TEMPO) (Scheme 3, entry 7 & 8) a rapid decrease in the yield of product (**4a**) was observed and upon further increasing the amount of the inhibitor (TEMPO), the reaction was fully suppressed. This finding indicated that a free radical pathway is involved in the reaction. The structure of the synthesized *N*-(*tert*-butyl)-2-phenyl-imidazo-[1,2-*a*]pyridin-3-amine was confirmed by recording its ^{1}H NMR, ^{13}C NMR, and IR spectra.

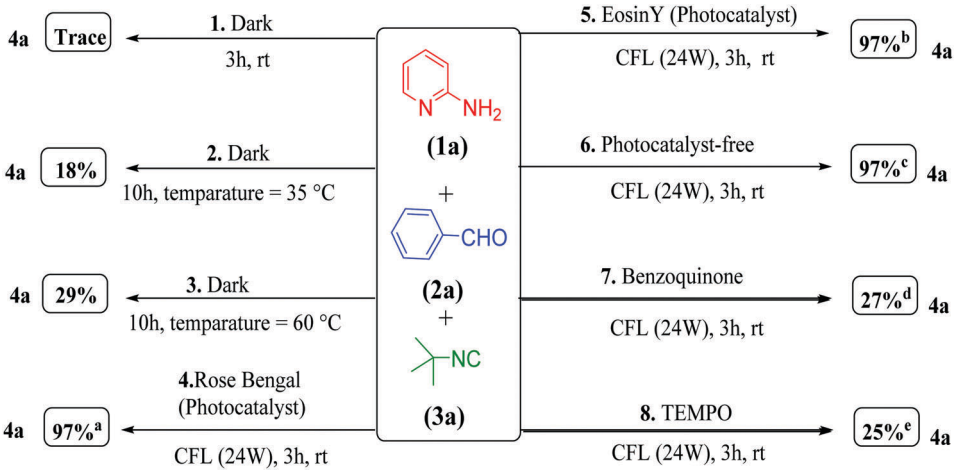
On the basis of a literature survey of visible-light induced protocols,[34–39] the proposed mechanism for the synthesis of

Table 1 Screening of visible light intensities for the synthesis of *N*-(*tert*-butyl)-2-phenyl-imidazo[1,2-*a*]pyridin-3-amine



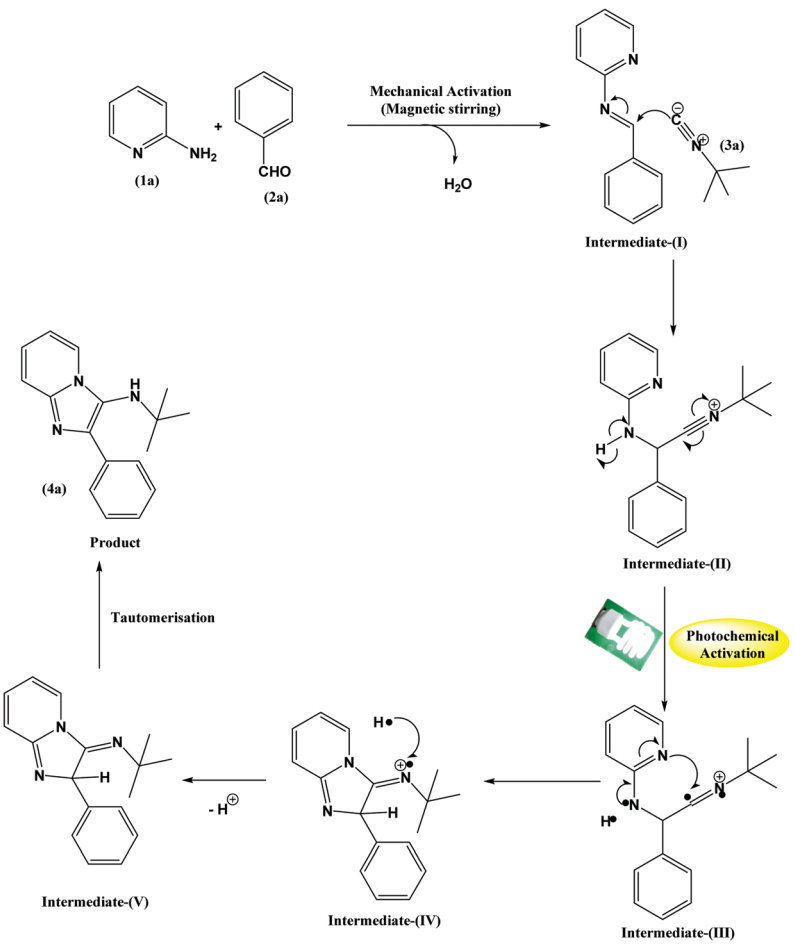
Entry	Reaction condition[a]	Time (h)	Yield[b] (%)
1	24 W, CFL, rt	3.00	97
2	20 W, CFL, rt	3.25	95
3	32 W, CFL, rt	3.00	97
4	No light, rt	3.00	Trace
5	32 W, LED, rt	3.00	82

[a] Reaction conditions: 2-aminopyridine (1 mmol), benzaldehyde (1 mmol) and *tert*-butylisocyanide (1 mmol) in a sealed RB under different reaction conditions. [b] Isolated yield, W = watt (unit of visible light intensity), rt = room temparature.



Scheme 3 Control experiments. Reaction conditions: **1a** (1 mmol), **2a** (1 mmol) and **3a** (1 mmol) in neat condition were irradiated in a closed round bottom flask at room temperature using a CFL (24 W). [a] Yield (%) of the product in the presence of Rose Bengal (2 mmol%). [b] Yield (%) of the product in the presence of Eosin Y (2 mmol%). [c] Yield (%) of the product in the absence of the photocatalyst. [d] Yield (%) of the product in the presence of benzoquinone (1 mmol). [e] Yield (%) of the product in the presence of (2,2,6,6-tetramethylpiperidin-1-yl)oxyl (1 equivalent); rt = room temperature, 25–30 °C.

N-tert-butyl-2-phenylimidazo[1,2-*a*]pyridine-3-amine is outlined in Scheme 4. A one-pot reaction was carried out in which 2-aminoheterocycle (**1**), aldehyde (**2**) and isocyanide (**3**) were mixed together in a sealed round bottom flask. The mechanism involved the reaction of 2-aminoheterocycle and benzaldehyde to form an imine (intermediate-(I)) which was afterwards attacked by



Scheme 4 A plausible mechanism for C–C and C–N bond formation and synthesis of imidazo[1,2-*a*]pyridines and imidazo[2,1-*b*]thiazoles.

Table 2 The synthesis of 3-aminoimidazo[1,2-*a*]pyridines *via* the Groebke–Blackburn–Bienaymé reaction[a]

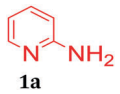
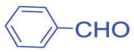
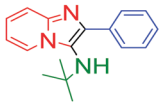
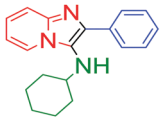
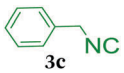
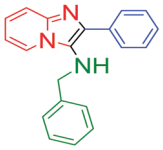
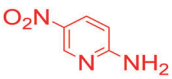
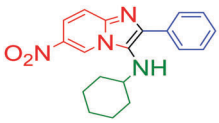
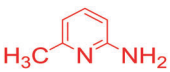
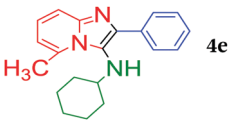
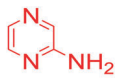
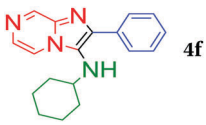
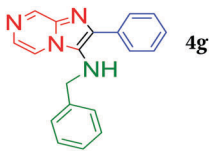
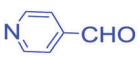
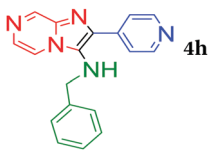
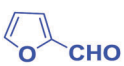
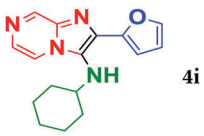
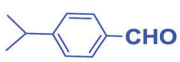
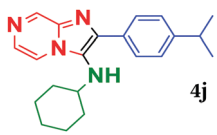
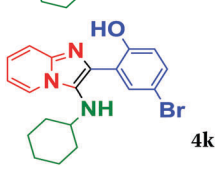
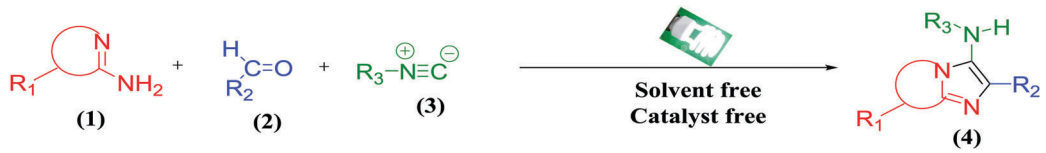
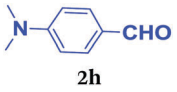
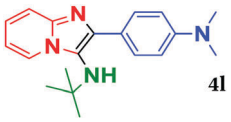
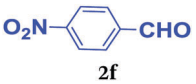
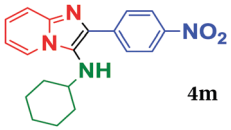
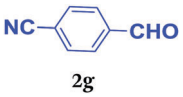
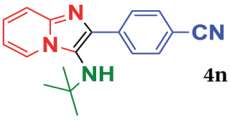
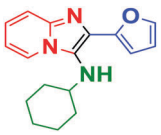
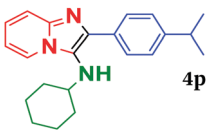
Entry	Comp. 1	Comp. 2	Comp. 3	Product[b]	Time (h)	Yield[c] (%)
1	 1a	 2a	 3a	 4a	3.00	97
2	1a	2a	 3b	 4b	3.00	98
3	1a	2a	 3c	 4c	3.00	95
4	 1b	2a	3b	 4d	5.00	83
5	 1c	2a	3b	 4e	2.75	95
6	 1d	2a	3b	 4f	2.50	96
7	1d	2a	3c	 4g	3.00	90
8	1d	 2b	3c	 4h	2.50	90
9	1d	 2c	3b	 4i	2.75	93
10	1d	 2d	3b	 4j	2.75	93
11	1a	 2e	3b	 4k	3.00	90

Table 2 (*continued*)



Entry	Comp. 1	Comp. 2	Comp. 3	Product[b]	Time (h)	Yield[c] (%)
12	**1a**	 **2h**	**3a**	 **4l**	3.00	88
13	**1a**	 **2f**	**3b**	 **4m**	2.50	97
14	**1a**	 **2g**	**3a**	 **4n**	2.50	97
15	**1a**	**2c**	**3b**	 **4o**	2.25	97
16	**1a**	**23**	**3b**	 **4p**	2.75	91

[a] Reaction conditions: 2-aminoheterocycle (1 mmol), aldehyde (1 mmol) and isocyanide (1 mmol). [b] All the compounds were confirmed by ^{1}H NMR and ^{13}C NMR spectral analyses. [c] Isolated yield.

the isocyanide to provide intermediate-(II). This intermediate (II) influenced by visible light radiation to generate free radical which were further cyclized followed by a 1,3-H shift to give the desirable product.

After optimizing the reaction conditions, in order to check the applicability of our method, we extended it to various amines, aldehydes, and isocyanides to obtain the corresponding imidazopyridine and imidazothiazole derivatives with good to excellent yield (Tables 2 and 3). All the results indicate that the electronic nature of the aminoheterocycles has an impact on the effectiveness of the reaction, and all the corresponding products are obtained in good to excellent yields. For example, aminoazines bearing an electron-withdrawing group like nitro gave (**4d**) in moderate yield (83%) with a prolonged reaction time, while electron donating groups like methyl gave (**4e**) in excellent yield (95%) with a shorter reaction time. On the other hand aldehydes with an electron donating group decreased the yield (Table 2, **4k** & **4l**) whereas electron withdrawing groups like nitro and cyanide afforded the corresponding imidazo-[1,2-*a*]pyridines (Table 2, **4m** & **4n**) in excellent yields (97%) with a reduction in reaction time.

The above results prompted us to extend this protocol to a wide range of substrates and it is predicted to be extremely promising in the field of diversity-oriented synthesis (DOS).

Conclusions

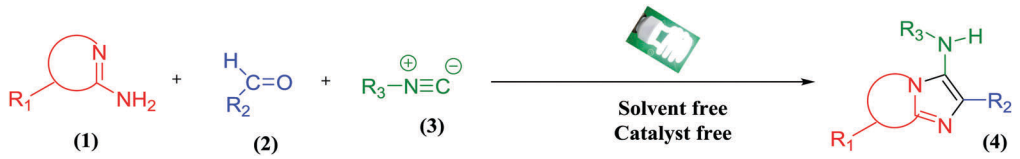
In conclusion, it is of great importance to explore an efficient and convenient synthetic method to meet the increasing scientific and practical demand for visible light activated, 'real' green one-pot strategy for the synthesis of imidazo-fused heterocycles *via* GBBR. All three reactants were mixed together in a pot without any prior activation. The key features of this procedure are mild conditions, appreciable yield, operational accessibility, atom efficiency and ecologically innocuous processes.

Experimental section

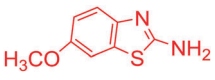
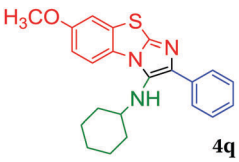
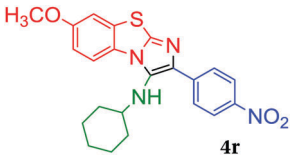
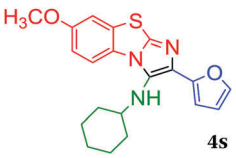
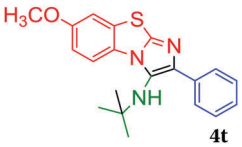
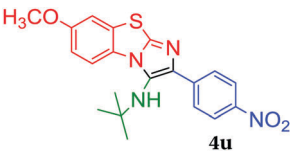
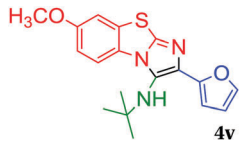
General information

Commercial reagents were purchased from Aldrich and Alfa Aesar and were used without further purification. ^{1}H and ^{13}C NMR spectra were recorded on a Bruker AVANCE 400 instrument using $CDCl_3$ as solvent. Chemical shifts δ are expressed in parts per million (ppm) and internally referenced to tetramethylsilane (TMS). Coupling constant, J is reported in Hz. The following abbreviations were used: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet. All the reaction procedures were monitored by TLC using 40 pre-coated sheets of silica gel G/UV-254 of 0.25 mm thickness (Merck 60F254) and

Table 3 The synthesis of 3-aminoimidazo[2,1-*b*]thiazole *via* the Groebke–Blackburn–Bienaymé reaction[a]



(1) (2) (3) (4)

Entry	Comp. 1	Comp. 2	Comp. 3	Product[b]	Time (h)	Yield[c] (%)
17	 **1e**	**2a**	**3b**	 **4q**	3.25	93
18	**1e**	**2f**	**3b**	 **4r**	2.25	97
19	**1e**	**2c**	**3b**	 **4s**	3.00	83
20	**1e**	**2a**	**3a**	 **4t**	2.50	92
21	**1e**	**2f**	**3a**	 **4u**	2.00	97
22	**1e**	**2c**	**3a**	 **4v**	2.25	82

[a] Reaction conditions: 2-aminoheterocycle (1 mmol), aldehyde (1 mmol) and isocyanide (1 mmol). [b] All the compounds were confirmed by ^{1}H NMR and ^{13}C NMR spectral analyses. [c] Isolated yield.

TLC plates were visualized by exposure to ultraviolet light and/or by exposure to iodine vapours and the product was obtained by column chromatography performed on silica gel (60–120 mesh). Infrared spectra were recorded on a Perkin Elmer FT-IR Spectrometer and are reported in frequency of absorption. Mass spectra were recorded on a JEOL SX-102 (FAB) mass spectrometer at 70 eV. Elemental analysis for C, H, N was performed on a Perkin Elmer model 2400 CHNS/O analyzer at SAIF Chandigarh.

Methods of preparation

General procedure for the synthesis of 3-aminoimidazo-fused heterocycles. 2-Amino heterocycles (1 mmol), aldehydes (1 mmol) and isonitriles (1 mmol) were added to a sealed round bottom flask. The resulting mixture was stirred under exposure to visible light from a 24 W, white CFL. The 24 W CFL was placed 9 cm away from the reaction mixture. The reaction progress was monitored using TLC with a mixture of hexane – EtOAc (7/3) which indicated that the reaction proceeded in a good manner and was completed in 3 hours. Since it was a solvent and catalyst free reaction, the product was directly subjected to silica gel column chromatography (hexane/EtOAc) to afford 3-aminoimidazo-fused heterocycles (**4a–4v**) as a solid.

***N*-(*tert*-Butyl)-2-phenylimidazo[1,2-*a*]pyridine-3-amine (4a)[29].** White solid; isolated yield 97%; M.p.-162–165 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 8.19 (d, J = 6.7 Hz, 1H), 7.89–7.87 (m, 2H), 7.56 (d, J = 9.2 Hz, 1H), 7.43 (t, J = 7.7 Hz, 2H), 7.32–7.26 (m, 1H), 7.14–7.8 (m, 1H), 6.79 (t, J = 6.7 Hz, 1H), 3.16 (s, 1H), 1.07 (s, 9H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 141.9, 140.7, 136.5, 129.7, 128.9, 123.4, 122.9, 116.8, 110.6, 55.9, 29.6; IR ν_{max}/cm^{-1}:

3319, 2966, 2928, 1606, 1509, 1445, 1368, 1335, 1213, 1025, 745; MS: *m*/*z*: 273.17 (M^+, 100%), 268.1 (19%); anal. calculated for $C_{17}H_{19}N_3$: C, 76.37; H, 7.92; N, 15.72 found: C, 76.28; H, 7.85; N, 15.63.

***N*-Cyclohexyl-2-phenylimidazo[1,2-*a*]pyridine-3-amine (4b)[29].** White solid; isolated yield 98%; M.p.-177–180 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 8.30 (d, J = 6.7 Hz, 1H), 8.03 (d, J = 7.2 Hz, 1H), 7.55 (d, J = 8.7 Hz, 1H), 7.47–7.43 (m, 2H), 7.34–7.26 (m, 1H), 7.21–7.16 (m, 1H), 7.12–7.15 (m, 1H), 6.94–6.89 (m, 1H), 6.7 (t, J = 6.5 Hz, 1H), 3.15 (m, 1H), 2.17–2.14 (m, 2H), 1.91–1.89 (m, 2H), 1.50–1.46 (m, 2H), 1.44–1.40 (m, 2H), 1.28–1.21 (m, 2H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 141.0, 134.1, 128.3, 127.1, 127.0, 125.1, 124.0, 122.7, 117.1, 111.6, 57.0, 34.1, 25.7, 24.8; IR ν_{max}/cm^{-1}: 3237, 2917, 2845, 1560, 1440, 1361, 1331, 1223, 734; MS: *m*/*z* 291.17 (M^+, 100%), 292.17 (21%); anal. calculated for $C_{19}H_{21}N_3$: C, 78.32; H, 7.26; N, 14.42 found: C, 78.25; H, 7.18; N, 14.38.

***N*-Benzyl-2-phenylimidazo[1,2-*a*]pyridin-3-amine (4c)[40].** White solid; isolated yield 95%; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 8.13–7.98 (m, 3H), 7.60–7.57 (m, 1H), 7.48 (t, J = 7.7 Hz, 2H), 7.40–7.27 (m, 6H), 7.19–7.13 (m, 1H), 6.79–6.75 (m, 1H), 4.19 (d, J = 6.2 Hz, 2H), 3.54 (t, J = 6.0 Hz, 1H), 2.49 (s, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 141.49, 138.98, 136.09, 134.09, 128.79, 128.29, 127.80, 127.64, 127.20, 125.79, 124.29, 122.52, 117.42, 112.02, 52.54; IR ν_{max}/cm^{-1}: 3246, 2924, 2849, 1568, 1451, 1364, 1337, 1229, 741; MS: *m*/*z*: 299.17 (M^+, 100%), 300.17 (23%); anal. calculated for $C_{20}H_{17}N_3$: C, 80.24; H, 5.72; N, 14.04 found: C, 80.29; H, 5.78; N, 14.35.

***N*-Cyclohexyl-6-nitro-2-phenylimidazo[1,2-*a*]pyridine-3-amine (4d)[29].** Golden yellow solid; isolated yield 83%; M.p.-160–164 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 9.19 (d, J = 2.5 Hz, 1H), 8.04 (d, J = 7.2 Hz, 2H), 7.97 (dd, J_1 = 9.7 Hz and J_2 = 2.3 Hz, 1H), 7.53 (d, J = 9.9 Hz, 1H), 7.47–7.52 (m, 2H), 7.35–7.40 (m, 1H), 3.26 (d, J = 4.3 Hz, 1H), 3.09–2.95 (m, 1H), 1.83 (d, J = 12.3 Hz, 2H), 1.75–1.67 (m, 3H), 1.35–1.14 (m, 5H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 141.5, 138.1, 135.8, 134.4, 129.0, 128.9, 122.8, 122.7, 119.1, 118.6, 117.1; IR ν_{max}/cm^{-1}: 3257, 2919, 2849, 1640, 1539, 1501, 1431, 1348, 1320; MS: *m*/*z*: 336 (M^+, 100%), 337 (22%); anal. calculated for $C_{19}H_{20}N_4O_2$: C, 67.84; H, 5.99; N, 16.66 found: C, 67.79; H, 6.18; N, 16.83.

***N*-Cyclohexyl-5-methyl-2-phenylimidazo[1,2-*a*]pyridin-3-amine (4e)[29].** Golden red solid; isolated yield 95%; M.p.-75–80 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 7.98–7.95 (m, 2H), 7.49–7.44 (m, 3H), 7.35–7.30 (m, 1H), 7.03 (dd, 1H, J_1 = 8.9 and J_2 = 6.9 Hz), 6.45 (d, 1H, J = 6.4 Hz), 3.14 (s, 1H), 2.96 (s, 3H), 2.78 (s, 1H), 1.70 (s, 2H), 1.60 (s, 2H), 1.05–0.98 (m, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 143.3, 138.0, 135.9, 134.9, 128.5, 128.0, 127.1, 127.1, 123.9, 60.1, 33.0, 26.0, 25.0, 20.0; IR ν_{max}/cm^{-1}: 3330, 3055, 2920, 2852, 1550, 1510, 1447, 1395, 1365, 1220, 1073, 765; MS: *m*/*z*: 305 (M^+, 100%), 306 (22%); anal. calculated for $C_{20}H_{23}N_3$: C, 78.60; H, 7.60; N, 13.75 found: C, 78.53; H, 7.49; N, 13.80.

***N*-Cyclohexyl-2-phenylimidazo[1,2-*a*]pyrazin-3-amine (4f)[29].** Brown solid; isolated yield 96%; M.p.-160–165 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 8.95 (s, 1H), 7.9 (d, 6.7 Hz, 3H), 7.83 (d, J = 4.3 Hz, 1H), 7.48–7.45 (m, 2H), 7.38–7.34 (m, 1H), 3.27 (s, 1H), 3.00 (s, 1H), 1.80 (d, J = 10.2 Hz, 2H), 1.70–1.68 (m, 2H), 1.26–1.11 (m, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 143.1, 138.8, 136.9, 133.7, 128.8, 128.8, 127.2, 126.5, 56.8, 34.9, 25.5, 24.7; IR ν_{max}/cm^{-1}: 3247, 2925, 2852, 1496, 1445, 1356, 1317, 1186, 767, 689; MS: *m*/*z*: 292.17 (M^+, 100%), 293.17 (20%); anal. calculated for $C_{18}H_{20}N_4$: C, 73.94; H, 6.89; N, 19.16 found: C, 73.88; H, 6.80; N, 19.09.

***N*-Benzyl-2-phenylimidazo[1,2-*a*]pyrazin-3-amine (4g)[40].** Off white solid; isolated yield 90%; M.p.-150–155 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 8.95 (d, J = 1.3 Hz, 1H), 7.99–7.94 (m, 2H), 7.85 (dd, J_1 = 4.6 and J_2 = 1.5 Hz, 1H), 7.78 (d, J = 4.6 Hz, 1H), 7.44 (t, J = 7.7 Hz, 2H), 7.40 (t, J = 7.4 Hz, 1H), 7.37–7.30 (m, 5H), 4.20 (d, J = 2.5 Hz, 2H), 3.67 (s, 1H), 2.19 (s, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 143.50, 138.80, 138.61, 136.82, 133.33, 129.08, 129.04, 128.94, 128.42, 128.19, 128.03, 127.41, 127.14, 115.39, 52.40; IR ν_{max}/cm^{-1}: 3250, 2935, 2863, 1503, 1439, 1365, 1349, 1193, 779, 697; MS: *m*/*z*: 300.15 (M^+, 100%), 301.15 (21%); anal. calculated for $C_{19}H_{16}N_4$: C, 75.98; H, 5.37; N, 18.65 found: C, 76.03; H, 5.40; N, 18.76.

***N*-Benzyl-2-(pyridin-4-yl)imidazo[1,2-*a*]pyrazin-3-amine (4h)[40].** Off white solid; isolated yield 90%; M.p.-144–148 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 9.00 (d, J = 1.4 Hz, 1H), 8.64 (dd, J_1 = 4.5 and J_2 = 1.6 Hz, 2H), 7.89 (dd, J_1 = 4.5 and J_2 = 1.6 Hz, 2H), 7.82–7.78 (m, 2H), 7.28 (dd, J_1 = 5.2 and J_2 = 1.8 Hz, 3H), 7.23 (dd, J_1 = 6.8 and J_2 = 2.5 Hz, 2H), 4.22 (d, J = 6.3 Hz, 2H), 3.68 (t, J = 6.2 Hz, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 150.50, 144.31, 140.92, 138.19, 137.16, 135.68, 129.44, 129.12, 128.43, 128.34, 128.27, 121.37, 115.32, 52.60; IR ν_{max}/cm^{-1} 3267, 2949, 2874, 1523, 1449, 1378, 1354, 1201, 789, 706; MS: *m*/*z*: 301.15 (M^+, 100%), 302.15 (20%): anal. calculated for $C_{18}H_{15}N_5$: C, 71.76; H, 5.02; N, 23.24 found: C, 71.80; H, 5.37; N, 23.29.

***N*-Cyclohexyl-2-(furan-2-yl)imidazo[1,2-*a*]pyrazin-3-amine (4i)[29].** Brown solid; isolated yield 93%; M.p.-115–120 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 8.92 (d, J = 1.5 Hz, 1H), 7.97–7.91 (m, 1H), 7.81 (d, J = 4.9 Hz, 1H), 7.52 (d, J = 2 Hz, 1H), 6.93–6.95 (m, 1H), 6.56–6.59 (m, 1H), 3.79 (s, 1H), 4.5 (s, 1H), 1.89–1.84 (m, 2H), 1.71–1.74 (m, 2H), 1.34–1.15 (m, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 149.5, 143.4, 142.1, 137.5, 129.2, 127.2, 115.8, 111.7, 107.7, 57.0, 34.1, 25.7, 25.0; IR ν_{max}/cm^{-1}: 3282, 2969, 2851, 1632, 1505, 1446, 1360, 1337, 1206, 1029, 750, 700; MS: *m*/*z*: 282.15 (M^+, 100%), 283.15 (17%); anal. calculated for $C_{16}H_{18}N_4O$: C, 68.06; H, 6.43; N, 19.84 found: C, 68.00; H, 6.38; N, 19.77.

***N*-Cyclohexyl-2-(4-isopropylphenyl)imidazo[1,2-*a*]pyrazin-3-amine (4j)[29].** Creamy solid; isolated yield 93%; M.p.-140–143 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 8.98 (d, J = 1.5 Hz, 1H), 8.2–8.0 (m, 1H), 7.93–7.91 (m, 2H), 7.82 (d, J = 4.9 Hz, 1H), 7.33 (d, J = 8.3 Hz, 2H), 3.21 (s, 1H), 3.00 (s, 1H), 2.97–3.00 (m, 1H), 1.85 (d, J = 10.3 Hz, 2H), 1.70–1.73 (m, 2H), 1.5 (d, J = 6.8 Hz, 6H), 1.26–1.13 (m, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 149.2, 143.2, 139.2, 136.6, 131.2, 128.8, 127.5, 127.0, 126.4, 115.6, 56.7, 34.1, 34.0, 29.9, 25.7, 24.7, 24.0; IR ν_{max}/cm^{-1}: 3250, 2953, 2925, 2850, 1550, 1505, 1449, 1350, 1289, 1200, 845, 730; MS: *m*/*z* 334.2 (M^+, 100%), 335 (23%); anal. calculated for $C_{21}H_{26}N_4$: C, 75.41; H, 7.84; N, 16.75 found: C, 75.36; H, 7.78; N, 16.69.

4-Bromo-2-(3-(cyclohexylamino)imidazo[1,2-*a*]pyridin-2-yl)phenol (4k)[29]. Off-white solid; isolated yield 90%; M.p.-150–155 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 13.12 (s, 1H), 8.50–8.29 (m, 1H), 8.09–8.03

(m, 1H), 7.49 (d, 1H, J = 9.3 Hz), 7.30–7.23 (m, 2H), 6.89–6.85 (m, 2H), 3.05–2.98 (m, 2H), 1.83 (d, 2H, J = 12.3 Hz), 1.77–1.75 (m, 2H), 1.40–1.29 (m, 3H), 1.23–1.12 (m, 3H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 157.0, 140.1, 135.2, 132.0, 129.3, 125.1, 122.9, 122.1, 119.2, 119.0, 116.9, 112.6, 110.4, 57.4, 33.9, 26.0, 25.1; IR ν_{max}/cm^{-1}: 3350, 3070, 2929, 2849, 1636, 1474, 1369, 1339, 1279, 1241, 1079, 810, 740; MS: m/z: 385.00 (M^+, 100%), 387.10 (98%); anal. calculated for $C_{19}H_{20}BrN_3O$: C, 59.08; H, 5.22; N, 10.88 found: C, 57.45; H, 5.76; N, 10.93.

***N*-*tert*-Butyl-2-(4-(dimethylamino)phenyl)imidazo[1,2-*a*]pyridin-3-amine (4l)[41].** Creamy yellow solid; isolated yield 88%; M.p.-185–189 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 8.26 (d, J = 6.9 Hz, 1H), 7.79 (d, J = 6.8 Hz, 2H), 7.54 (d, J = 9.3 Hz, 1H), 7.09 (t, J = 8 Hz, 1H), 6.73–6.80 (m, 3H), 3.00 (s, 6H), 1.10 (s, 9H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 150.0, 141.9, 140.9, 129.1, 123.9, 123.4, 122.0, 121.8, 116.9, 111.9, 110.0, 56.7, 40.7, 29.8; IR ν_{max}/cm^{-1}: 3429, 2370, 1633, 1413, 760; MS: m/z: 308.20 (M^+, 100%), 309.20 (21%); anal. calculated for $C_{19}H_{24}N_4$: C, 73.99; H, 7.84; N, 18.17 found: C, 74.11; H, 7.76; N, 18.20.

***N*-Cyclohexyl-2-(4-nitrophenyl)imidazo[1,2-*a*]pyridine-3-amine (4m)[29].** Orange-red brown color solid; isolated yield 97%; M.p.-200–204 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 8.35–8.29 (m, 4H), 8.09 (d, 1H, J = 6.9 Hz), 7.4 (d, 1H, J = 9.2 Hz), 7.20–7.16 (m, 1H), 6.9 (t, 1H, J = 6.5 Hz), 3.10 (d, 1H, J = 5.0 Hz), 3.00–2.95 (m, 1H), 1.89–1.84 (m, 3H), 1.74–1.72 (m, 2H), 1.29–1.14 (m, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 147.0, 142.8, 140.8, 134.7, 126.9, 125.8, 124.8, 123.7, 122.5, 118.1, 12.9, 56.9, 34.1, 25.8, 24.9; IR ν_{max}/cm^{-1}: 3239, 2920, 2850, 1601, 1510, 1449, 1368, 1330, 1112, 857, 729; MS: m/z: 336.15 (M^+, 100%), 337.15 (22%); anal. calculated for $C_{19}H_{20}N_4O_2$: C, 67.84; H, 5.99; N, 16.66 found: C, 68.02; H, 6.10; N, 16.70.

4-(3-(*tert*-Butylamino)imidazo[1,2-*a*]pyridin-2-yl)benzonitrile (4n)[41]. Light yellow solid; isolated yield 97%. M.p.-155–160 °C. ^{1}H-NMR (400 MHz, $CDCl_3$) δ: 8.20–8.16 (m, 3H), 7.70 (d, J = 8 Hz, 2H), 7.51 (d, J = 9.2 Hz, 1H), 7.20 (t, J = 6.8 Hz, 1H), 6.79 (t, J = 6.8 Hz, 1H), 3.07 (s, 1H), 1.10 (s, 9H). ^{13}C-NMR (100 MHz, $CDCl_3$) δ: 143.1, 140.1, 137.7, 133.0, 132.6, 131.8, 129.1, 128.4, 128.1, 127.7, 127.1, 126.9, 126.5, 125.4, 125.1, 124.7, 123.8, 119.4, 116.4, 114.3, 112.2, 111.5, 56.9, 30.9, 29.6; IR ν_{max}/cm^{-1}: 3330, 2969, 2925, 1633, 1610, 1500, 754, 549; MS: m/z 290.10 (M^+, 100%), 291.10 (20%); anal. calculated for $C_{18}H_{18}N_4$: C, 74.46; H, 6.25; N, 19.30 found: C, 74.39; H, 6.19; N, 19.70.

***N*-Cyclohexyl-2-(furan-2-yl)imidazo[1,2-*a*]pyridine-3-amine (4o)[29].** Creamy solid; isolated yield 97%; M.p.-125–127 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 8.03 (d, 6.7 Hz, 1H), 7.52–7.55 (m, 2H), 7.13–7.08 (m, 1H), 6.84 (d, J = 3.3 Hz, 1H), 6.75 (t, J = 6.5 Hz, 1H), 6.52–6.55 (m, 1H), 3.59 (d, J = 6.7 Hz, 1H), 2.99–2.91 (m, 1H), 1.8 (d, J = 12.1 Hz, 2H), 1.74–1.72 (m, 2H), 1.32–1.12 (m, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 150.2, 141.5, 128.0, 125.3, 123.8, 122.7, 111.5, 111.4, 106.3, 56.9, 34.0, 25.76, 24.9; IR ν_{max}/cm^{-1}: 3220, 2921, 2851, 1541, 1491, 1350, 1339, 1090, 1010, 740, 727; MS: m/z: 281.15 (M^+, 100%), 282.15 (18%); anal. calculated for $C_{17}H_{19}N_3O$: C, 72.57; H, 6.81; N, 14.94 found: C, 72.45; H, 6.76; N, 14.90.

***N*-Cyclohexyl-2-(4-isopropylphenyl)imidazo[1,2-*a*]pyridin-3-amine (4p)[29].** White solid; isolated yield 91%; M.p.-161–166 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 8.10 (d, 6.8 Hz, 1H), 7.99 (d, J = 8.3 Hz, 2H), 7.51 (d, J = 8.8 Hz, 1H), 7.30 (d, J = 8.3 Hz, 2H), 7.13–7.09 (m, 1H), 6.79–6.76 (m, 1H), 3.11–3.0 (s, 1H), 2.98–2.91 (m, 2H), 1.82 (d, J = 12.2 Hz, 2H), 1.72–1.70 (m, 2H), 1.3 (d, J = 6.8 Hz, 6H), 1.26–1.14 (m, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 147.8, 141.7, 136.4, 132.1, 126.9, 126.7, 124.9, 123.5, 122.9, 117.4, 111.6, 56.8, 34.2, 34.0, 25.9, 24.6, 24.2; IR ν_{max}/cm^{-1}: 3260, 2958, 2929, 2851, 1628, 1506, 1450, 1363, 1345, 1224, 1105, 845, 752; MS: m/z: 333.2 (M^+, 100%), 334 (23%); anal. calculated for $C_{22}H_{27}N_3$: C, 79.24; H, 8.16; N, 12.6 found: C, 79.19; H, 8.10; N, 12.2.

***N*-Cyclohexyl-6-methoxy-2-phenylbenzo[*d*]imidazo[2,1-*b*]thiazol-3-amine (4q)[29].** Orange solid; isolated yield 93%; M.p.-60–65 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 7.93 (d, J = 8.8 Hz, 1H), 7.84–7.87 (m, 2H), 7.42–7.40 (m, 2H), 7.27–7.23 (m, 1H), 7.14 (d, J = 2.4, 1H), 6.99–7.02 (m, 1H), 3.87 (s, 3H), 3.16 (s, 1H), 2.97 (s, 1H), 1.87 (d, J = 10.3 Hz, 2H), 1.67–1.65 (m, 2H), 1.27–1.13 (m, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 156.4, 142.9, 137.5, 134.9, 131.5, 129.0, 128.3, 127.2, 126.8, 126.4, 114.1, 112.9, 108.7, 57.3, 56.0, 33.5, 25.9, 25.0; IR ν_{max}/cm^{-1}: 3307, 2929, 2850, 1661, 1603, 1572, 1546, 1469, 1448, 1397, 1264, 1180, 1026, 830, 702; MS: m/z: 389.1 (M^+, 100%), 390.1 (25%); anal. calculated for $C_{22}H_{23}N_3OS$: C, 70.92; H, 5.95; N, 10.79 found: C, 70.88; H, 5.90; N, 10.74.

***N*-Cyclohexyl-6-methoxy-2-(4-nitrophenyl)benzo[*d*]imidazo-[2,1-*b*]thiazol-3-amine (4r)[29].** Orange solid; isolated yield 97%; M.p.-185–190 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 8.19–8.12 (m, 2H), 8.10–8.05 (m, 2H), 7.80 (d, J = 8.8 Hz, 1H), 7.17 (d, J = 2.4 Hz, 1H), 6.99–7.02 (m, 1H), 3.83 (s, 3H), 3.10 (d, J = 4.4 Hz, 1H), 2.93–2.91 (m, 1H), 1.85 (d, J = 12.7 Hz, 2H), 1.69–1.67 (m, 2H), 1.25–1.18 (m, 4H), 1.16–1.2 (m, 2H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 157.3, 145.9, 144.1, 141.0, 135.9, 131.9, 131.0, 127.0, 126.2, 123.5, 114.1, 113.0, 108.9, 57.7, 56.0, 33.9, 32.5, 25.7, 24.8, 22.9, 14.0; IR ν_{max}/cm^{-1}: 3336, 2929, 2850, 1595, 1496, 1330, 1267, 1230, 1110, 1033, 853, 709; MS: m/z: 434.1 (M^+, 100%), 435.1 (25%); anal. calculated for $C_{22}H_{22}N_4O_3S$: C, 63.58; H, 5.10; N, 12.89 found: C, 63.47; H, 5.07; N, 12.84.

***N*-Cyclohexyl-2-(furan-2-yl)-6-methoxybenzo[*d*]imidazo[2,1-*b*]-thiazol-3-amine (4s)[29].** Brown oil; isolated yield 83%; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 7.9–7.93 (m, 1H), 7.45 (d, J = 1.5 Hz, 1H), 7.13 (s, 1H), 6.98–6.94 (m, 1H), 6.64–6.63 (m, 1H), 6.51–6.50 (m, 1H), 3.87 (s, 3H), 3.61–3.64 (m, 1H), 2.95–2.90 (m, 1H), 2.06–2.0 (m, 2H), 1.73–1.71 (m, 2H), 1.35–1.16 (m, 6H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 156.9, 150.7, 143.2, 140.5, 131.4, 130.0, 128.3, 127.2, 114.5, 113.0, 111.1, 108.5, 104.2, 58.0, 56.0, 33.5, 29.9, 25.9, 25.0; IR ν_{max}/cm^{-1}: 3355, 2926, 2849, 1600, 1539, 1500, 1464, 1350, 1265, 1234, 1170, 1040, 807, 734; MS: m/z: 379.1 (M^+, 100%), 380.1 (23%); anal. calculated for $C_{20}H_{21}N_3O_2S$: C, 66.47; H, 5.58; N, 11.07 found: C, 66.35; H, 5.52; N, 11.01.

***N*-(*tert*-Butyl)-6-methoxy-2-phenylbenzo[*d*]imidazo[2,1-*b*]thiazol-3-amine (4t)[29].** Creamy white solid; isolated yield 92%; M.p.-150–154 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 8.22 (d, J = 8.7 Hz, 1H), 7.79–7.72 (m, 2H), 7.45–7.38 (m, 2H), 7.30–7.25 (m, 1H), 7.15 (d, J = 2.4 Hz, 1H), 6.94–6.97 (m, 1H), 3.88 (s, 3H), 3.20 (s, 1H), 1.05 (s, 9H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 156.9, 143.0, 140.9, 135.1, 131.5, 128.1, 127.8, 127.9, 126.8, 115.5, 112.4, 108.6, 56.8, 55.9, 29.8; IR ν_{max}/cm^{-1}: 3286, 2967, 2967,

2924, 2854, 1604, 1553, 1492, 1445, 1366, 1300, 1235, 1194, 1068, 1029, 910, 730, 700; MS: *m*/*z*: 363.1 (M^+, 100%), 364.1 (23%); anal. calculated for $C_{20}H_{21}N_3OS$: C, 69.39; H, 5.82; N, 11.56 found: C, 69.28; H, 5.75; N, 11.51.

***N*-(*tert*-Butyl)-6-methoxy-2-(4-nitrophenyl)benzo[*d*]imidazo-[2,1-*b*]thiazol-3-amine (4u)[29].** Orange solid; isolated yield 97%; M.p.-183–188 °C; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 8.19–8.12 (m, 2H), 8.10–8.05 (m, 2H), 7.80 (d, J = 8.8 Hz, 1H), 7.17 (d, J = 2.4 Hz, 1H), 6.99–7.03 (m, 1H), 3.83 (s, 3H), 3.10 (s, 1H), 1.15 (s, 9H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 157.3, 145.9, 144.1, 141.0, 135.9, 131.9, 131.0, 127.0, 126.2, 123.5, 114.1, 113.0, 108.9, 57.7, 56.0, 29.7; IR ν_{max}/cm^{-1}: 3336, 2929, 2850, 1595, 1496, 1267, 1230, 1110, 1033, 853, 709; MS: *m*/*z*: 408.1 (M^+, 100%), 409.1 (23%); anal. calculated for $C_{20}H_{20}N_4O_3S$: C, 61.75; H, 4.94; N, 13.72 found: C, 61.67; H, 4.88; N, 13.69.

***N*-(*tert*-Butyl)-2-(furan-2-yl)-6-methoxybenzo[*d*]imidazo[2,1-*b*]-thiazol-3-amine (4v)[29].** Brown oil; isolated yield 82%; ^{1}H-NMR (400 MHz, $CDCl_3$), δ: 7.9–7.03 (m, 1H), 7.45 (d, J = 1.5 Hz, 1H), 7.13 (s, 1H), 6.98–6.94 (m, 1H), 6.64–6.63 (m, 1H), 6.51–6.50 (m, 1H), 3.87 (s, 3H), 3.12 (s, 1H), 1.12 (s, 9H); ^{13}C-NMR (100 MHz, $CDCl_3$), δ: 156.9, 150.7, 143.2, 140.5, 131.4, 130.0, 128.3, 127.2, 114.5, 113.0, 111.1, 108.5, 104.2, 58.0, 56.0, 29.9; IR ν_{max}/cm^{-1}: 3355, 2926, 2849, 1600, 1539, 1500, 1464, 1265, 1234, 1170, 1040, 807, 734; MS: *m*/*z*: 353.1 (M^+, 100%), 354.1 (20%); anal. calculated for $C_{18}H_{19}N_3O_2S$: C, 64.57; H, 5.42; N, 11.89 found: C, 64.49; H, 5.35; N, 11.80.

Conflicts of interest

There are no conflicts to declare.

Acknowledgements

We gratefully acknowledge the financial support from the University Grant Commission and CSIR. The authors are also grateful to SAIF, Punjab University Chandigarh, for providing all the spectroscopic and analytical data.

References

1 (*a*) S. Bassi, M. G. Albizzati, C. Ferrarese, L. Frattola, B. Cesana, R. Piolti and A. Farolfi, *Clin. Neuropharmacol.*, 1989, **12**, 67–74; (*b*) A. Munir, S. Azam, S. Ali, A. Mehmood, A. H. Shah, M. S. Khan, R. Manzoor, M. Sana, S. A. Mufti and S. Fazal, *Drug Des.*, 2017, **6**, 1–7.
2 Y. Katsura, S. Nishino and H. Takasugi, *Chem. Pharm. Bull.*, 1991, **39**, 2937–2943.
3 K. Mizushige, T. Ueda, K. Yukiiri and H. Suzuki, *Cardiovasc. Drug Rev.*, 2002, **20**, 163–174.
4 S. Z. Langer, S. Arbilla, J. Benavides and B. Scatton, *Adv. Biochem. Psychopharmacol.*, 1990, **46**, 61–72.
5 L. Almirante, L. Polo, A. Mugnaini, E. Provinciali, P. Rugarli, A. Biancotti and A. Gamba, *J. Med. Chem.*, 1965, **8**, 305–312.
6 S. Payra, A. Saha, C. M. Wu, B. Selvaratnam, T. Dramstad, L. Mahoney, S. K. Verma, S. Thareja, R. Koodali and S. Banerjee, *New J. Chem.*, 2016, **40**, 9753–9760.
7 M. J. Miller, I. Farahmandian, F. Arfaa, N. Katz, E. Winsor and E. Bennett, *South. Med. J.*, 1978, **71**, 137–140.
8 (*a*) J. Davies, S. G. Booth, S. Essafi, R. A. W. Dryfe and D. Leonori, *Angew. Chem., Int. Ed.*, 2015, **54**, 14017–14021; (*b*) D. P. Hari and B. Konig, *Chem. Commun.*, 2014, **50**, 6688–6699.
9 K. Yamada, M. Okada, T. Fukuyama, D. Ravelli, M. Fagnoni and I. Ryu, *Org. Lett.*, 2015, **17**, 1292–1295.
10 J. Jin and D. W. C. MacMillan, *Nature*, 2015, **525**, 87–90.
11 S. K. Guchhait and C. Madaan, *Synlett*, 2009, 628–632.
12 J. Wu, F. Z. Xu, S. L. Feng, W. Xue and Z. Z. Wang, *Heterocycles*, 2016, **92**, 1629–1642.
13 S. Shaaban and B. F. Abdel-Wahab, *Mol. Diversity*, 2016, **20**, 233–254.
14 A. Shaabani, M. Seyyedhamzeh, S. Shaabani and N. Ganji, *Res. Chem. Intermed.*, 2015, **41**, 2377–2383.
15 A. Shaabani, H. Nosrati and M. Seyyedhamzeh, *Res. Chem. Intermed.*, 2015, **41**, 3719–3727.
16 A. L. Rousseau, P. Matlaba and C. J. Parkinson, *Tetrahedron Lett.*, 2007, **48**, 4079–4082.
17 R. S. Varma and D. Kumar, *Tetrahedron Lett.*, 1999, **40**, 7665–7669.
18 S. Rostamnia, K. Lamei, M. Mohammadquli, M. Sheykhan and A. Heydari, *Tetrahedron Lett.*, 2012, **53**, 5257–5260.
19 H. Cao, X. Liu, L. Zhao, J. Cen, J. Lin, Q. Zhu and M. Fu, *Org. Lett.*, 2014, **16**, 146–149.
20 H. Cao, H. Zhan, Y. Lin, X. Lin, Z. Du and H. Jiang, *Org. Lett.*, 2012, **14**, 1688–1691.
21 C. Wang, S. Lei, H. Cao, S. Qiu, J. Liu, H. Deng and C. Yan, *J. Org. Chem.*, 2015, **80**, 12725–12732.
22 S. Lei, H. Cao, L. Chen, J. Liu, H. Cai and J. Tan, *Adv. Synth. Catal.*, 2015, **357**, 3109–3114.
23 H. Cao, S. Lei, N. Li, L. Chen, J. Liu, H. Cai, S. Qiu and J. Tan, *Chem. Commun.*, 2015, **51**, 1823–1825.
24 H. Huang, X. Ji, X. Tang, M. Zhang, X. Li and H. Jiang, *Org. Lett.*, 2013, **15**, 6254–6257.
25 Y. Zhang, Z. Chen, W. Wu, Y. Zhang and W. Su, *J. Org. Chem.*, 2013, **78**, 12494–12504.
26 J. Liu, W. Wei, T. Zhao, X. Liu, J. Wu, W. Yu and J. Chang, *J. Org. Chem.*, 2016, **81**, 9326–9336.
27 H. Cao, X. Liu, L. Zhao, J. Cen, J. Lin, Q. Zhu and M. Fu, *Org. Lett.*, 2014, **16**, 146–149.
28 P. R. Adiyala, G. S. Mani, J. B. Nanubolu, K. C. Shekar and R. A. Maurya, *Org. Lett.*, 2015, **17**, 4308–4311.
29 S. Vidyacharan, A. H. Shinde, B. Satpathi and D. S. Sharada, *Green Chem.*, 2014, **16**, 1168–1175.
30 P. Rai, Rahila, H. Sagir and I. R. Siddiqui, *ChemistrySelect*, 2016, **1**, 4550–4553.
31 A. Ibad, M. A. Waseem, F. Ibad, K. Ansari, A. M. Lone, G. Watal and I. R. Siddiqui, *ChemistrySelect*, 2017, **2**, 4587–4592.
32 Rahila, P. Rai, A. Ibad, H. Sagir and I. R. Siddiqui, *ChemistrySelect*, 2016, **1**, 1300–1304.
33 M. Pelaez, *et al.*, *Appl. Catal., B*, 2012, **125**, 331–349.
34 T. Xiong and Q. Zhang, *Chem. Soc. Rev.*, 2016, **45**, 3069–3087.

35 Y. Wang, P. Ren, X. Gu, X. Wen, Y. Wang, X. Guo, E. R. Waclawik, H. Zhuc and Z. Zheng, *Green Chem.*, 2016, **18**, 1482–1487.
36 A. Mishra, M. Srivastava, P. Rai, S. Yadav, B. P. Tripathi, J. Singh and J. Singh, *RSC Adv.*, 2016, **6**, 49164–49172.
37 M. Zhang, Q.-Y. Fu, G. Gao, H.-Y. He, Y. Zhang, Y.-S. Wu and Z.-H. Zhang, *ACS Sustainable Chem. Eng.*, 2017, **5**, 6175–6182.
38 N. Yadav, H. Sagir, M. D. Ansari and I. R. Siddiqui, *Catal. Lett.*, 2018, **148**, 1676–1685.
39 T. Kaur, P. Wadhwa, S. Bagchi and A. Sharma, *Chem. Commun.*, 2016, **52**, 6958–6976.
40 D. B. Salunke, E. Yoo, N. M. Shukla, R. Balakrishna, S. S. Malladi, K. J. Serafin, V. W. Day, X. Wang and S. A. David, *J. Med. Chem.*, 2012, **55**, 8137–8151.
41 A. T. Baviskar, C. Madaan, R. Preet, P. Mohapatra, V. Jain, A. Agarwal, S. K. Guchhait, C. N. Kundu, U. C. Banerjee and P. V. Bharatam, *J. Med. Chem.*, 2011, **54**, 5013–5030.